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The Value of Microscopic Features in the Examination of Human Head Hairs: Statistical Analysis of Questionnaire Returns

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ABSTRACT: There is an apparent diversity of opinion with respect to the probative value of hair in the United Kingdom and in North America. A questionnaire was devised and widely circulated in an attempt to discover the reasons behind this diversity and to seek the views of a broad range of hair examiners. This paper reports on the statistical analyses of the answers to the closed form questions. The majority of replies to most questions favored the number of categories given in the questionnaire. The general impression is that U.K. scientists tend to want fewer categories for classification of microscopic features than the North Americans. The largest divisions of opinion concerned pigment distribution and density and the medulla, where North American scientists want more categories for classification and the U.K. scientists fewer. The implications of these results in the choice and description of features to be examined in human hairs is considered in the second paper concerned with this questionnaire.

KEYWORDS: forensic science, hairs, microscopy

It is evident from the recent international meetings in Birmingham (UK), Wiesbaden (FRG), Quantico (USA), and a section within the 10th International Association of Forensic Scientists Conference at Oxford (UK) that there is a renewed interest in an awareness of the problems with hair examinations in the forensic science context. Enzyme typing of hair sheath material, sex determination, and the analysis of cosmetic treatments are potentially useful techniques for improving the probative value of hair examination. However, at present, the ability to discriminate between hairs in routine work depends on microscopic examinations. Robertson [*1*], in reviewing microscopic features, pointed out the need for more adequate definitions of features and some progress has been made in this regard. He also discussed the apparent diversity of opinion with respect to the probative value of hair between examiners in the United Kingdom and Gaudette in Canada.

A questionnaire was devised by the authors and widely circulated in an attempt to discover the reasons behind this diversity and to seek the views of a broad range of hair examiners. It was also hoped that the answers provided might enable a scheme for the examination of hairs

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to be produced which would find widespread acceptance within the forensic science community and would act as a focal point for further research. The statistical analyses of the answers to the closed form questions on the questionnaire are reported in this paper, while a fuller discussion of the numerous comments and suggestions contained in the questionnaire returns are given in the following paper (Robertson and Aitken [2]).

The questionnaire was distributed to forensic science laboratories throughout Western Europe, Canada, the United States, Australia, and New Zealand. The survey was designed to test opinions on the value of certain characteristics in the comparison of Caucasian head hairs so the distribution was restricted to these areas, and took place in the first few months of 1983. Replies continued to be received till December 1983 at which time there were 303 replies. The analyses reported in this paper are based on these replies. The distribution of the frequency of replies over various regions are given in Table 1. The letter and questionnaire are given in Appendix III.

It is not possible to work out a response rate as it is not known how many people in the laboratories are actively interested in microscopic comparisons of human head hairs. It is not, therefore, possible to know how many people should be replying, a requirement for the calculation of a response rate. However, over 1000 questionnaires were sent out in an attempt to ensure that no person who wanted one was without a questionnaire. Also, despite an injunction to the contrary, several forms were returned with more than one name attached, implying that a concensus opinion had been reached. The number of questionnaire forms returned is therefore a slight underestimate of the number of people replying.

A coding scheme was drawn up for the closed form questions of the questionnaire so that graphs could be drawn and simple summary statistics could be evaluated in order to illustrate better, both visually and numerically, the differences of opinion between various respondents. The answers were coded using the numbers (1, 2, 3) corresponding to (Fewer, Exactly correct, More categories) or (1, 2, 3, 4, 5) corresponding to ranks 1 for "not at all useful" to 5 for "very useful" as given in the appropriate questions. If an ambiguous answer was given the Number 8 was allocated. If no answer was given the Number 9 was allocated. An example of an ambiguous answer would be when more than one number was ringed in answer to a particular question. In the analyses, all questions with ambiguous or missing answers were omitted. Thus, total replies for any particular feature will often be less than 303.

No attempt has been made to weight the responses to account for the relative experience of the respondents.

Two points should be emphasized. The questionnaire was aimed in the first instance at eliciting opinions about the *number* of categories into which a particular feature should be classified. A respondent might agree with the number of categories while not being in agreement with the descriptions used. Space was provided to enable respondents to give their own scheme. While the classification used in the questionnaire was based on a scheme previously published

TABLE 1—*Number of questionnaire responses for each region.*

Region	Number of Replies		Large Region
Scotland	10		
U.K. excluding Scotland	64	74	U.K.
Canada	19		
U.S.A.	168	187	North America
Europe excluding U.K., but including U.S. Army bases in Europe	30		
Australia and New Zealand	12	42	Rest of the world
Total	303		

(Robertson [1]), this should not be taken as implying that the authors support a scheme along identical lines. Indeed, it was hoped that comments and suggestions about the categories defined would emerge. The second point concerns the population to which the questionnaire was sent. It was sent only to laboratories in countries where a major part of the population is Caucasian. In analyzing the results it has been borne in mind that it might well be difficult, if not impossible, for a respondent who is used to dealing with a mixed ethnic population not to consider a broader range of features. The idea of restricting this research to only Caucasian hair is clearly artificial and was a shortcoming in the original design. Nevertheless, inferences drawn from the analysis of the replies can only be made concerning Caucasian populations and should not be made about Oriental or Negroid populations.

Presentation of Results

Contingency tables were constructed to compare the responses to the various questions over the different regions. Chi-squared statistics were calculated for each of the tables. The tables are not reproduced here, but a summary of the statistical analyses is given in Table 2.

The six regions listed in Table 1 were partially combined to form three larger regions which are

1. U.K.:	(Scotland and U.K. excluding Scotland)	with 74 replies
2. North America:	(U.S.A. and Canada)	with 187 replies
3. Rest of the world:	(Europe excluding U.K., Australia, and New Zealand)	with 42 replies

All ambiguous answers (coded *8*) and missing answers (coded *9*) were omitted from individual analyses. The tables were constructed and the χ^2 statistics were evaluated from a computer file of the original responses using the statistical package 'Minitab' [3].

Table 2 gives the results of 17 such tests. Bar charts corresponding to these tests and showing the distribution of replies within the three larger regions are shown in Figs. 1 to 17 in Appendix I. The following information is given for each feature. There is the value of the χ^2 statistic with

TABLE 2—*Classification of responses by large region. Chi-squared statistics and significance probabilities.*

Number	Feature	χ^2 Statistic	Degrees of Freedom	Significance Probability, %	Degree of Significance[a]
1	Color	11.9	4	<5	*
2	Pigment distribution	24.6	4	<0.1	***
3	Pigment density	15.3	2	<0.1	***
4	Pigment size	5.7	2	>5	NS
5	Medulla	40.5	4	<0.1	***
6	Tip	7.5	2	<5	*
7	Root	0.02	2	>99	NS
8	Cross-sectional shape	20.4	4	<0.1	***
9	More cross-sectional shape	13.7	4	<1	**
10	Numerical features	20.5	6	<1	**
11	Nonnumerical features	4.2	4	>25	NS
12	Maximum length	3.7	8	>75	NS
13	Mean length	7.4	8	>25	NS
14	Maximum shaft diameter	18.5	8	<5	*
15	Mean shaft diameter	24.2	8	<1	**
16	Medullary index	24.0	8	<1	**
17	Scale index	30.6	6	<0.1	***

[a] See Appendix II, Note 3 for definition of symbols.

the appropriate value for the degrees of freedom (d.f.) and the significance probability P together with the degree of significance. The degree of significance is an abbreviated form of the significance probability and a description of the interpretation which can be placed on the classifications, together with other technical notes, is given in Appendix II. For Figs. 1 to 8, the numbers of divisions of the feature on which the respondent was asked to comment (Fewer, Exactly correct, or More) are also given.

Comments on the χ^2 statistic are given if the significance probability is 1% or less. This is a rather conservative procedure and may not draw attention to forensically significant results which do in fact exist. However, this is thought to be less unsatisfactory than coming to conclusions about forensic science significance more often than should be done simply because a large number of tests have been conducted.

The first result of note concerns the pigment distribution. It would seem that more people than expected in America and fewer people in the U.K. and the rest of the world would like more categories for classifying pigment distribution and density. There is also strong evidence of a difference of opinion about the number of features required to classify the medulla. It appears that U.K. scientists tend to want fewer categories for the medulla. There is a slightly anomalous result for the cross-sectional shape. There is strong evidence that U.K. scientists want fewer categories for classifying cross-sectional shape; however only three categories were given in the questionnaire, so presumably forensic scientists only want two. The answer to the question regarding more information from cross sections provides evidence of a difference of opinion. However, the main contributor to the χ^2 statistic was the cell corresponding to the number of "don't knows" in the U.K. where there are more than would be expected. The impression is that U.K. scientists are not certain of the usefulness of cross-sectional shape: 16/62 respondents in the U.K. want fewer than three categories while only 10/171 in North America and 5/37 in the rest of the world want fewer categories. This is reflected in the large proportion of people in the U.K. replying "don't know" to the question about obtaining further information from cross sections. There is no evidence of a difference of opinion between regions about the usefulness of nonnumerical features; they are rated highly. There is evidence of a difference about the usefulness of numerical features where fewer than expected outside the U.K. and America think they are not at all useful and fewer people than expected in the U.K. think they are useful. More people than expected in the U.K. think that the mean shaft diameter, the medullary index, and the scale index are not at all useful.

Conclusions

The general impression is that U.K. scientists tend to want fewer categories than the rest of the world who want fewer than the North Americans.

The χ^2 tests which are not significant, at the 5% level, are those for

(1) pigment size
(2) the root,
(3) nonnumerical features,
(4) maximum length, and
(5) mean length.

This implies that there is insufficient evidence of a major division of opinion about the number of categories for pigment size, the root, or about the usefulness of nonnumerical features or the length, maximum or mean. In all three regions the number of categories, three, specified for pigment size and the root is thought by most respondents to be correct. Most respondents rated nonnumerical features as highly useful. Most thought maximum and mean length were fairly useful features.

The largest divisions of opinion concerned pigment distribution and density and the medulla where North American scientists want more categories for classification, the U.K., fewer.

There are also, statistically, highly significant results for cross-sectional shape and the scale index. The former is almost certainly because of the uncertainty of the U.K. respondents, the latter is influenced by four people in the rest of the world region who think it is a very useful feature.

Most replies to most questions favored the number of categories given in the questionnaire.

These results may help to explain the worldwide diversity of opinion with respect to the probative value of hair. If fewer categories are used to define a feature, and indeed fewer features are used, then it follows that there must be a reduction in the "potential" to discriminate between hairs. It may be argued that the approach in the U.K. which the replies to the questionnaire imply is being followed, is too conservative. Equally, it is possible that those scientists who support more categories are introducing too high a risk factor by making the features subjective.

It would seem reasonable to suggest that, in part, the diversity of opinion between hair examiners may be a function of their own ability to recognize and record the variation present in hair features. This is likely to be a function of the training and experience of the examiner. Other aspects of this question will be considered in the second paper concerned with this questionnaire.

Acknowledgment

The authors gratefully thank all respondents for the time and effort taken in completing and returning questionnaires.

APPENDIX I

Bar Charts Showing the Distribution of Replies Within the Three Large Regions

1. There are three separate bar charts within each figure, one for each of the three large regions, U.K., North America, and the rest of the world.
2. The categories in Figs. 1 to 8 are Fewer (1), Exactly correct (2), More (3); in Fig. 9 Yes (1), No (2), Don't know (3); in Figs. 10 and 11 Very low (1) to Very high (5); and in Figs. 12 to 17 Not at all useful (1) to Very useful (5).
3. The numbers in parentheses below the title of the region are the numbers of valid replies received to that question.
4. The heights of the bars measure the relative frequency, as a percentage within each region, of the replies in that particular category. The absolute frequencies are given by the numbers above the bars.

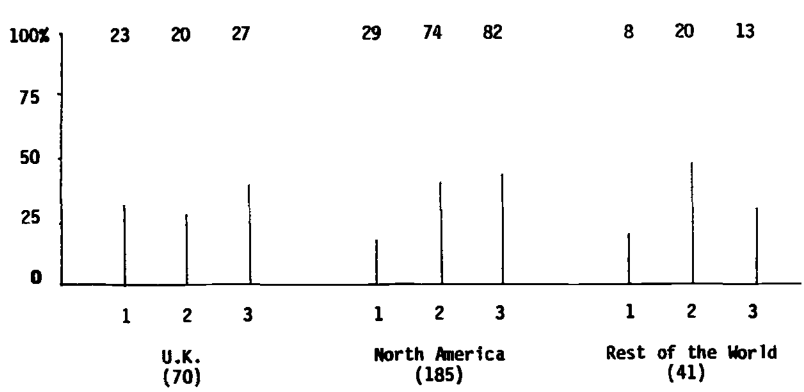

FIG. 1—*Bar chart to show distribution within region of replies to question on color. Nine divisions.* $\chi^2 = 11.9$, *4 d.f.*, $P < 5\%$, *(*).*

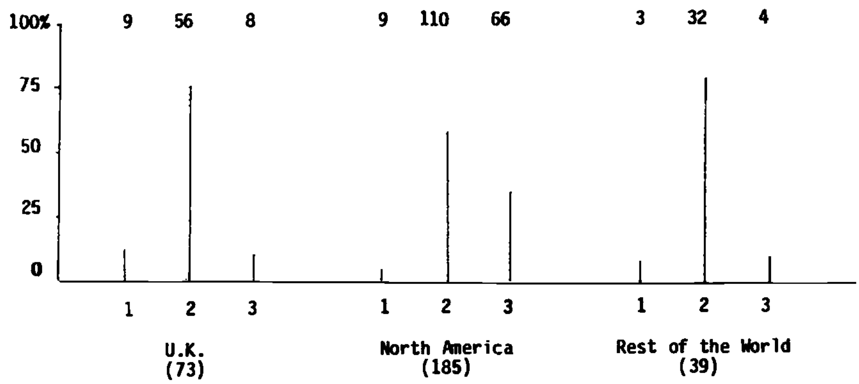

FIG. 2—*Bar chart to show distribution within region of replies to question on pigment distribution. Five divisions.* $\chi^2 = 24.6$, *4 d.f.*, $P < 0.1\%$, *(***).*

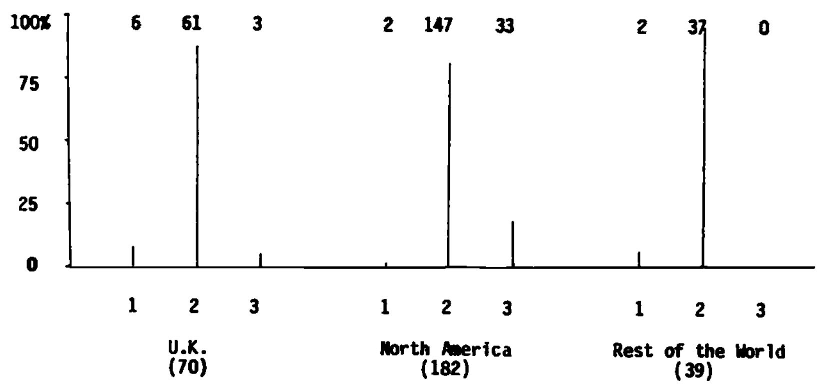

FIG. 3—*Bar chart to show distribution within region of replies to question on pigment density. Four divisions.* $\chi^2 = 15.3$, *2 d.f.*, $P < 0.1\%$, *(***), Categories 1,2 merged.*

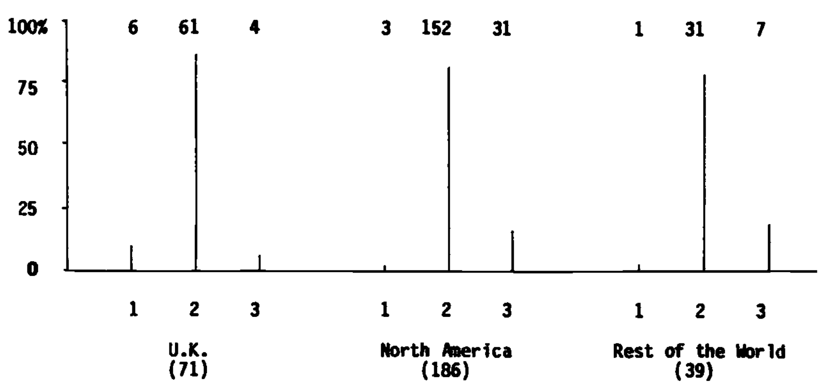

FIG. 4—*Bar chart to show distribution within region of replies to question on pigment size. Three divisions.* $\chi^2 = 5.7$, *2 d.f.*, $P > 5\%$, *(NS), Categories 1,2 merged.*

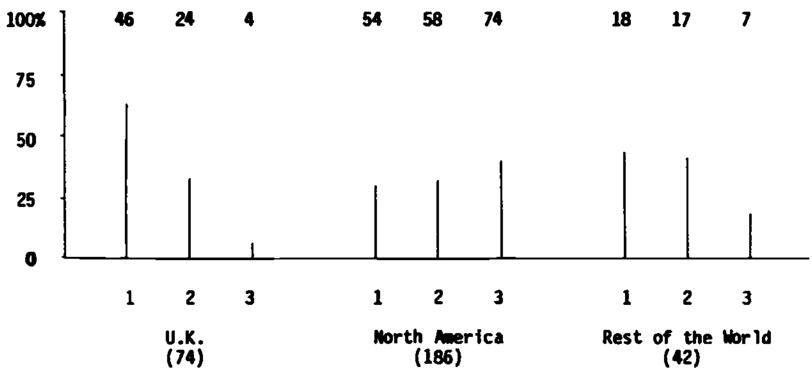

FIG. 5—*Bar chart to show distribution within region of replies to question on medulla. Six divisions.* $\chi^2 = 40.5$, *4 d.f.*, P < *0.1%, (***).*

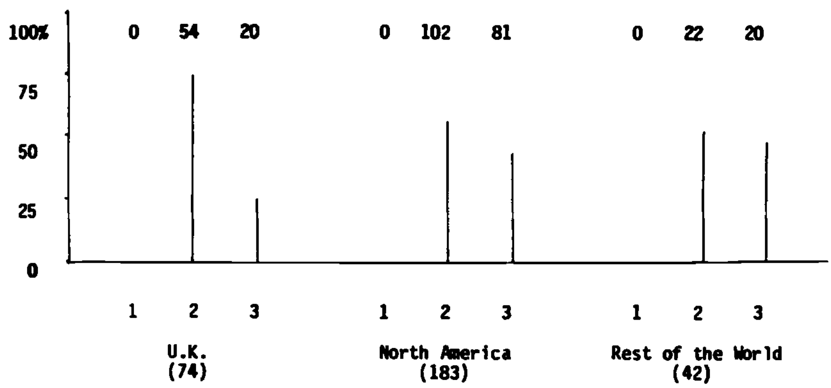

FIG. 6—*Bar chart to show distribution within region of replies to question on tip. Three divisions* $\chi^2 = 7.5$, *2 d.f.*, P < *5%, (*).*

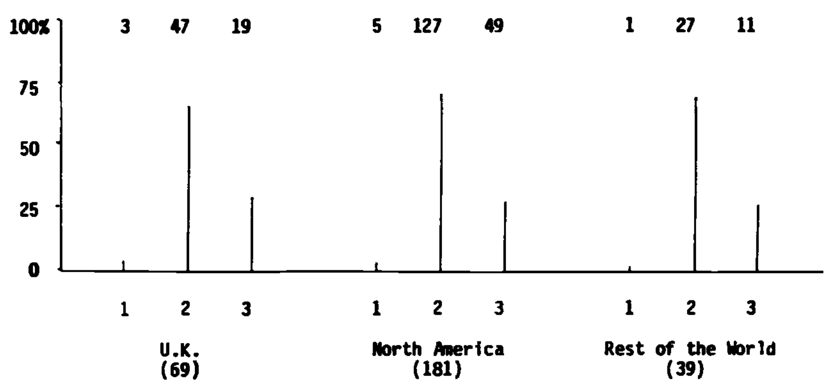

FIG. 7—*Bar chart to show distribution within region of replies to question on root. Three divisions.* $\chi^2 = 0.02$, *2 d.f.*, P > *99%, (NS), Categories 1,2 merged.*

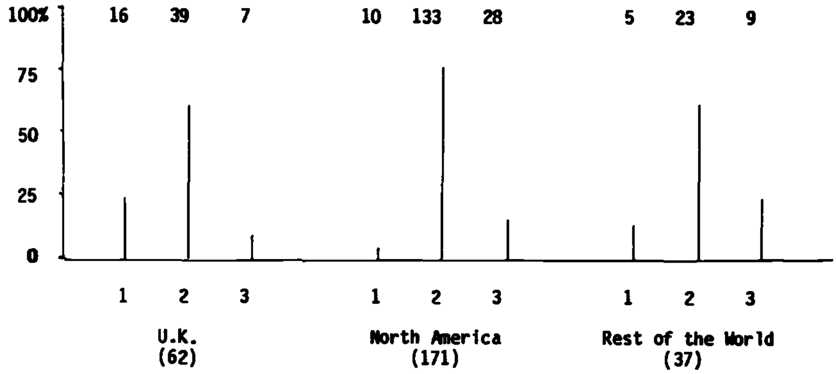

FIG. 8—*Bar chart to show distribution within region of replies to question on cross-sectional shape. Three divisions.* $\chi^2 = 20.4$, *4 d.f.*, $P < 0.1\%$, *(***).*

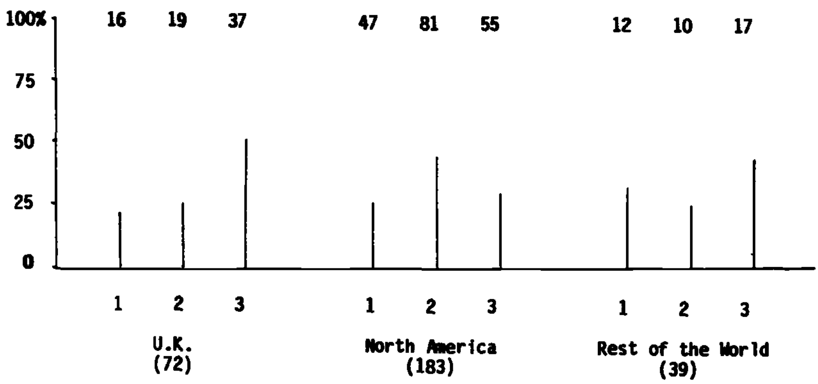

FIG. 9—*Bar chart to show distribution within region of replies to question on more cross-sectional shape.* $\chi^2 = 13.7$, *4 d.f.*, $P < 1\%$, *(**).*

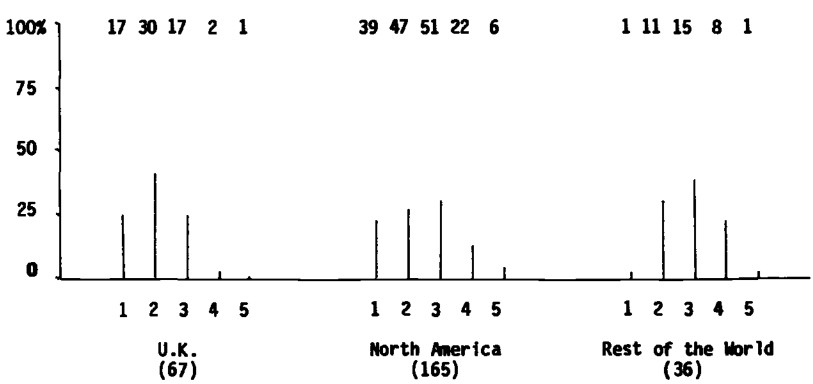

FIG. 10—*Bar chart to show distribution within region of replies to question on numerical features.* $\chi^2 = 20.5$, *6 d.f.*, $P < 1\%$, *(**), Categories 4,5 merged.*

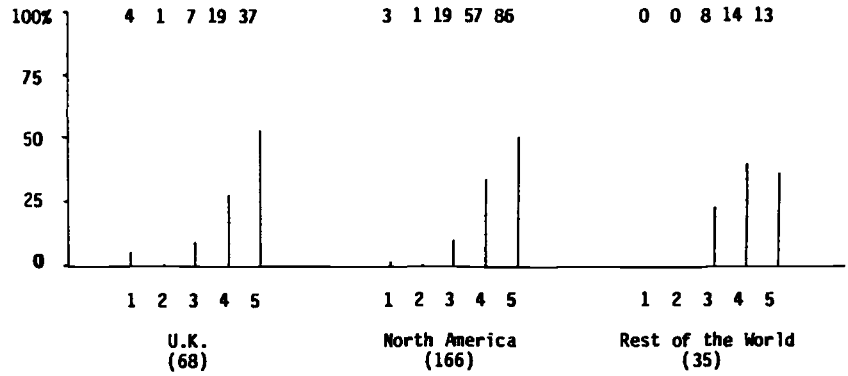

FIG. 11—*Bar chart to show distribution within region of replies to question on nonnumerical features.* $\chi^2 = 4.2$, *4 d.f.*, P > 25%, *(NS), Categories 1,2,3 merged.*

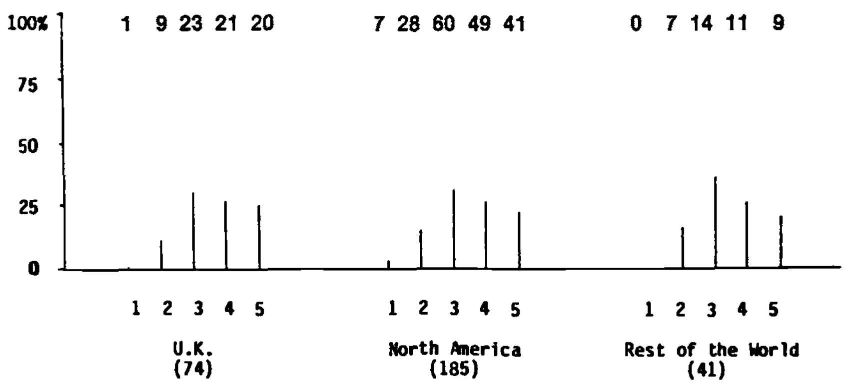

FIG. 12—*Bar chart to show distribution within region of replies to question on maximum length.* $\chi^2 = 3.7$, *8 d.f.*, P > 75%, *(NS).*

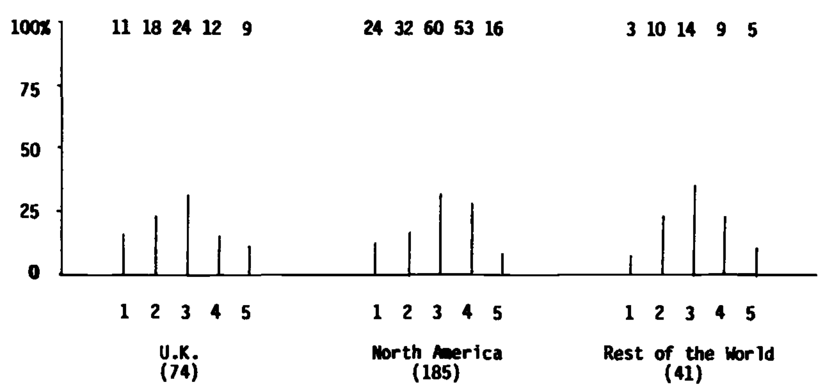

FIG. 13—*Bar chart to show distribution within region of replies to question on mean length.* $\chi^2 = 7.4$, *8 d.f.*, P > 25%, *(NS).*

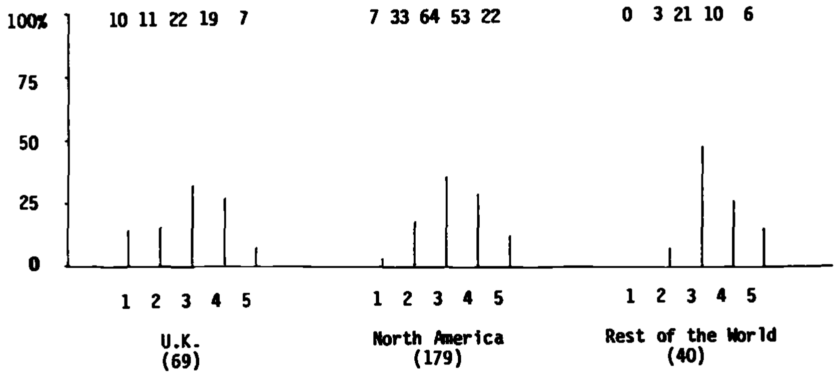

FIG. 14—*Bar chart to show distribution within region of replies to question on maximum shaft diameter.* $\chi^2 = 18.5$, *8 d.f.*, $P < 5\%$, *(*)*.

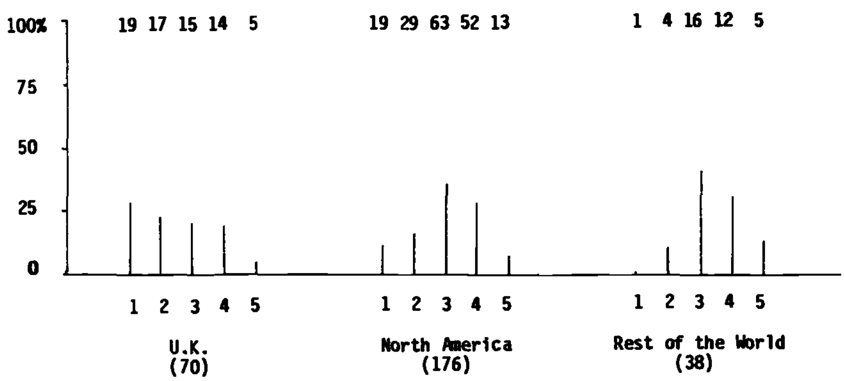

FIG. 15—*Bar chart to show distribution within region of replies to question on mean shaft diameter.* $\chi^2 = 24.2$, *8 d.f.*, $P < 1\%$, *(**)*.

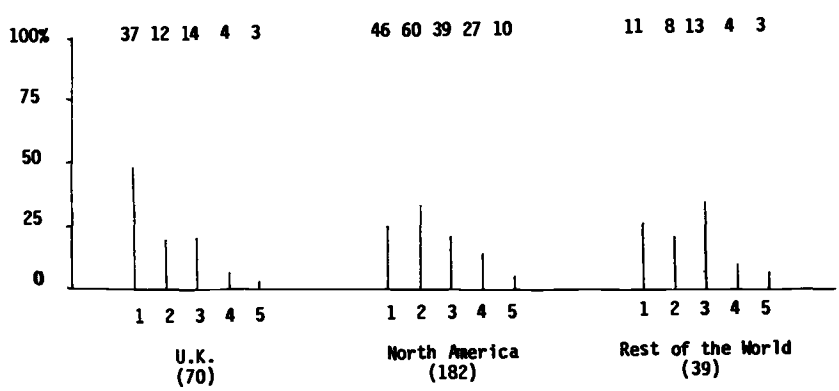

FIG. 16—*Bar chart to show distribution within region of replies to question on medullary index.* $\chi^2 = 24.0$, *8 d.f.*, $P < 1\%$, *(**)*.

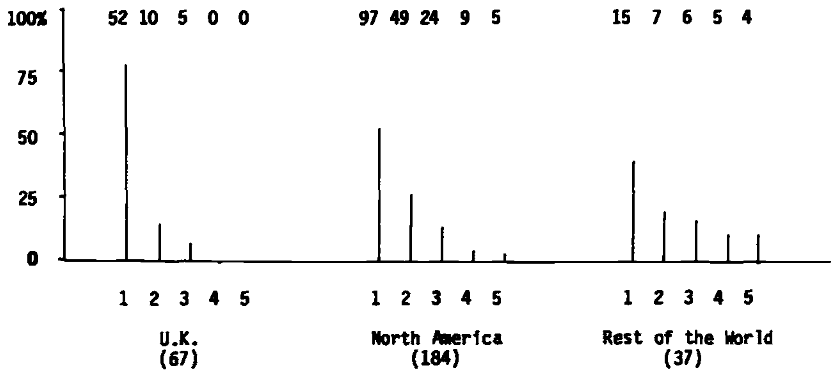

FIG. 17—*Bar chart to show distribution within region of replies to question on scale index.* $\chi^2 = 30.6$, *6 d.f.*, $P < 0.1\%$, *(***), Categories 4,5 merged.*

5. Below the bar charts are given the value of the χ^2 statistic, the number of degrees of freedom, the significance probability, and the degree of significance as given in Table 2. A note is also made of the categories which have been merged, if any, to satisfy the conditions given in Note 1 of Appendix II.

APPENDIX II

Technical Notes

1. χ^2 is the value of the χ^2 goodness-of-fit statistic and is defined by

$$\chi^2 = \sum_{i=1}^{k} (O_i - E_i)^2/E_i$$

where k is the number of cells and O_i and E_i are the observed and expected values, respectively, for the ith cell. The expected values are calculated assuming that the opinion on the number of categories required for classifying a feature is independent of the region in which that particular forensic scientist is based. If too many cells had expected frequencies that were too small, a χ^2 analysis was not done. A good, but conservative, rule of thumb is that not more than 20% of the cells should have expected cell frequencies less than 5 and no cell should have an expected cell frequency less than 1. If this condition was not satisfied then categories were combined until the condition was satisfied and the number of degrees of freedom was reduced accordingly.

2. The significance probability P is the probability of obtaining a value of the χ^2 statistic as large as or larger than the value quoted, assuming that there is not a relationship between the region and opinions on the number of categories for classifying the feature under consideration. Thus, for example, "$<1\%$" implies that there is a less than 1 in a 100 chance of obtaining the value given or anything larger.

3. The degree of significance is an abbreviated form for the significance probability.

(a) NS: not significant at the 5% level, which implies there is insufficient evidence to suggest that the opinions about the number of categories used for that feature, or its usefulness, differ from one region to another.

(b) *: significant at the 5% level but not at the 1% level, which implies there is evidence of an association between opinions about the number of categories used for that feature, or its usefulness, and the regions.

(c) **: significant at the 1% level but not at the 0.1% level which implies there is strong evidence of an association between opinions about the number of categories used for that feature, or its usefulness, and the regions.

(d) ***: significant at the 0.1% level, which implies there is very strong evidence of an association between opinions about the number of categories used for that feature, or its usefulness, and the regions.

4. A word of caution is necessary before attempting to interpret the figures in Table 2. The significance probability P is calculated assuming that the two variables which are being compared are independent. The interpretation is that *if* the variables are independent then the probability of observing a value of the χ^2 statistic as large as or larger than that actually observed is P. For example, if $P = 5\%$ then on 5% of the occasions on which a χ^2 statistic was calculated when the variables were in fact independent a value of the statistic greater than the 5% value would be observed. Another way of expressing this is that in a large number of independent tests it would be expected that 5% of these tests would produce a result *statistically* significant at the 5% level, even though the two variables were independent and there was no *forensic* significance in the result.

APPENDIX III

THE VALUE OF MICROSCOPIC FEATURES IN THE FORENSIC EXAMINATION OF HUMAN HEAD HAIRS

Dear Colleague,

We are considering devising a method for the characterization of Caucasian human head hair. In order that this scheme may be as widely acceptable as possible, we would like the views of forensic scientists before we start collecting and analyzing the data. First, in Section A, we would like your opinion on the features it would be helpful to consider if a method were developed, and second, in Section B, your opinion on the usefulness of head hair examinations in general. To this end we would be grateful if you could complete the attached questionnaire. We emphasize that you should complete it independently of other people and should not collaborate with them in any way.

Please note that the questionnaire has been devised to investigate Caucasian head hairs only. It is fully appreciated that some microscopic features may be of considerable value in characterizing either the body origin or the ethnic origin of the hair. We are primarily concerned here with features which will be of value in the characterization of head hairs from Caucasians.

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THE VALUE OF MICROSCOPIC FEATURES IN THE FORENSIC EXAMINATION OF HUMAN HEAD HAIRS

SECTION A. These questions concern the possible features which could be used for characterisation of human head hairs.

1. We list below 8 features which may be used in a system of classifying head hairs, together with a scheme for categorizing each feature. For each feature please indicate, by ringing the appropriate number, whether you think the scheme would be improved by including more or fewer categories or whether the scheme includes the correct number.

   After each feature there are several blank lines. If you have any reservations regarding the choice of categories for that particular feature please comment there.

   a. **Colour:** colourless - translucent, yellow-brown, yellow-red, reddish brown, light brown, mid-brown, dark brown, greyish brown, black.

   Fewer 1
   Exactly correct 2
   More. 3

   Any other comments. . . . .
   . . . .
   . . . .
   . . . .

   b. **Pigment distribution:** uniform, peripheral, about medulla, one side, clusters.

   Fewer 1
   Exactly correct 2
   More. 3

   Any other comments. . . . .
   . . . .
   . . . .
   . . . .

   c. **Pigment density:** Absent, light, medium, heavy

   Fewer 1
   Exactly correct 2
   More. 3

   Any other comments. . . . .
   . . . .
   . . . .
   . . . .

   d. **Pigment size:** Fine, medium, large.

   Fewer 1
   Exactly correct 2
   More. 3

   Any other comments. . . . .
   . . . .
   . . . .
   . . . .

Page 2

e. **Medulla:**
Absent,
scanty,
fragmentary,
fractional-broken,
broken,
continuous.

Fewer 1
Exactly correct 2
More. 3

Any other comments. . . . .

. . . .

. . . .

. . . .

f. **Tip:**
Natural taper,
cut,
other (specify condition).

Fewer 1
Exactly correct 2
More. 3

Any other comments. . . . .

. . . .

. . . .

. . . .

g. **Root:**
Absent,
anagen with sheath,
catagen or telogen.

Fewer 1
Exactly correct 2
More. 3

Any other comments. . . . .

. . . .

. . . .

. . . .

h. **Cross-sectional shape:**
Oval,
round,
elliptical.

Fewer 1
Exactly correct 2
More. 3

Any other comments. . . . .

. . . .

. . . .

. . . .

(i) Do you think that further information can be obtained from cross-sections other than cross-sectional shape?

Yes 1
No. 2
Don't know. 3

(ii) If yes, please specify.

. . . .

. . . .

. . . .

2. How useful do you find each of the following features?
Rate 5 as very useful and 1 as not at all useful.

	Very useful				Not at all useful
Maximum length.	5	4	3	2	1
Mean length	5	4	3	2	1
Maximum shaft diameter.	5	4	3	2	1
Mean shaft diameter	5	4	3	2	1
Medullary index	5	4	3	2	1
Scale index	5	4	3	2	1

3. In general, can you please indicate how highly you rate numerical and non-numerical features.
Rate 5 as very high and 1 as very low.

	Very high				Very low
Numerical features.	5	4	3	2	1
Non-numerical features.	5	4	3	2	1

4. Finally, what other features, if any, do you think would be of value?

. . . .

. . . .

. . . .

SECTION B. Whilst it is recognised that the overall value of examining human head hairs will depend on the details of the case and on the microscopic features of the hairs involved, it would be helpful if you could comment on the following general questions.

5. How often are you able to reach a positive inclusion or exclusion of case hairs?
Rate 5 as always and 1 as never.

Always				Never
5	4	3	2	1

6. If more information about variation in hairs was available do you think this would improve your ability to discriminate hairs?
Please ring the appropriate number.
If Yes or No please specify:

Yes. 1

No 2

Don't know 3

. . . .

. . . .

. . . .

. . . .

7. Do you use some form of data sheet or scheme in examining head hairs?
Please ring the appropriate number and then proceed to (i) or (ii).

Yes . . 1 . .proceed to 7(i)
No . . 2 . .proceed to 7(ii)

Page 4

(i) Are you happy with the data sheet you use?
Rate 5 as very happy and 1 as not at all happy.

Very happy				Not at all happy
5	4	3	2	1

If you have any reservations regarding your data sheet please give them here.

. . . .

. . . .

. . . .

(A copy of your data sheet would be of great value in this survey if you are able to enclose one with your returned questionnaire)

(ii) Please explain, if possible, why you do not use a data sheet?

. . . .

. . . .

. . . .

Do you think that the use of an analytical data sheet would help you in hair examinations?
Please ring the appropriate number.

Yes 1
No 2
Don't know . . . 3

If you have any reservations regarding the use of data sheets in general please give them here.

. . . .

. . . .

. . . .

If there are any general comments which you would like to make please do so here. If you require more space extra sheets may be attached.

Please fill in the following details and return the completed questionnaire in the enclosed envelope as soon as possible to:

Dr J. Robertson,
Forensic Science Unit,
Royal College,
University of Strathclyde,
Glasgow G1 1XW

Name. . . . .

Organisation. . . . .

. . . .

Position in organisation. . . . .

You may, of course, remain anonymous if you wish though the organisation and position will be valuable for our records.

References

[1] Robertson, J., "An Appraisal of the Use of Microscopic Data in the Examination of Human Head Hair," *Journal of the Forensic Science Society*, Vol. 22, No. 4, Oct. 1982, pp. 390-395.
[2] Robertson, J. and Aitken, C. G. G., "The Value of Microscopic Features in the Examination of Human Head Hairs: Analysis of Comments Contained in Questionnaire Returns," *Journal of Forensic Sciences*, Vol. 31, No. 2, April 1986, pp. 563-573.
[3] Ryan, B. F., Joiner, B. L., and Ryan, T. A., *'Minitab' Handbook*, 2nd ed., Duxbury Press, Boston, 1985.

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