Glass on clothing and shoes of members of the general population and people suspected of breaking crimes

SA COULSON, JS BUCKLETON

Institute of Environmental Science and Research Ltd., Private Bag 92-021, Auckland, New Zealand

AB GUMMER

40 Milton Street, Somerfield, Christchurch, New Zealand

and

CM TRIGGS

University of Auckland, Private Bag 92019, Auckland, New Zealand

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The outer clothing and footwear of 122 people attending a university gymnasium and a private gymnasium were searched for fragments of glass. Both the surfaces and the pockets of the clothing and the uppers and soles of the footwear were searched. New Zealand forensic glass cases have been reviewed to determine the amount of non-matching glass present on the clothing of people who are suspected of breaking crimes. Data from 114 suspects who had no matching glass on their clothing and shoes were accumulated. Statistical modelling techniques have been applied to the data collected.

Die Oberbekleidung und Schuhe von 122 Personen eines universitären und eines privaten Fitnesszenters wurden auf Glasfragmente hin untersucht. Sowohl die Oberflächen als auch die Taschen der Bekleidung sowie die Sohlen und das Obermaterial der Schuhe sind in die Suche einbezogen worden. Es erfolgte eine Überprüfung der in Neuseeland bearbeiteten Fälle, bei denen Glasfragmente als Spuren auftraten. Dabei wurde die Anzahl der nicht übereinstimmenden Glaspartikel auf der Bekleidung jener Personen bestimmt, die Einbruchsdelikten verdächtigt werden. Die Auswertung der Daten von 114 Verdächtigen, bei denen sich weder auf der Kleidung noch auf den Schuhen übereinstimmende Glasfragmente befanden, erfolgte mit statistischen Modellberechnungen.

Les vêtements externes et les chaussures de 122 personnes qui utilisaient une salle de gymnastique d'une université et d'une société privée ont été étudiés pour la présence de fragments de verre. Aussi bien les surfaces que les poches des habits ainsi que les parties supérieures et les semelles des chaussures ont fait l'objet de l'investigation. Des cas de verre retrouvés sur les habits de gens suspectés d'avoir commis des crimes avec débris de verre en Nouvelle-Zélande ont été passés en revue pour déterminer la quantité de verre non concordant présent. Les données concernant 114 suspects sur les habits et les souliers desquels aucun verre concordant n'a été retrouvé ont été accumulés. Des modèles statistiques ont été appliqués aux données récoltées pour leur interprétation.

Se investigan los fragmentos de vidrio en las ropas externas y el calzado de 122 personas que asistían a un gimnasio de la universidad y a uno privado. La investigación se realizó tanto en los exteriores y bolsillos de la ropa como en las partes externas y en las suelas del calzado. Se han revisado los casos forenses de vidrios en Nueva Zelanda para determinar la cantidad de vidrios dispares que aparecen en la ropa de la gente sospechosa de algún delito. Se acumulan datos de 114 sospechosos que tenían en su ropa y calzado vidrios dispares. Se han aplicado técnicas de modelos estadísticos a los datos recopilados.

Key Words: Forensic science, statistics, glass, clothing, survey, Bayesian.

Introduction

One of the major areas of work for criminalistic laboratories is the comparison of glass fragments recovered from a suspect's clothing and footwear with glass samples taken from a broken glass object, such as a window. A number of methods are available for this comparison. In New Zealand the measurement of refractive index (RI) and the examination of surface features of individual fragments by interferometry are used [1,2].

Once these analyses have been completed, an assessment of the evidence must be carried out. Since the late 1980s New Zealand has implemented an assessment method based on the presentation of a likelihood ratio [3] and, more recently, incorporating the continuous method [4].

This approach weighs the probability of the evidence under each of two (or more) alternative hypotheses. The first, typically, being that the suspect is the person who broke the window in question, and the second being that the suspect is not the person who broke the window in question. In most cases to facilitate the calculation of the probability given the second hypothesis it is assumed that the suspect is a person picked at random from some relevant population. This leads to the question of "what population should be surveyed" in order to model the relevant probabilities [5].

Published surveys may be roughly divided into those on members of the general population and those on persons suspected of crime. We review here some of the previously published work, adding this work and discussing the merits of the relative approaches. We also propose statistical models to predict P and S values for casework.

General population surveys

A number of surveys of glass on clothing and shoes of members of the general population have been published. These surveys are designed to answer the question, "How much glass is on a member of the general population?"

In 1971 Pearson, May and Dabbs [6] published their results of a survey of 100 men's suits submitted to a dry cleaners in Reading, England. No grouping analysis was carried out on the refractive index values so we are unable to determine how many different groups of glass were present on each suit. This survey only examined debris collected from the pockets and turn-ups of the suits. The surfaces of these garments were not examined.

McQuillan and Edgar [7] (ME) examined jackets, pullovers and trousers from members of a youth club, part-time members of the Ulster Defence Regiment and recruits into the Royal Ulster Constabulary. A summary of the findings for this survey are presented in Tables 1 and 2. They concluded that it was unusual to find more than six fragments of glass from the same source on clothing and that when a large number of glass fragments was found they tended to originate from multiple sources.

TABLE 1 The number of groups of glass found for different search strategies from the McQuillan and Edgar [7] survey. Data have been grouped using the Evett and Lambert [13] grouping algorithm. This data was reworked by Buckleton and Pinchin (pers comm) from the raw data and differs slightly from the published set.

No. of groups of glass	*Upper garments surface only*	*Upper garments surface & pockets*	*Upper & lower garments surface only*	*Upper & lower garments surface & pockets*
P0	0.811	0.641	0.636	0.403
P1	0.146	0.180	0.238	0.272
P2	0.029	0.053	0.087	0.087
P3	0.000	0.063	0.010	0.053
P4	0.010	0.024	0.010	0.092
P5	0.005	0.015	0.005	0.015
P6	0.000	0.000	0.000	0.019
P7	0.000	0.000	0.005	0.005
P8	0.000	0.015	0.000	0.019
P9	0.000	0.005	0.000	0.015

TABLE 2 The size of groups of glass found for different search strategies from the McQuillan and Edgar [7] survey. Data have been grouped using the Evett and Lambert [13] grouping algorithm. This data was reworked by Buckleton and Pinchin (pers comm) from the raw data and differs slightly from the published set.

Size of groups of glass	*Upper garments surface only*	*Upper garments surface & pockets*	*Upper & lower garments surface only*	*Upper & lower garments surface & pockets*
1 or 2 fragments	0.980	0.958	0.971	0.965
3 or more	0.020	0.042	0.029	0.035

Examination of the data in Tables 1 and 2 shows that the probability of finding a certain number of groups is dependent on the search strategy used. For example, one is more likely to find a group of glass on clothing if the surfaces and pockets are searched compared to searching only the surface of the garment(s). The probability of finding a certain number of groups of glass on clothing has been called the P term [3] where P refers to the Presence of glass.

The P values can be used to compare the results of different surveys. However, for a meaningful comparison it is important to compare P values based on the same search strategy. Additionally, when these values are used to interpret casework, it is vital that the P value mirrors the search strategy used in the case.

The data presented by McQuillan and Edgar [7] has also been used to calculate the S term. S was chosen by Evett and Buckleton [3] to represent the Size of the group(s) of glass. The S term is less dependent on the search strategy used. In fact, regardless of the search procedure used, if glass is found the size of the group is likely to be 1.

Lau *et al.* [8] surveyed the outer clothing and footwear of 213 high school students in Vancouver. They argued that this portion of the population approximated the ideal survey of people who were not involved in crime, while still representing a range of financial, sociological and ethnic backgrounds.

Another general population survey was carried out by Petterd *et al.* [9] who searched the upper outer garments of 2008 people at a shopping centre in Canberra, Australia. They found that six garments bore one fragment of glass each. The authors concluded that the prevalence of glass on members of the general population in Canberra was of a similar order of magnitude to the Canadian survey, but was significantly less than the Northern Ireland survey.

TABLE 3 The number and size of groups found for different categories from the LSH survey. The data has been read from the graphs published.

	Surfaces	*Pocket*	*Shoe*	*Individual*
P_0	0.40	0.48	0.450	0.250
P_1	0.26	0.28	0.190	0.220
P_2	0.12	0.14	0.100	0.140
P_3	0.09	0.02	0.090	0.140
P_4	0.05	0.04	0.050	0.069
P_5	0.03	0.01	0.030	0.064
P_6	0.02	0.02	0.040	0.033
P_7	0.01	0.01	0.010	0.033
P_8	0.02	0.00	0.030	0.022
P_9	0.00	0.00	0.005	0.020
P_{10+}	0.00	0.00	0.005	0.013
S_1	0.82	0.80	0.83	0.71
S_2	0.10	0.13	0.12	0.15
S_3	0.03	0.03	0.02	0.07
S_4	0.03	0.02	0.01	0.02
S_{5+}	0.03	0.02	0.02	0.05

In summary, a number of researchers have tackled the problem of "how much glass is on the clothing and footwear of members of the general population?" A wide range of results has been published, which suggest that the geographical location of the survey may have a significant effect on the results, as well as the search methodology and strategy used.

Surveys of suspects' clothing and shoes

McQuillan and Edgar [7] argued that "persons suspected of a crime involving breaking glass may recently have been associated with other similar incidents, and consequently the background levels of glass on their clothing could be disproportionately high" compared to members of the general population. Using this argument they decided to survey members of the general population.

However, this same argument can be used to justify surveying people who have come to the police's attention as suspects for breaking incidents. Without making any contentious assumptions about the guilt or innocence of the casework subjects, it is indisputable that they are people who have come to the police's notice in connection with the investigation of breaking offences. It can be convincingly argued that this is the relevant population to be considered when treating the suspect as an innocent person.

Several researchers have already addressed the question of how much background glass is present on the clothing and footwear of people who are suspected by the police of involvement in crime [10].

Lambert, Satterthwaite and Harrison (LSH) [11] presented a large study collating the results of 405 glass cases, involving 589 individuals.

Grouping analysis of the data was carried out. The paper reported P values (in graphical form) for non-matching glass found in three different locations, those being the surfaces, the pockets and the shoes and also per individual. They also reported S values for the same categories. These values are shown in Table 3.

They concluded that "it is not unusual to find large numbers of non-matching glass fragments on the clothing of an individual suspected of criminal activity, although it is unusual to find more then three fragments of non-matching glass from a single source on the clothing of an individual".

Ross and Nguyen [12] surveyed 87 garments (excluding footwear) from non-glass casework from the Victoria Forensic Science Centre in Australia. Only one fragment of glass was recovered from each of two garments. No glass

TABLE 4 P and S values for a search of the upper garment surface only.

Target Pop.	Case - Suspects Ross &Nguyen	Community Petterd et al.	Community Lau et al.	Community ME from graph
P_0	0.977	0.997	0.991	0.811
P_1	0.023	0.003	0.009	0.146
P_2	0.000	0.000	0.000	0.029
P_3	0.000	0.000	0.000	0.000
P_4	0.000	0.000	0.000	0.010
P_5	0.000	0.000	0.000	0.005
P_6	0.000	0.000	0.000	0.000
P_7	0.000	0.000	0.000	0.000
P_8	0.000	0.000	0.000	0.000
P_9	0.000	0.000	0.000	0.000
P_{10}	0.000	0.000	0.000	0.000
S_1	1.000	1.000	1.000	0.900
S_2	0.000	0.000	0.000	0.080
S_3	0.000	0.000	0.000	0.020
S_4	0.000	0.000	0.000	
S_5	0.000	0.000	0.000	

TABLE 5 P and S values for a search of the upper and lower garments.

Target Pop.	Community Lau et al.	Community ME	Glass suspects LSH from graph
P_0	0.920	0.636	0.400
P_1	0.033	0.238	0.260
P_2	0.014	0.087	0.120
P_3	0.000	0.010	0.090
P_4	0.000	0.010	0.050
P_5	0.000	0.005	0.030
P_6	0.000	0.000	0.020
P_7	0.000	0.005	0.010
P_8	0.000	0.000	0.020
P_9	0.000	0.000	0.000
P_{10}	0.000	0.000	0.000
S_1	0.357	-	0.810
S_2	0.500	-	0.100
S_3	0.143	-	0.050
S_4	0.000	-	0.020
S_5	0.000	-	0.000

was found on any of the other items of clothing. This result would suggest that people suspected of crimes that do not involve a breaking offence have considerably less background glass on their clothing than people suspected of breaking crimes.

Comparison of published surveys

Next a comparison of some of these surveys is considered. This is hampered by the different search strategies employed and the summary nature of some of the reporting. However, it does seem possible to compare the P and S values for some of the published research.

Table 4 shows the results for glass found on the surfaces of the upper clothing. Three of the surveys targeted members of the general population while the fourth survey looked at people suspected of non-breaking crimes. All of these surveys show similar amounts of glass on the upper surfaces. In fact there is very little glass on the upper clothing in any of these surveys, with the McQuillan and Edgar survey displaying the largest amount of glass.

Table 5 compares the glass found on the surfaces of the upper and lower clothing. Unfortunately data from only three surveys can be arranged in this way for comparison. The obvious difference from this comparison is that the glass suspects (LSH) appear to have more glass on them than members of the general population.

From our experience in performing surveys based on casework data there is considerable difficulty in processing the information. Both the UK and NZ have "stopping rules". This means that the search of a suspect's clothing is terminated if certain criteria are met. For instance, if a large amount of matching glass is found on an upper garment then no further search is made. This suggests that any non-matching glass on lower garments may never be searched for. Other possible systematic editing includes the possibility that an incomplete set of clothing may be submitted. If, for instance, only a pair of shoes is submitted, then it is impossible to determine how much glass may, or may not, have been on that individual's clothing.

Notwithstanding these concerns we are of the opinion that the advantage of surveying the relevant population (that is the population of glass suspects) outweighs these disadvantages.

It was therefore proposed to perform both a survey of the general population and a survey of people suspected of breaking crimes in New Zealand.

Experimental

General Population Survey

Two Auckland gymnasia were approached to assist in this survey. In total, 112 males and 10 females participated.

Each participant was asked to package their upper clothing, lower clothing and footwear (including socks) into three appropriately labelled plastic bags. A team of "shakers" then processed each garment while the participant was attending the gymnasium. This gave the team of shakers approximately one hour to collect debris from the clothing and footwear. The surfaces of each garment, with the pockets taped shut, were shaken over clean paper and the debris collected. The debris from any pockets was then collected.

The surfaces of the footwear were brushed with a stiff brush to remove debris which was collected separately. The soles of the footwear were then examined using a stereomicroscope (x7 magnification). Any embedded glass fragments were collected. For each set of clothing and footwear a maximum of six debris samples were collected: sufaces of upper and lower clothing and footwear (inc. socks); pockets of upper and lower clothing; and, soles of footwear.

Each participant was asked to complete a brief questionnaire, which recorded sex, age, race, occupation and whether the participant was aware of recent contact with a source of broken glass in the clothing and footwear that they were wearing.

While searching the clothing and shoes a note was made of the types of garments submitted and their qualities with respect to glass retention.

The debris samples were subsequently searched under a stereomicroscope (x7 magnification) and the number of glass fragments found noted. Glass fragments that showed an original surface were examined using an interferometer to determine whether the fragment had come from a flat, patterned or curved source of glass. Where the fragment was of a sufficient size the colour was also noted. The refractive index of recovered glass fragments was determined using GRIM with the silicon oil, Locke B. Of the 141 fragments found, one fragment was too small to successfully measure the refractive index. Grouping of the individual fragments was carried out by plotting the results and grouping by eye.

Survey of suspects from casework

Glass case files for the years July 1996 to March 1999 were reviewed. Only cases where the glass found did not match the control glass submitted were included. This allowed examination of glass on the clothing of individuals who had come to the police's attention in relation to a breaking incident, but who did not have any matching glass on them.

This resulted in casework data from 114 suspects. The following information was recorded for each person; the garments examined, the number of fragments found on each garment, the number and size of groups of glass on each garment and the cumulative total of the number and size of groups of glass.

TABLE 6 Cumulative categories used to group data from suspects survey.

Upper surface
Upper surface and pockets
Upper and lower surfaces
Upper and lower surfaces and pockets
Clothing and shoe surfaces
Upper and lower surfaces and pockets and shoe surfaces
Upper and lower surfaces, pockets, shoe surfaces and soles
Per person (regardless of clothing items)

For each suspect as many relevant categories as possible were filled in (Table 6). In cases where not all of the clothing was submitted not every category was filled in. For example, for a case where only a jumper and a pair of shoes were submitted and examined, the categories involving lower surfaces and pockets were not relevant.

Problems were also encountered where not all of the clothing and shoes that had been submitted were examined. This was normally due to enactment of stopping rules. For example, it was common that if no matching glass was found on the surfaces of the clothing and the shoes then any pockets and the soles of the shoes would not be examined. This has had the effect of reducing the number of garment pockets and shoe soles data recorded.

Results and Discussion

General population survey

The number of garments examined and the number of glass fragments found is shown in Table 7. Of note is that no fragments of glass were found on the surfaces of the upper or lower clothing and that only seven of the total fragments were found in the pockets of the clothing. By far the majority of glass fragments (87%) were found in the soles of the footwear.

Twenty-three of the 141 recovered fragments contained original surfaces which were examined using an interferometer. These results are shown in Table 8. It is interesting to note that the majority of fragments (91%) containing an original surface have not come from a source of flat glass. In the McQuillan and Edgar [7] survey 51 of 631 fragments were reported as having an original surface and of these 34 (67%) were flat. This contrasts with our finding. However, as only a small portion of the recovered fragments had original surfaces only limited conclusions can be drawn from this observation.

TABLE 7 Number of garments examined and number of glass fragments found for general population survey (gym survey).

Garment	*No. of garments examined*	*No. of glass frags found*
Surfaces of upper clothing	120	0
Pockets of upper clothing	61	2
Surfaces of lower clothing	113	0
Pockets of lower clothing	107	5
Surfaces of footwear (incl. socks)	81	12
Soles of footwear	79	122
Total	314	141

TABLE 8 Colour and Original Surfaces of recovered fragments from gym survey.

Original surface only		*Colour only*		*Original surface & colour*	
Flat	2	Yellow/brown	18	Curved & Green	3
Curved	12	Green	4	Curved & Yellow	1
Patterned	5				

Twenty six (18%) fragments in this work were large enough for their colour to be determined (Table 8). The majority of coloured glass was yellow. Comparing these results to those of McQuillan and Edgar, we found slightly more coloured glass, compared to their finding of 7%. However, yellow (amber) appears to dominate amongst the coloured fragments in both countries.

Grouping by eye was carried out on the RI values to determine how many different groups of glass were present on the clothing and footwear of each individual. Grouping by eye, rather than using a grouping algorithm, was used as it allows accommodation of issues such as the presence of original surfaces on recovered fragments. At present, the casework approach used by this laboratory is to group by eye, while using grouping algorithms for guidance.

Grouping of the fragments enabled calculation of the probability of finding x groups of glass on a person's clothing (P) and the probability of the size of these groups (S) (Figures 1 and 2). Figures 1 and 2 also show the P and S values for this data if only the glass found on the clothing is considered.

As there are only seven fragments of glass recovered from the clothing, all of which were from the pockets, the values (other than P_0) are not well determined. Therefore, whilst this general population survey, and others, show that the other P values are typically small, these values are approximate.

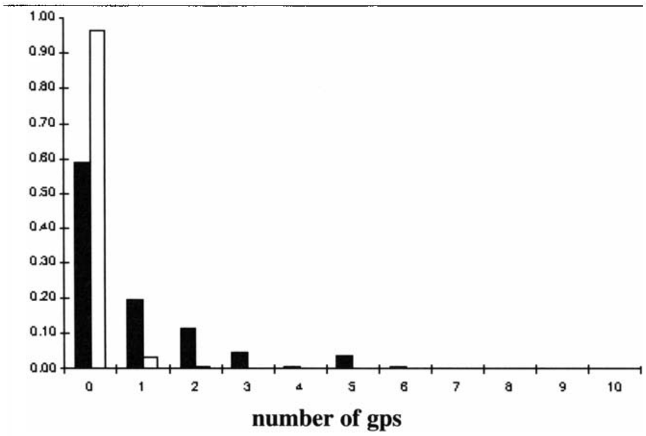

FIGURE 1 P values for glass on members of the general population (gym survey).
■ Clothing and shoes per person □ Clothing only per person.

Survey of suspects from casework

A total of 114 suspects were identified as having no glass that matched the control glass submitted on their clothing. Fifty one of the suspects had no glass on the items examined. The distribution of where the fragments of glass were found and the total number of garments examined is shown in Table 9. The category of "clothing combined" relates to cases where both the upper and lower garments have been submitted in the same package and therefore any glass found on the surfaces of these items cannot be related back to a specific item. Similarly, the category of "clothing and shoe surfaces combined" relates to cases where all of the clothing and the shoes have been submitted in the same package.

TABLE 9 Survey of glass on clothing from suspects taken from casework.

	No. of garments examined	*No. of frags per item*
Upper surface	86	92
Upper pockets	28	21
Lower surface	65	36
Lower pockets	36	15
Shoe surface	67	26
Shoe sole	45	43
Clothing combined	9	15
Clothing & shoe surfaces combined	6	2
Total number frags		**250**

Table 9 indicates that upper garments constitute the most commonly recorded item. This is because upper garments are always searched first and it is therefore a result of the search strategy used in casework, rather than a reflection of the types of garments usually submitted. Therefore, more information relating to the amount of glass on the surface of upper garments was found than for any other type of

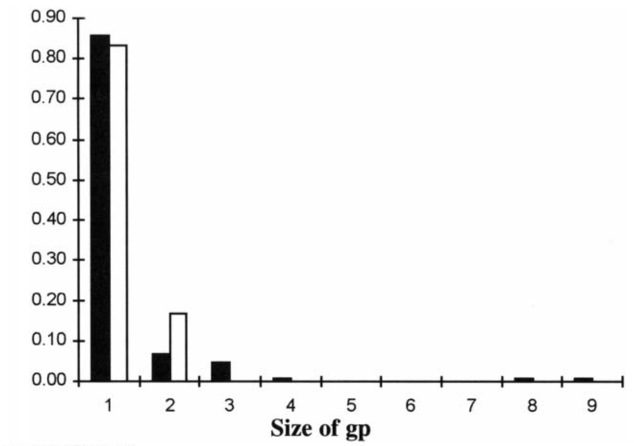

FIGURE 2 S values for glass on members of the general population (gym survey). ■ Clothing and shoes per person □ Clothing only per person.

garment. Conversely, the stopping rules enacted in casework meant that shoes were the last item to be examined, resulting in less data in this category.

After the data was assigned to cumulative categories, including garments where no glass fragments had been found, the raw values for P and S for each category could be calculated (Tables 10 and 11). These tables are specifically constructed to facilitate a likelihood ratio interpretation.

Comparison of Survey Data

A comparison of the general population survey and the suspects' survey show that there is considerably more glass present on the clothing of people who are suspected of breaking crimes. Of particular note is the high number of fragments present on the surfaces of suspects' garments compared to the finding of no fragments of glass on either the upper or lower surfaces of garments from members of the general population.

However, even for the suspects' survey, when fragments of glass are found, the majority of these fragments fall into group sizes of only one or two fragments, regardless of which items are examined. This data supports the conclusion drawn by Lambert *et al.* and reinforces the high significance of finding a large group of glass on the clothing of a suspect [11].

A comparison of the results for glass on upper surfaces for the gym survey, the suspects' survey and previously published surveys is shown in Table 12. As can be seen the gym survey showed comparable results to Lau *et al.* and Petterd *et al.*'s surveys [8,9]. Whereas, the suspects' survey showed considerably more glass than Ross and Nguyen's non-glass case suspects' survey and approximately the same amount of glass as the McQuillan and Edgar survey [7,12].

In fact, comparison of the surveys for other search strategies shows that the amount of glass found in the general population gym survey is comparable to both the Canadian and Australian general population surveys and has significantly less glass than the McQuillan and Edgar [7] survey.

The suspects' survey has similar amounts of glass to the McQuillan and Edgar survey and less glass than the Lambert *et al.* work [11].

TABLE 10 P values for survey of suspects from casework.

Cumulative Number of Groups	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*>10*
Upper surface	0.721	0.151	0.070	0.047	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Upper surface and pockets	0.536	0.179	0.107	0.036	0.107	0.036	0.000	0.000	0.000	0.000	0.000	0.000
Upper and lower surfaces	0.639	0.208	0.083	0.042	0.014	0.014	0.000	0.000	0.000	0.000	0.000	0.000
Upper and lower surfaces and pockets	0.429	0.286	0.114	0.086	0.057	0.029	0.000	0.000	0.000	0.000	0.000	0.000
Clothing and shoe surfaces	0.625	0.264	0.056	0.014	0.014	0.014	0.014	0.000	0.000	0.000	0.000	0.000
Upper and lower surfaces and pockets and shoe surface	0.510	0.306	0.122	0.020	0.020	0.000	0.000	0.020	0.000	0.000	0.000	0.000
Upper and lower surfaces and pockets and shoe surfaces and soles	0.409	0.159	0.205	0.159	0.000	0.023	0.023	0.023	0.000	0.000	0.000	0.000
Per Person (regardless of clothing items)	**0.451**	**0.221**	**0.150**	**0.106**	**0.027**	**0.018**	**0.009**	**0.018**	**0.000**	**0.000**	**0.000**	**0.000**

TABLE 11 S values for survey of suspects from casework.

Cumulative Size of Groups	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*>10*
Upper surface	0.659	0.171	0.073	0.000	0.000	0.049	0.000	0.000	0.000	0.000	0.049
Upper surface and pockets	0.774	0.097	0.065	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.032
Upper and lower surfaces	0.689	0.156	0.044	0.022	0.000	0.022	0.022	0.000	0.000	0.000	0.044
Upper and lower surfaces and pockets	0.795	0.128	0.000	0.000	0.000	0.026	0.026	0.000	0.000	0.000	0.026
Clothing and shoe surfaces	0.711	0.156	0.044	0.022	0.000	0.000	0.000	0.022	0.000	0.000	0.044
Upper and lower surfaces and pockets and shoe surfaces	0.732	0.146	0.000	0.049	0.000	0.024	0.000	0.024	0.000	0.000	0.024
Upper and lower surfaces and pockets and shoe surfaces and soles	0.766	0.141	0.031	0.016	0.016	0.000	0.016	0.016	0.000	0.000	0.000
Per Person (regardless of clothing items)	**0.737**	**0.146**	**0.044**	**0.015**	**0.007**	**0.015**	**0.007**	**0.007**	**0.000**	**0.000**	**0.022**

TABLE 12 Comparison of P and S values with published surveys.

Target Population	*Community*	*Glass suspects*	*Case suspects*	*Community*	*Community*	*Community*
	Auckland Gym Survey	*Auckland casework suspects*	*Ross & Nguyen*	*Petterd et al.*	*Lau et al.*	*ME*
P_0	1.000	0.721	0.977	0.997	0.991	0.811
P_1	0.000	0.151	0.023	0.003	0.009	0.146
P_2	0.000	0.070	0.000	0.000	0.000	0.029
P_3	0.000	0.047	0.000	0.000	0.000	0.000
P_4	0.000	0.012	0.000	0.000	0.000	0.010
P_5	0.000	0.000	0.000	0.000	0.000	0.005
P_6	0.000	0.000	0.000	0.000	0.000	0.000
P_7	0.000	0.000	0.000	0.000	0.000	0.000
P_8	0.000	0.000	0.000	0.000	0.000	0.000
P_9	0.000	0.000	0.000	0.000	0.000	0.000
P_{10}	0.000	0.000	0.000	0.000	0.000	0.000
S_1	-	0.659	1.000	1.000	1.000	-
S_2	-	0.171	0.000	0.000	0.000	-
S_3	-	0.073	0.000	0.000	0.000	-
S_4	-	0.000	0.000	0.000	0.000	-
S_5	-	0.000	0.000	0.000	0.000	-
S_6	-	0.049	0.000	0.000	0.000	-
S_7	-	0.000	0.000	0.000	0.000	-
S_8	-	0.000	0.000	0.000	0.000	-
S_9	-	0.000	0.000	0.000	0.000	-
S_{10}	-	0.000	0.000	0.000	0.000	-
$S_{>10}$	-	0.049	0.000	0.000	0.000	-

The differing amounts of glass found depending on the population surveyed appears intuitively correct. It does however highlight the need to consider the ideal population to survey when using these results to interpret glass cases.

Using a likelihood ratio approach, the use of general population surveys would produce significantly stronger evidence than if a population of suspects' survey was used.

We are convinced that the survey of choice is that of background glass on people suspected of breaking crimes. To provide data for interpreting casework we have used our suspects' survey data to produce models to predict P and S values for different casework search strategies.

Statistical modelling of P values

The data collected is expected to be subject to sampling error. This has at least two implications. First each estimate has some error. This has the greatest consequence for those values that are small as the likelihood ratio is very sensitive to any variation in these numbers. Second, many of the parameters of interest are unobserved. This suggests that some modelling of these terms is desirable. It does, however, seem plausible to assume that the data are either monotonically decreasing (decrease in a smooth manner) or are unimodal. It was therefore decided that any model used should fit these criteria. The model used was the maximum likelihood estimation (MLE) of a power series.

The estimation statistic was:

$$-\frac{\zeta(\hat{\alpha})'}{\zeta(\hat{\alpha})} = \frac{1}{N}\sum_{n=1}^{\infty} r_n \log(n+1)$$

This was calculated and the power α and normalising constant $\frac{1}{\zeta(\hat{\alpha})}$

were estimated by interpolation from a table of values of the estimation function $-\frac{\zeta(\hat{\alpha})}{\zeta(\hat{\alpha})}$

for $1 < \alpha < 6$.

This gave raw values for α and $\frac{1}{\zeta(\hat{\alpha})}$ (Table 13).

The steeper the line of best fit, the faster the graph tails off. For example, we would expect the graphs for P_x values of glass found on upper surfaces to be steeper than for glass found on the surfaces and in the pockets.

TABLE 13 Statistical modelling of P values.

	α raw	$\frac{1}{\zeta(\hat{\alpha})}$ raw	α altered	$\frac{1}{\zeta(\hat{\alpha})}$ altered
Upper surfaces	2.5768	0.7615	2.5768	0.7615
Upper surfaces and pockets	2.0597	0.6277	2.0597	0.6277
Upper and lower surfaces	2.3751	0.7169	2.3751	0.7169
Upper and lower surfaces and pockets	1.9919	0.6049	1.9919	0.6049
Clothing and shoe surfaces	2.3824	0.7187	2.3000	0.6983
Upper and lower surfaces and pockets and shoe surfaces	2.1673	0.6610	1.9500	0.5897
Upper and lower surfaces and pockets and shoe surfaces and soles	1.8919	0.5681	1.8919	0.5681

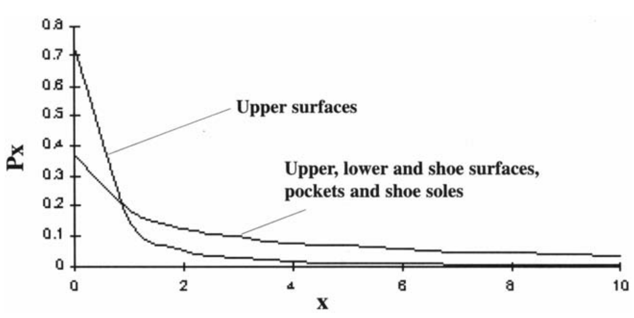

FIGURE 3 Calculated P_x values from modelled line fitting.

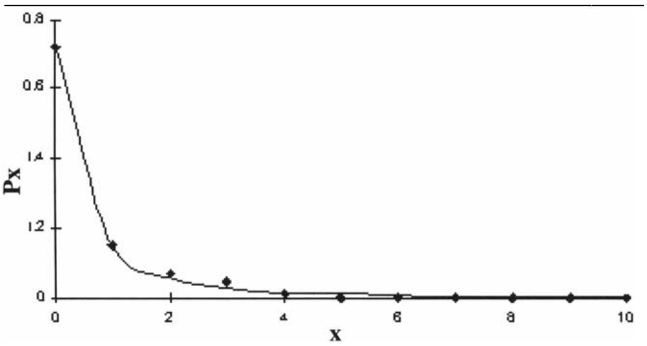

FIGURE 4 Comparison of survey and predicted values for P_x for upper surfaces. — Predicted; ♦ Casework survey.

This trend was observed in the raw data for 'upper surfaces' which was steeper than 'upper and lower surfaces' which was steeper than 'upper surfaces and pockets'.

The other four categories gave slope values of approximately the right magnitude, however, they did not show the decrease in slopes as expected. These lines have the least observations and therefore it was decided to "subjectively impose" a more reasonable slope upon them to ensure that they decrease down the categories (Table 13).

It is of interest to observe that all likelihood ratios contain a P term in both the numerator and denominator. For instance, for y matching groups and z non-matching groups the term P_z appears in the numerator and P_{z+y} in the denominator. Substituting the modelled values into the LR suggests that the ratio of P values will be:

$$\text{LR} \propto \left(\frac{z+y+1}{z+1}\right)^b$$

This exercise informs us that LR is not proportional in any way to the normalising constant and that lowering the value of b (as was done when we subjectively intervened) is always conservative (since y is always non-negative).

Figure 3 illustrates the proportions that these equations will produce for different P_x values for 'upper surfaces' and for 'upper and lower surfaces and pockets and shoe surfaces and soles'. Figure 4 shows a comparison of the raw data for 'upper surfaces' from the suspects, survey and the values predicted using the equation.

Statistical modelling of S values

As for P values, the method of maximum likelihood estimation (MLE) of the power series was used to model the S data. As can be seen from Table 11, the S values were reasonably consistent across the different search categories. It was therefore decided to only model the size of groups on the per person category, since this was the category containing the most observations.

The estimation statistic:

$$-\frac{\zeta(\hat{\alpha})'}{\zeta(\hat{\alpha})} = \frac{1}{N}\sum_{n=1}^{\infty} r_n \log n$$

was calculated and the power α and normalising constant were estimated as before.

This gave values of 2.4880 for α and 0.7430 for $\frac{1}{\zeta(\hat{\alpha})}$

Estimation using the MLE gives a better fit visually to S_1 but appears to have less density in the tail than the raw data. Simulation of 1000 samples of size 137 from a power law distribution with exponent 2.5 gave a very good fit to the data and therefore the MLE model was accepted.

The final equation (from MLE) to predict S_x values is:

$$S_x = \frac{0.7430}{x^{2.488}}$$

Figure 5 shows a comparison of the raw data from the suspects' survey and the values predicted using this equation. As S terms appear exclusively in the denominator both the intercept and slope affect the likelihood ratio (LR). There is no clear intervention that is always "conservative".

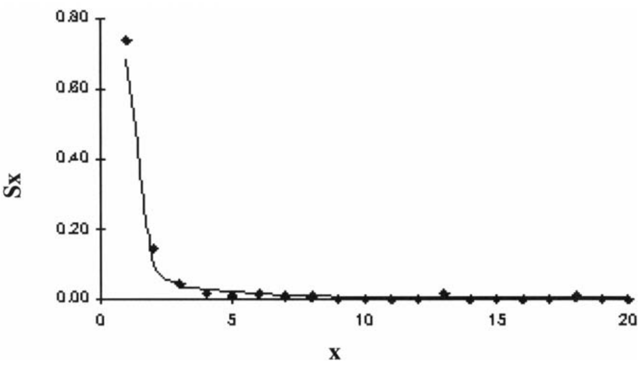

FIGURE 5 Comparison of survey and predicted values for S_x. — Predicted; ♦ Casework survey.

Conclusion

The majority of glass found on the clothing and shoes of people unconnected with breaking crimes was found on the footwear, and more specifically in the soles. No glass fragments were found on the surfaces of the clothing and only a few fragments of glass were found in the pockets of the clothing.

In comparison, considerably more fragments of glass were found on the clothing and shoes of people suspected of breaking crimes, who in fact had no glass on their garments that matched the control glass submitted. However, the group size of this background glass present on suspects' clothing and shoes is small, with most of the fragments being of group size 1 or 2, regardless of where the fragments of glass were found. This reinforces the significance of finding a large group of matching glass on a suspect's clothing and shoes.

Statistical modelling of the data has produced equations to predict both P_x and S_x terms. The evidential value of the presence of glass can be described by the slope of the modelled line and the evidential value of the size of the group of glass can be described by the slope and intercept of the modelled line.

The authors recommend interpretation using a likelihod ratio approach with these modelled values.

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