A population survey was carried out to analyze examples of the coloured fibre population that may be expected to exist in both front- and top-loading domestic washing machines during Spring, in Sydney, Australia. White cotton t-shirts were washed both individually, and with a normal household wash load, then taped to recover extraneous fibres transferred during the wash cycle. Twelve thousand one hundred and seventy-eight fibres were classified according to length, colour and generic class. Cotton fibres were most prevalent (69.9%), followed by man-made fibres (24.2%). The most common colour/generic class combinations were black/grey cotton (27%), blue cotton (20%) and red cotton (15.6%). Other combinations generally represented under 2% of the total fibre population. Two thirds (65.9%) of the recovered, fibres were under 2 mm in length, the proportion of fibres decreasing with increasing fibre length. Variations in machine type did not affect the distribution of fibres with respect to fibre type, colour or length.

A study was undertaken to analyze examples of a population of coloured fibres that one may retrieve in domestic washing machines. Twelve thousand one hundred and seventy-eight fibres were classified according to length, colour and generic class. Cotton fibres were most prevalent (69.9%), followed by man-made fibres (24.2%). The most common colour/generic class combinations were black/grey cotton (27%), blue cotton (20%) and red cotton (15.6%). Other combinations generally represented under 2% of the total fibre population. Two thirds (65.9%) of the recovered, fibres were under 2 mm in length, the proportion of fibres decreasing with increasing fibre length. Variations in machine type did not affect the distribution of fibres with respect to fibre type, colour or length.

Eine Populationsumfrage wurde durchgeführt, um Beispiele aus der Population farbiger Fasern zu analysieren, die in Front- und Toplader-Waschmaschinen in Sydney, Australien, im Frühjahr zu erwarten sein könnten. T-Shirts aus weißem Baumwoll wurden sowohl alleine als auch zusammen mit anderen Textilien gewaschen. Anschließend wurden die dabei übertragenen Fremdfasern mittels Klebeband gesichert. 12.178 Fasern wurden bezüglich ihrer Länge, Farbe und des Materials klassifiziert. Baumwollfasern waren mit 69,4% weit häufiger als Chemiefasern mit 24,2%. Die häufigsten Kombinationen bezüglich Farbe und Material waren schwärzegrau, blau und rote Baumwolle mit 27%, 20% bzw. 15,6%. Andere Kombinationen repräsentierten jeweils weniger als 2% des gesamten Faserüberschusses. Zwei Drittel (65,9%) der gesicherten Fasern waren weniger als 2 mm lang; mit steigender Faserlänge wurden die Anteile immer kleiner. Unterschiedliche Maschinentypen hatten keinen Einfluss auf die Faserverteilung bezüglich ihrer Art, Farbe oder Lange.

Se realizaron una encuesta a población para analizar ejemplos de poblaciones de fibras coloreadas que pueden encontrarse en lavadoras tanto de carga vertical como de carga frontal en Sidney (Australia). Se lavaron camisetas blancas de algodón primero por separado y después con otra ropa de lavado doméstico normal. Después se pasaron por cinta adhesiva para recuperar las fibras extraviadas que se hubieran adherido en el proceso de lavado. Se clasificaron 12.178 fibras en función de la longitud, color y clase genética. Las fibras de algodón eran las más comunes (69,4%), seguidas por fibras de origen sintético (24,2%). Las combinaciones más comunes de colores y clases genéticas eran el algodón negro/gris (27%), algodón azul (20%) y algodón rojo (15,6%). Otras combinaciones representaban por lo general menos del 2% de la población de fibras. Dos tercios (65,9%) de las fibras recolectadas medían menos de 2 milímetros siendo menos frecuentes a medida que eran más largas. Las variaciones en el tipo de lavadora usada no tuvieron influencia en la distribución de las fibras en lo que se refiere al tipo, color o longitudes.

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Key words Forensic science, fibres, population survey, washing machines.
Introduction

The value of textile fibres in physical evidence has long been
instituted. The ubiquitous nature of textile fibres facilitates
their likely presence at most crime scenes. Extraneous fibres recovered
during and following criminal events are subjected to a series of
elements, such as hairs, fibres, inorganic particles, and fluids. Textile fibre
can thus be invaluable in establishing associations between people,
locations and objects in a wide variety of criminal cases [1].

Whilst fibre evidence can be instrumental in forensic investiga-
tions, the common occurrence of textiles in daily life also cul-
tinuates a major source of background fibres. This is of particular
importance when evidence is recovered from surfaces that are po-
tentially in constant contact with numerous textiles. The question
of commonality is often posed to the expert with regards to fibre
evidence, with the aim of suggesting that the acquired evidence
is not significant. Knowledge of the frequency of occurrence
of fibre types in a given population is therefore required in order
to assess the evidential value of finding that fibre which
aren’t be differentiated from a suspect source. In general, the more
common the fibre, the lesser the value of the evidence. Conversely,
fibres which are rare due to unusual morphological character-
istics, specific usage, limited production or obsoletion will
have strong evidential value.

Relevant literature identifies that the basis of any fibres case
will be how the crime

Under the circumstances under which the evidence
was collected [3]. In the time that elapses between
the commission of a crime and the removal of evidence for exau-
nishment, garments worn by the victim or the perpetrator during the
crime may be laundering. In such cases, an idea of the background
fibres population that can be expected to be generated by washing
will be important in facilitating the differentiation of crime
related fibres that are relevant to the case from background
fibres that are not crime-related.

The current research involved a survey of the population
of coloured textile fibres transferred to white cotton T-shirts
during washing, with a variety of machines during Spring, Sydney, Australia. The influence of
machine type on the primary transfer of fibres between garments
during washing was also examined.

Experimental method

The fibres in this research were collected in Spring 2001,
from washing machines used in 11 households situated
across Sydney, Australia. Machines comprised five top-loading wash-
ners, five front-loading washers and one combination washer/dryer
(Table 1). Trends in Australia over the last decade have seen a de-
decline in the purchase of top-loading machines, popular throughout
in the United States, in favour of more efficient and low-
loading machines that are common throughout Europe. Both ma-
tine type were incorporated into this study to ascertain whether
this trend could pose any potential consequences for the interpre-
tation of fibre evidence.

Garment preparation

New, white, 100% cotton T-shirts were pre-cleaned before wash-
ing using a lint remover with disposable adhesive surfaces,
followed by adhesive taping. This treatment was carried out twice to
remove all adhering extraneous fibres so that any coloured fibres
ultimately recovered would be attributable to the washing process.

Table 1 Washing machines used in population survey.

<table>
<thead>
<tr>
<th>Machine Type</th>
<th>Brand</th>
<th>Capacity</th>
<th>Agitator</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Top-loading</td>
<td>Sanyo</td>
<td>4.0 kg</td>
</tr>
<tr>
<td>T2</td>
<td>Top-loading</td>
<td>Fisher &amp; PAYKO</td>
<td>5.5 kg</td>
</tr>
<tr>
<td>T3</td>
<td>Top-loading</td>
<td>Fisher &amp; PAYKO</td>
<td>5.0 kg</td>
</tr>
<tr>
<td>T4</td>
<td>Top-loading</td>
<td>Simpson</td>
<td>3.0 kg</td>
</tr>
<tr>
<td>T5</td>
<td>Top-loading</td>
<td>NEC</td>
<td>4.5 kg</td>
</tr>
<tr>
<td>F1</td>
<td>Front-loading</td>
<td>LG</td>
<td>7.0 kg</td>
</tr>
<tr>
<td>F2</td>
<td>Front-loading</td>
<td>Whirlpool</td>
<td>5.0 kg</td>
</tr>
<tr>
<td>F3</td>
<td>Front-loading</td>
<td>Omega</td>
<td>4.5 kg</td>
</tr>
<tr>
<td>F4</td>
<td>Front-loading</td>
<td>Whirlpool</td>
<td>5.0 kg</td>
</tr>
<tr>
<td>C1</td>
<td>Wash/ Dryer</td>
<td>Norda</td>
<td>6.0 kg</td>
</tr>
</tbody>
</table>

Cleaning T-shirts were then stored in unused plastic zip lock bags.
Control t-shirts were subjected to the procedure yielded
no more than 3 coloured fibres per T-shirt, most of which were
less than 0.5 mm long. This was considered an acceptable level
of background noise, as this number was low in comparison to
the number of fibres recovered after washing and found under
5.0 mm in length were not counted in this survey.

Washing procedure

T-shirts were distributed to volunteers in sets of three with
instructions for washing. Shirt “A” was washed by itself in order to
investigate the population of residual fibres present in the wash-
ing machine receptacle. Shirt “B” was washed with a normal load
of household washing to compare the effect of washing machine
type on the primary transfer of fibres between garments during
washing. Volunteers recorded the type, colour and fibre com-
position of accompanying garments. Shirt “C” was washed by itself
directly after to assess the proportion of residual fibres that may
be attributable to garments from the immediately proceeding wash.
This also provided a measure of the reproducibility of the popula-
tion from different fibres present in the washing machines.

Fibre recovery and analysis

The entire surface of each washed T-shirt was taped us-
ing Scotch tape to a Xerox machine by Scotch Tapes to
record extraneous fibres transferred during washing. The
front and back of the T-shirts were each divided into six sections—left and right upper region, left
and right lower region—and a separate strip of adhesive tape
was used for each section. Tapes were fixed onto 44 sized
standardized transparencies then examined visually using a LEICA
MZ15 stereomicroscope with LEICA CLS150 light source at 32x
magnification. Fibre “A” and “B” fibres from each set were
measured by comparison with a millimetre scale under the
magnifying glass to a thousand one hundred and seventy-eight coloured fibres’
was measured by comparison with a millimetre scale under the
steromicroscope. Fibres less than 0.5 mm in length were not in-
cluded, as these were generally considered too small by microscopy and the analysis of control T-shirts indicated that cleaning tech-
iques were not efficient at eliminating all contaminant fibres of
this length. Fibre frequencies were then calculated for colour,
gender, class, generic, class, and a range of outdoor items
Sydney, Australia. Machines comprised five top-loading
machines during Spring, Sydney, Australia. The influence of
machine type on the primary transfer of fibres between garments
during washing was also examined.

Results

Twelve thousand one hundred and seventy-eight coloured fibres’
recovered from the washed T-shirts were analysed. Multivariate
analysis showed that washing machine type gave no significant
variation in the number of fibres recovered from washed T-shirts,
the distribution of these fibres in terms of generic, colour, and
length. No correlation was evident between the number of fibres
recovered from washed T-shirts and the number of garments
included in the wash load or the capacity of the washing
machine.

Fibre type and colour

The generic class distribution for fibres recovered from the full
population of T-shirts is shown in Figure 1. Cotton fibres made
up the greatest proportion (69.4%), followed by man-made fibres
(24.2%). Other vegetable fibres, wool and other animal fibres
(mainly human hairs, some cat and rabbit fibres) constituted
only a small proportion of the overall fibre population (2.3, 1.7,
1.7% respectively). Less than 1% of fibres were unidentified as
to class, with the majority of these being shorter fibres that were
difficult to classify definitively as being either cotton or other vegetable fibres.
The distribution of fibre types was almost identical for top-
and front-loading washing machines (Figure 2). The combination
was dryer did not yield significantly different background population.

The predominant colous for all fibres recovered and classified
were black (41.9%), blue (28.2%) and red (19.2%), accounting
for above 90% of the total fibre population. Brown h-
filaments constituted 5.6% of analysed fibres, with other colours each
representing less than 2% (Figure 3). The distribution of the
colour/generic class combinations reflected the popularity of in-
dividual fibre classes and colours. Black/cotton was the most
common (28.6%) followed by black/wool and blue/wool (14.3%)
collectively. Collectively, these three combinations accounted for al-
most two thirds of all fibres recovered. Only six of the remaining 26
colour/generic class combinations frequented more than 1% (Figure 4).
These were black/non-made fibres (12.2%), blue man-
made fibres (7.1%), brown cotton (3.0%), red non-made fibres

1 All significant results were at the 1% level.
The population of coloured textile fibres in domestic washing machines

Figure 1  Total fibre population by generic class (N = 12,178).

Figure 2  Generic class distribution for top- and front-loading washing machines (W = 6,524, Ns = 4,696).

Figure 3  Total fibre population by colour (N = 12,179).

(2.9%), green cotton (1.4%), and black vegetable fibres, other than cotton (1.1%).

When one considers that fibres within each colour category are not identical but include a wide range of colours, whose individual frequencies will be much lower, the significance of finding fibres of colours in the less common categories in casework is increased. Similarly, the further classification of man-made fibres by polymer type can be expected to reduce the frequencies of individual fibre types.

Figure 4  Frequencies for the most common colour/generic class combinations (N = 12,178).

Length
The majority of recovered fibres analysed (65.9%) were shorter fragments, less than 2 mm in length. The most common fibre length was 1-2 mm (37.2%), followed by fibres of length 0.5-1 mm (28.7%). After these two categories, the proportion of the total fibre population generally decreased with increasing fibre length (Figure 5). Machine type did not appear to influence the fibre length distribution (Figure 6). For cotton, other vegetable.

Figure 5  Fibre population by fibre length (N = 12,171). Seven fibres were curled up or coiled into a tuft such that the fibre length could not be estimated.

Figure 6  Fibre length distribution for top- and front-loading machines.
man-made and unclassified fibres, which collectively comprised 97% of all fibres analysed, the length distribution within each class was not significantly different to that for the total population with fibres under 2 mm being the most common and longer fibres much less frequent (Figure 7). In contrast, wool and other animal fibres showed much greater proportions of longer fibres.

Washes with accompanying garments
The major effect of including additional garments in the wash load was to increase the number of extraneous fibres transferred to the T-shirts during washing. Whilst the fibre populations were not affected in terms of the colour and generic class distributions, differences in the fibre length distributions were observed between T-shirts washed individually and T-shirts washed with other items (Figure 8).

For all T-shirts, the order of fibre lengths—most common to least common—was cotton, synthetic and wool. However, a significantly higher proportion of shorter fibres (0.5-1 and 1-2 mm) were recovered from T-shirts washed individually from cinema seats, Sydney, with man-made fibres the second most popular fibre class and other vegetable fibres and non-wool animal fibres also in similar proportions. The most common fibre colours, black-grey and blue, were consistent between the two Australian studies. The hierarchy of fibre colour/class combinations was also similar, the only notable differences were higher proportions of black wool fibres and lower proportion of red cotton fibres recovered from cinema seats. Wool fibres comprised a lesser proportion of fibres from washing machines (17.8%) compared to cinema seats (48.2%).

The survey of cinema seats was conducted during Winter, so it could be expected that a high proportion of fibres transferred from garments to T-shirts during a normal wash would have been unattractive to the current season. In contrast, the current research was conducted during the warmer months of Spring. This was reflected in the garments included in the household washing loads, in which only 12% were warmer items of clothing such as jackets and close-fitting garments. Of these, only one pair of trousers was reported to contain wool. This could account for the slightly higher relative occurrence of wool fibres reported by Cantrell compared to the current research. Differences in colour groupings (purple/pink rather than pink) could have contributed to the differences in the frequency of red fibres.

The more contemporary overseas studies have also reported similar results to the current research with regard to the most frequent fibre types encountered. Cotton fibres have consistently been found to be the most abundant fibre type, being the most common of fibres recovered from T-shirts, [7], various outdoor surfaces, [9], casework undergarments, [5], human head hair [12], car seats [11] and casework items of evidence [6]. Man-made fibres have constituted the next most frequent fibre type, with black-grey and blue cotton fibres the most common colour/class combinations. Discrepancies in percentages and the order of fibres recovered from T-shirts washed in the household laundry load, indicating that hairs transferred to garments in subsequent washes and can be transferred between garments during washing. Furthermore, fibre persistence has been shown to decrease with increasing fibre length [16-18] such that the proportion of short fibres on garments immediately before washing could be expected to consist of mainly shorter fragments. Thus, the population of fibres available for secondary transfer to other garments during washing would likely consist of shorter fibres.

Animal fibres, other than wool, were recovered from most samples, many of which still contained the hair root. These were recovered both from T-shirts washed just after being worn and from T-shirts washed in the household laundry load, indicating that hairs as well as cuticle fibres will remain in machine receptacles to be transferred to garments in subsequent washes and can be transferred between garments during washing. The practical implication of this is that when hairs forming evidence in a given case have been recovered from garments that are known to have been washed, the location of the hair and the fact that they were recovered from a particular garment should be interpreted with caution.

Fibres recovered from washed "B" and "C" T-shirts that could not be attributed to any accompanying garments were most likely the result of a secondary transfer of extraneous fibres present on the surface of the garments included in the wash, rather than from fibres constituting garments in previous (unrecorded) washes.

Figure 7 Length distribution within each generic class for total fibre population (N = 12,171).

Figure 8 Fibre length distribution for A, B and C T-shirts—all machines.
remaining in the receptacle for several washes. For machine T1, brown and yellow wool fibres were recovered from both "B" and "C" T-shirts where no woolen items were included in the wash load. For this machine, the composition of garments included in each wash had been recorded for the month preceding the experimental washes and no brown or yellow woolen garments had been included in those times. Concurrent studies on the redistribution of textile fibres during washing have confirmed that a secondary transfer of fibres does occur between garments, and that fibres tend not to persist in machine receptacles for more than one wash [19].

This can also account for the high proportion of black cotton fibres recovered from "B" and "C" T-shirts washed in machine F4 where no black cotton garments were included in the wash load. Population surveys of the fibres recovered from worn T-shirts have shown black cotton fibres to be one of the most common type of extraneous fibres found [7, 8]. It would be reasonable to expect that black cotton fibres would be present on the surface of clothing included in the wash, such that a secondary transfer of these fibres to other garments (in this case, whilst cotton T-shirts) would occur during washing. This phenomenon accentuates the inherently precarious nature of inferring associations based on comparisons of extraneous fibres recovered from multiple evidentiary items without known source samples, a hazard that is exacerbated when it is known or suspected that the items have been laundered.

Conclusion

The current survey of domestic washing machines showed that the majority of recovered fibres were cotton (96%) with black, grey and red and blue containing two thirds of the total fibre population. Aside from black and blue mm-made fibres, other colour/generic class combinations represented only very low proportions, mostly less than 2%. The practical implication is that the finding of fibres of the less-common colour/generic class combinations will carry higher potential evidential value, even when it is known that the garment under investigation has been laundered.

Two thirds of the recovered fibres were under 2 mm in length. the proportion of fibres decreasing with increasing fibre length. Variations in machine type and the presence of other garments in the wash load increased the number of fibres recovered compared to T-shirts washed individually, the number of fibres recovered was not seen to correlate with the number of additional garments in the washing machine capacity.

The results were generally consistent with results reported in previous studies, both domestic and overseas, with regard to the most popular fibre types, colours, and colour/generic class combinations. Small discrepancies that existed could be explained by variations in climate for the locale surveyed, or by particular facets of the methodology used in alternate studies such as the exclusion of certain fibre types.

In casuista, even when it is known that evidential garments have been washed, it is not likely that the other garments included in the wash load will be known. The information gained by this project is useful as providing knowledge of the likely background fibre population generated by washing machines, in order to facilitate a more meaningful interpretation of the significance of recovered fibre evidence. The results not only showed that a secondary transfer of fibres occurs between garments during laundering but also that machine washing facilitates the secondary transfer of extraneous fibres present on the surface of one garment to another. These extraneous fibres, as well as constraints from the excluded garments, can remain in the machine receptacle and be transferred to garments in subsequent washes. As such, interpretations based on the distribution of fibres recovered from garments that are known to have been laundered should be made with caution.

References


