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An Attempt at Determining Probabilities in Human Scalp Hair Comparison

"You have testified that the hair found at the scene of the crime is similar to those of the accused's scalp. What are the chances that it could have originated from someone else?" This familiar question is frequently asked examiners presenting hair evidence in court. It was in an attempt to answer such questions that this study was begun.

In this paper, a system for coding the macroscopic and microscopic characteristics of human scalp hair is presented. Using this method, which circumvents the problem of making a very large number of comparisons directly with a comparison microscope, a statistical analysis of the probabilities involved in human scalp hair comparison is carried out. Thus, a first estimate of the probabilities of hairs from different sources being similar is given. It is hoped that this study will stimulate other work, thereby making it possible someday to give definite answers in all cases to questions such as that posed above.

Method

One hundred different individuals were asked to submit a sample of 80 to 100 hairs randomly selected from various regions of the scalp. From these, depending on the homogeneity of the sample, six to eleven mutually dissimilar hairs were selected macroscopically to represent the range of length, coarseness, and color present in the 80 to 100 hairs. This step serves to reduce the labor involved and does not destroy the randomness introduced in the original selection. The six to eleven hairs were then mounted individually on labeled glass slides and observed under one hundred magnifications on a comparison microscope.[3]

Some characteristics of each hair as viewed longitudinally were coded on punch cards[4] (see Fig. 1 and Table 1). These cards were singly punched if only one type of a particular characteristic was evinced and doubly punched if more than one type per characteristic was observed. The cards for each individual were then sorted with the cards of others, and those that were similar were retrieved. For example, by probing Hole 5 followed in order by Holes 9, 13, 16, 23, 25, 28, 35, 44, 47, 48, 50, 52, and 60, cards would be retrieved for any other hair which was light brown with fine pigment granules, uniform pigment distribution, and coarse cortical texture; was untreated; had an absent medulla;

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[3] American Optical "Duo Star."

[4] McBee Keysort® Cards.

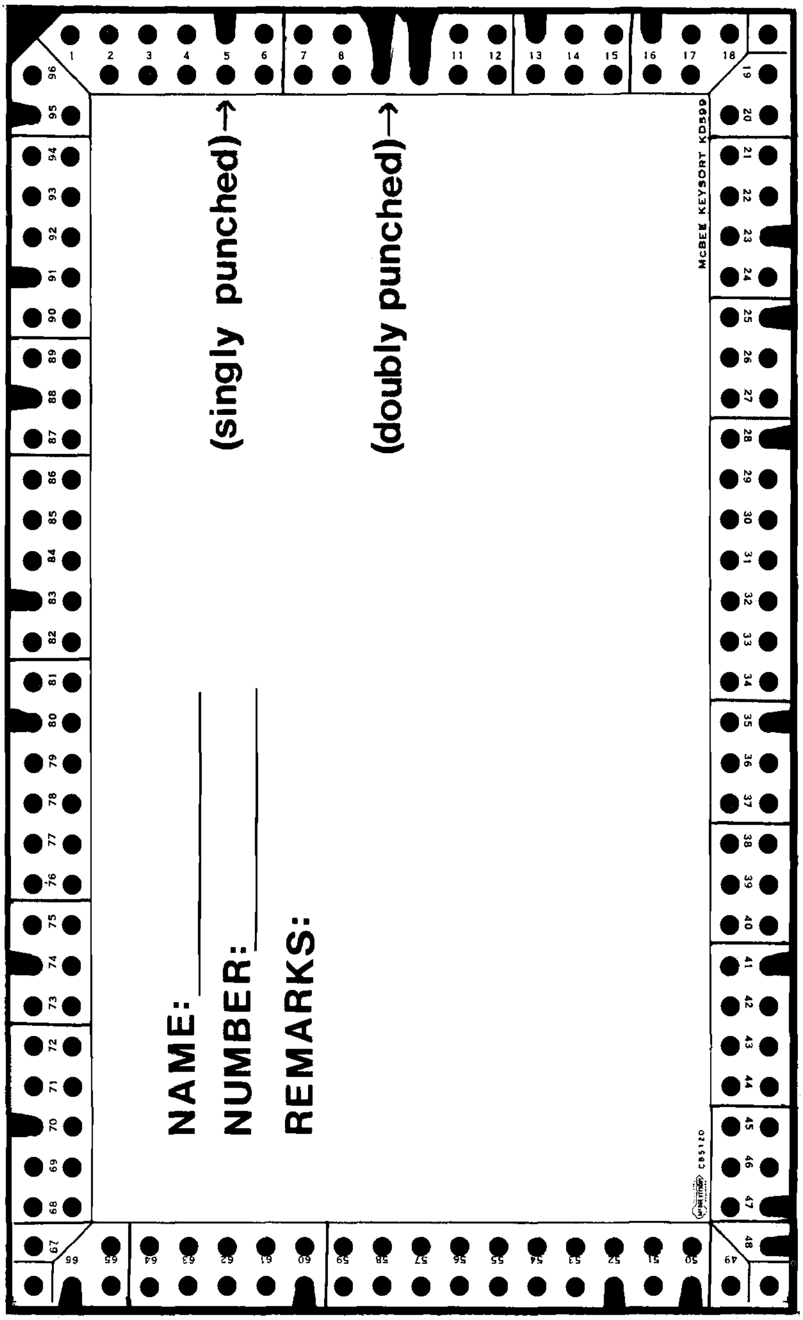

FIG. 1—*A McBee Keysort® card.*

TABLE 1—*Characteristics used for coding on McBee cards.*

Group	Characteristic	Type	No.
A	Color[a]	gray	1
		yellow	2
		yellow brown	3
		red	4
		brown	5
		black	6
B	Pigment Density[b]	absent	7
		sparse	8
		light	9
		medium	10
		heavy	11
		opaque	12
C	Pigment Size[c]	fine	13
		medium	14
		large	15
D	Pigment Distribution[a]	uniform	16
		peripheral	17
		about medulla	18
		one side	19
		clusters	20
		graying	24
E	Cortical Texture[b]	fine	21
		medium	22
		coarse	23
F	Treatment[a]	none observable	25
		dyed	26
		bleached	27
G	Medulla[a]	absent	28
		continuous opaque	29
		continuous translucent	30
		continuous opaque and translucent	31
		fragmentary opaque	32
		fragmentary translucent	33
		fragmentary opaque and translucent	34
H	Maximum Diameter[b]	fine (< 0.04 mm)	35
		medium (0.04–0.08 mm)	36
		coarse (> 0.08 mm)	37
I	Medullary Index[b]	$< 0.167 \neq 0$	38
		0.167–0.250	39
		> 0.250	40
J	Shaft[b]	constant diameter	41
		slight smooth variation in diameter	42
		wide smooth variation in diameter	43
		abrupt variation	44
K	Cuticular Margin[c]	smooth	45
		slightly serrated	45
		serrated	47
L	Vacuoles[c]	present	48
		not present	49
M	Root[a]	bulb	50
		ribbon (flat)	51

(*Continued*)

TABLE 1—Continued.

Group	Characteristics	Type	No.
N	Tip[b]	natural taper	52
		cut within 7 days	53
		cut within 14 days	54
		cut within 21 days	55
		cut within 28 days or more	56
		rounded and frayed	57
		split and frayed	58
		crushed	59
O	Length[b], in.	< 1	60
		1–3	61
		3–6	62
		6–12	63
		> 12	64
P	Scale Count[c]	fine (>26 in 0.2 mm)	65
		medium (22–26 in 0.2 mm)	66
		coarse (<22 in 0.2 mm)	67
Q	Cross Section Contour[b]	round	68
		elliptical	69
		oval	70
		kidney-shaped	71
		triangular	72
R	Cross Section Cuticle[c]	broad	73
		medium	74
		narrow	75
S	Cross Section Color[a]	gray	76
		yellow	77
		yellow brown	78
		red	79
		brown	80
		black	81
T	Cross Section Pigment Density[b]	absent	82
		light	83
		medium	84
		heavy	85
		opaque	86
U	Cross Section Pigment Size[c]	fine	87
		medium	88
		coarse	89
V	Cross Section Pigment Distribution[c]	uniform	90
		periphery	91
		about medulla	92
		one side	93
		clusters	94
W	Cross Section Cortical Texture[a]	smooth	95
		granular	96

[a] Major characteristic.
[b] Either major or minor depending on types exhibited (usually major between types two numbers apart and minor between types with adjacent numbers).
[c] Minor characteristic.

was less than 0.04 mm in maximum diameter; had abrupt variations in diameter, a serrated cuticle, vacuoles, a bulb root, and a natural taper; and was less than 1 in. long. Those considered similar for this purpose had all major characteristics similar and no more than five minor characteristics dissimilar (see Table 1). These criteria were chosen based empirically on considerable experience in forensic hair examinations. They were chosen to ensure that leeway was allowed so that no similar hairs would be eliminated at this stage, while at the same time ensuring that enough dissimilar hairs were eliminated to minimize unnecessary comparison microscope work. The requirement that five minor characteristics be dissimilar before two hairs were eliminated as being dissimilar, should tend to compensate for any slight differences in coding by the same examiner from day to day.

The hairs for each of these similar cards were then compared microscopically at 100 magnifications. Some of these were found to be similar and others were eliminated as being dissimilar at this stage. Those hairs still found to be similar within the above limits were then embedded in a mixture of three parts of Cutex® clear nail polish and one part isoamyl acetate and then removed to produce a scale impression, and were cross-sectioned using a fiber microtome.[5] The characteristics of the scales and cross section were then observed microscopically at ×100 and were coded on the cards. These cards were then sorted again and the hairs for the cards still found to be similar were compared microscopically in cross section and scale count under the comparison microscope. Since scale count is a minor characteristic, the making of scale impressions is not felt to be vital for future studies.

Those hairs which were indistinguishable longitudinally and in cross section were called similar. A total of 861 hairs from 100 different individuals was examined and compared in this way.

Results and Discussion

With 861 hairs, the number of comparisons made was $(861 \times 860)/2 = 370{,}230$. However, from this number must be subtracted the comparisons between hairs from the same individual, since these were deliberately chosen to be distinct. There were 100 individuals and, say, x hairs from each, giving $100 \cdot [x(x - 1)]/2$ comparisons. Actually x was not quite constant, but can be taken as 9, an approximate average of the 6 to 11 hairs chosen. This gives 3600 comparisons to be subtracted, leaving 366,630 comparisons which were made by this method—certainly many times more than could have been made by direct individual comparison with a comparison microscope.

From all these comparisons, only nine pairs of hairs were found to be indistinguishable (see Table 2). It is interesting to note that one individual was involved in three of the similar pairs and another in two. The significance of this finding cannot presently be determined, due to the small sample of similar hairs.

The probability, then, that a hair taken at random from Individual A is indistinguishable from a hair taken at random from Individual B in the population studied may be estimated at 9/366,630 or 1 in 40,737. If nine dissimilar hairs are independently chosen to

TABLE 2—*Similar hairs.*

D.H. 6 and D.S. 4	
B.G. 8 and E.C. 9	
J.R. 7 and D.G. 6	
V.G. 7 and R.S. 9	
V.G. 9 and B.J. 8	
G.C. 1 and G.B. 7	
G.C. 4 and S.G. 7	G.C. 4 = M.S. 6 = S.G. 7
G.C. 4 and M.S. 6	
M.S. 6 and S.G. 7	

[5] Mico Instrument Co. No. 200-A.

represent the hairs on the scalp of Individual B, the chance that the single hair from A is distinguishable from all nine of B's may be taken as $[1 - (1/40{,}737)]^9$, which is approximately $1 - (1/4500)$. This means that the probability that in *at least one* of the nine cases the two hairs examined would be indistinguishable is about 1/4500. If the number of hairs chosen for comparison is 6, 7, 8, 10, or 11, this probability would be somewhat different, but still small (less than 1/3700).

The argument above may be clearer if applied to a more familiar situation. The chance of observing a double six in a throw with two honest dice is 1/36. The chance of *not* throwing double six is $1 - (1/36)$. The chance of no double six in 24 independent throws is $[1 - (1/36)]^{24}$, which is about 0.51. The chance of at least one double six in 24 throws is therefore $1 - 0.51 = 0.49$, just under an even chance.

The calculation, as far as the hairs are concerned, assumes that the 9 hairs selected for comparison are randomly chosen from all the hairs in the population studied. In practice they would all be from the scalp of one individual, but, as noted above, hairs from the same person may differ in many characteristics, and it seems reasonable to assume that the probability of finding at least one of nine hairs from B indistinguishable from the single hair from A is about the figure given above. Thus, if a human scalp hair from the scene of a crime is found to be indistinguishable from at least one of a group of nine hairs taken from Individual B, there is a very strong presumption that the hair did indeed belong to B. Using the parameters shown in this study the chance of error seems to be about 1 in 4500.

If two or more hairs found at the scene are similar to those from B, in the sense described above ("similar" means indistinguishable), there are two possible cases.

1. The hairs themselves are similar. The probability that they could have come from some source other than B remains approximately 1 in 4500.

2. The hairs are dissimilar, but all agree with hair from B in the sense that at least one indistinguishable pair exists. The chance that all n hairs are from some source other than B is about $(1/4500)^n$, which is negligible for $n = 3$ or more.

The second case, with some modification, includes the two-way transfer of hairs between individuals; that is, one or more hairs similar to those of A are found on B's clothing, and one or more hairs similar to those of B are found on A's clothing. If, say, two hairs are found on B and a comparison with a group of nine hairs from A establishes that both of them are indistinguishable from at least one of the nine, the chance that they do not really belong to A is only about $(1/4500)^2$ or 1 in 20 million. Furthermore, if a couple of hairs found on A's clothing agree with hair from B in the same sense, the chance that both identifications are wrong would be smaller still. It cannot be calculated by multiplying probabilities, however, because the events can hardly be regarded as independent, since if A's hair is found on B, it seems *a priori* likely that B's hair might be found on A.

The assumption is made that the six to eleven hairs are representative of all the types of hair present on the scalp of an individual. This assumption consists of two parts. The first is that 80 to 100 randomly selected hairs are representative of all the hairs on the scalp of an individual. This assumption was developed empirically by several examiners and has been used routinely in forensic hair examinations in the Royal Canadian Mounted Police (RCMP) Crime Detection Laboratories. The investigator is asked to submit 80 to 100 hairs from various regions of the scalp as a standard sample. The second part is the assumption that six to eleven dissimilar hairs selected macroscopically are representative of the 80 to 100 hairs. This assumption was tested experimentally for ten of the individuals. It was found that all of the combinations and types of the major characteristics present in the 80 to 100 hairs, together with several of the minor characteristics, were represented by these six to eleven hairs. Further study in this area is under way.

The hair samples were not chosen from the population at random, but were selected so that the probability of two hairs being similar would be greater, if anything, than in the population at large (see Table 3). The study included one family consisting of a grandmother, a mother, a father, and six children; a family of four brothers and sisters; and a set of identical twins. It is interesting to note that in these family and twin groups no members were found with indistinguishable hairs.

TABLE 3—*A comparison of the sample used in this study with the characteristics of the population at large.*

Characteristics	% in Population at Large[a]	% in Study
Age		
0–14	33.0	3
15–19	9.2	8
20–35	19.7	80
35–65	30.5	6
Over 65	7.7	3
Sex		
M	50.5	67
F	49.5	33
Racial Origin		
Caucasian	98.1	92
Mongoloid	1.7	6
Negroid	0.2	2

[a] Source: 1966 census of Canada.

With nine cases of indistinguishable hairs out of 366,630, the probability is so small that the Poisson approximation, whereby the variance is equal to the mean, should be applicable. Thus, in this case, the variance would be approximately 9 and the standard deviation 3. Hence the standard deviation of the probability 1/40,700 would be very nearly one third of this or 1/122,100. On the same basis, the standard deviation of the probability 1/4500 would be $\frac{1}{3} \times 1/4500$ or 1/13,500. There is a 97.5 percent chance that the probability would be less than the sum of the probability and two standard deviations, in this case $1/4500 + \frac{2}{3}(1/4500)$, or 1/2700.

The importance of examining hairs in cross section, in addition to whole mount, was demonstrated by this study. Of the 861 hairs studied, 163 cross sections were required to gain additional characteristics for differentiation.

The card coding method was tried with more than one examiner to check the reproducibility between examiners. However, due to the fact that so many of the characteristics coded are subjective (for example, color, texture), it was not possible to get complete reproducibility between two or more examiners coding the same hair. The method must be confined to the same examiner, as in this research.

Summary

By use of a card coding system for some macroscopic and microscopic characteristics of human scalp hairs, 366,630 comparisons were made between 861 hairs from 100 different individuals. Of these, nine pairs were found to be indistinguishable. It is estimated that if one human scalp hair found at the scene of a crime is indistinguishable from at least one of a group of about nine dissimilar hairs from a given source, the probability that it could have originated from another source is very small, about 1 in 4500. If, instead of one hair, n mutually dissimilar human scalp hairs are found to be indistinguishable from those of a given source, this probability is then estimated to be $(1/4500)^n$, which is negligible for $n = 3$ or more.

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