Accepted Manuscript

Title: The transfer of fibres via weapons from garments

Authors: Daniel Sneath, Helen Tidy, Ben Wood

PII:	S0379-0738(18)30674-1
DOI:	https://doi.org/10.1016/j.forsciint.2019.05.027
Reference:	FSI 9811
To appear in:	*FSI*
Received date:	30 August 2018
Revised date:	3 May 2019
Accepted date:	13 May 2019

Please cite this article as: Sneath D, Tidy H, Wood B, The transfer of fibres via weapons from garments, *Forensic Science International* (2019), https://doi.org/10.1016/j.forsciint.2019.05.027

The Transfer of Fibres Via Weapons from Garments

Daniel Sneath, Helen Tidy and Ben Wood

School of Science, Engineering and Design, Teesside University, Middlesbrough, Tees Valley, TS1 3BZ, United Kingdom.

Corresponding Author: H Tidy, H.Tidy@tees.ac.uk, School of Science, Engineering and Design, Teesside University, Middlesbrough, Tees Valley, TS1 3BZ

Highlights

- Transfer of fibres during stabbings not driven entirely by the shedability.
- Surface of transference area can influence number of fibres transferred.
- Degree of garment fraying can influence number of fibres transferred.
- Number of fibres transferred cannot be predicted in exact numbers.

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Abstract

Stabbings have been reported as the most frequent violent crime in countries where there is a severe restriction on obtaining firearms, such as the United Kingdom. Knives, scissors, and screwdrivers, as studied in this research, are among the most commonly encountered weapons involving stabbing events. When any of these implements are used in a stabbing, there is potential for the garment(s) worn by the victim to be damaged. In such an instance, there is an opportunity for fibres to be transferred to the weapon used, thus providing forensic evidence of proof of transfer from the victim's clothing to the weapon. This can offer valuable information in establishing what weapon was used to harm the victim through linking fibres from the victim's garment(s) to a weapon recovered from a suspect.

This research simulates vertical stabbings - performed by a human participant – in to a polystyrene block supporting the clothing (essentially acting as the victim's torso), to reflect an authentic scenario. The aforementioned weapons were used along with 3 varieties of garments (cotton, polyester and a linen/viscose mix) offering different characteristics of shedability and structure for the simulated stabbings. Low power microscopy was utilised to view the transferred fibres. The amount of fibres transferred on to the implement were recorded for each repeat. 2,279 individual fibres were found over 10 repeats from the knife in relation to the linen/viscose garment. This was the highest amount of transference found with the lowest number attributed to the screwdriver-polyester relationship, providing 320 recorded fibres over 10 repeats. The findings of this study suggest that the number of fibres transferred is not only related to the shedability of the garment but also the surface area characteristics of the receiving weapon and the ability for the garment to tear.

Keywords

Forensic science, Fibre examination, Fibres, Weapon, Transference, Stabbing

Introduction

Fibres are ubiquitous and are therefore found at a host of crime scenes, making them an invaluable source of forensic evidence [1,2]. In most criminal cases, the individuals involved are clothed, meaning the potential for fibre transfer is considerably high [3]. This is particularly true for stabbing related incidents where victims are often clothed [4]. Naturally, as the individual is stabbed, damage to their clothing is usually inflicted [5] and there is the potential for fibre transfer on to the weapon.

Fibre transfer occurs when a fibre-containing article comes in to contact with another item. One-way fibre transfer occurs when fibres are transferred from object (a) to object (b) but cannot be transferred vice versa. Two-way fibre transfer occurs when fibres are transferred between objects (a) and (b) [6, 7]. This study will involve one-way fibre transfer only, from the garment to the weapon used. This study aims to clarify the degree of transference between a series of weapons and a selected fabric type in a simulated stabbing scenario.

Stabbings have been reported as the most frequent violent crime in countries where there is a severe restriction on obtaining firearms, such as the United Kingdom [8, 9]. Knives or other sharp instruments are the leading method of homicide in England and Wales, with 6% of all violent incidents in 2015/16 involving a knife or other stabbing implement [10]. There is a multiplicity of weapons used in stabbing attacks with kitchen knives, utility knives, scissors, screwdrivers and glass bottles being cited as those frequently encountered [5]. A lot of these weapons are household implements which suggests they are used as part of an impulsive act rather than a pre-meditated attack.

Knife crime is considered a huge problem in the UK with nearly 14,000 people hospitalised each year due to stab and slash injuries [11]. London in particular has recently received a great deal of negative press pertaining to knife crime with knife-related stabbings reported as the highest among cities in the UK [12]. In February 2018, London exceeded New York's homicide rate for the first time in modern history as an unprecedented surge in knife crime occurred; 15 people were murdered in London compared to 14 in New York [13]. Stabbing incidents occupied a staggering 25% of all cases treated at the Accident and Emergency Unit, Royal London Hospital in 2012 [14]. Approximately 40,100 attacks involving a knife or sharp implement were recorded in the year ending March 2018 in England and Wales. In an 8-year series this was the highest number recorded [15]. Although slightly dated, a study [16] examined the number of patients who had suffered stab wounds and subsequently attended the Accident and Emergency Department of Glasgow Royal Infirmary from

1978 to 1983. Within this 5-year period, there were 318 patients who had endured stab wounds; the chest (143 patients) and abdomen (113 patients) were found to be the most common sites of injury [16,17].

When occurred during a stabbing incident, textile damage can potentially provide information about the object that produced the damage and, as such, clothing is a regular site of examination in forensic casework [18,19]. Studying the damage caused by a weapon can be used to subsequently corroborate or refute a crime scenario and/or witness testimony [20]. In addition to fabric damage, fibres can also be transferred from the garment on to the weapon used [21]. It is critical that this fibre presence is acknowledged in order to recover them efficiently and allow for further examination.

There is an assortment of literature which affirms a specific weapon can be identified by examining the damage characteristics present on the clothing worn by a victim at the time of an incident [18,22]. Fabric elasticity and tension applied to the fabric have been identified as major factors influencing the damage of fabric resulting from a stabbing attack [5]. The fibre examiner can infer typical characteristics from the damaged fabric(s) as well other information [19]. For example, idiosyncratic markings will be present along the severance edge where a serrated edge of a blade has been used whereas a sharp knife will produce neatly cut yarns [23]. A blunt tip will usually create additional distortion at the point of penetration due to fabric being pulled in to the wound prior to the blade severing or tearing the yarns [24]. A sharp blade is likely to produce smooth edges and stretching of the yarns, whereas a blunter tip will produce more irregular tearing of the edges [25]. It is expected that where certain implements will produce a more irregular puncture, this could increase the likelihood of fibre transfer. This is because fibres are more likely to be distorted and separated from the surface of the fabric. The value of such information, where the clothing of a victim is found but the individual is not presently available, is that it can provide a strong indication of the trauma they have suffered through the examination of the damage to the garment(s) [14]. Furthermore, by examining damage to a victim's garment, the forensic examiner can potentially provide further intelligence such as the type of weapon used.

The association between a weapon and the damage caused to a garment is a well-researched area of forensic science, whereas the transfer of fibres to a weapon during an assault has not been explored as rigorously. It is widespread forensic practice to tape weapons in order to recover potential fibre evidence, because it is accepted that fibre transfer from the garment to the weapon provides an association between the victim and the weapon used but the underpinning research in this area is limited. Schnegg *et al* [21] used mechanical apparatus to simulate vertical stabs in to a garment resting on a block of ballistic soap. Two types of kitchen knives and one chef's knife were used in conjunction with two garments in a single stab action resulting in 50 to more than 1,500 fibres being transferred. The authors acknowledge that one of the limiting factors of the research was the use of the ballistic soap which is sticky in texture. Consequently, this may have led to an over-transfer of fibres due to the ballistic soap imparting its tackiness to the weapon collecting fibres as the blade pulled back up through the garment. Their recommendations for further work include the need for more realistic simulations using different garments and weapons, which is precisely what this research aims to achieve [21].

Research performed in this study serves the function of aiding criminal justice for use in the court room. In terms of the outcome of this research, proving a link between a weapon used to cause harm to an individual and the victims clothing is of potential forensic significance.

Method

Weapon Selection

A kitchen knife, flat head screwdriver and a pair of sewing scissors were used within this research as shown in Figure 1. These weapons were selected due to their commonness in stabbing-related incidents thus generating a requirement to understand more about the way in which they retain fibres [26,27,28,29].

Garment Selection.

All three fabric types in this experiment were selected due to their demand for production and abundance in clothing fabrics. Cotton was chosen for this reserarch due to its popularity within the general population; for example, Biermann & Grieve (1998) conducted a study in which they concluded 70% of summer clothing consisted of cotton [30]. In addition, it is the most common fibre type due to its consistent presence in high street clothing shops [31]. On a morphological level, cotton consists of cellulose, a polymer of glucose [32]. The crystalline alignment of cotton molecules results in strong intermolecular forces; promoting fibre tenacity. As a result, cotton fabrics do not tear or break formation without the application of considerable force.

Polyester demand rose dramatically in the early 2000's and was recently the most in demand fibre type in the world [33]. The popularity of polyester tracksuits and sportswear, as well as outdoor clothing, supports the use of the polyester garment within the study [34]. The main characteristic lending itself to the popularity of polyester is its high durability [35]. This holds importance because the study focuses on stabbing incidents where clothing is worn by the victim; outdoor clothing could have a significant probability of involvement. In considering the purpose of this research, it is highly likely that data collected from the use of polyester in this study will be applicable to case scenarios.

In addition, a linen/viscose blend garment was chosen, all garments utilised in this research are shown in Figure 2.

The fibre selection represents a range of target fibres that have common occurrence in the general fibre population [36]. A shedability test for each garment was conducted prior to the start of the research with cotton showing high shedability, linen/viscose medium-high shedability and polyester low shedability.

Experimental Procedure

In order to limit the inconsistency of research practicalities with real-life stabbing incidents, the researcher in this study avoided the use of material which may contribute to increasing or decreasing fibre transfer. As such, a solid base which provides structure to the experiment as a substitute for a human torso was selected. A polystyrene block was used; there is no research to suggest that polystyrene has any properties which may affect fibre transfer.

A factor which required consideration during this research was that it is incredibly difficult to reproduce, in an experimental format, the morphology of the human torso including layers of skin, fat, muscle and blood. In the absence of any documented proxy for the human torso, the researchers in this study was confident that the use of a polystyrene block would be sufficient for experimental purposes. Although the presence of blood could potentially increase the presence of fibres on the weapon, it is not necessarily true that these fibres would be present at the time of examination. Additionally, in a forensic scenario the presence of blood on a weapon may be considered to hold far more evidential and investigative value than presence of fibres [37]. As a result of these factors it was decided that the use of blood or a similar substance in this experimental format would not provide any benefit to the study.

The polystyrene block (40cm high) was placed on a flat and firm surface. The donor garments were placed individually over the block to simulate the wearing of the garment. The weapon was then thrust downwards from a height of 50 cm, (measured from the tip of the weapon to the polystyrene block), in to the garment and polystyrene block. Manual application of force was preferred to simulate a real-life situation. The same researcher repeated all experiments to ensure consistency across the experimental procedure with the same approximate force of impact maintained.

Immediately after the weapon was used to stab the garment, the fibres were recovered. This was carried out by placing 12 10cm lengths of J-Lar tape to the weapon to recover any extraneous fibres. The weapon was divided in to sections to ensure the fibres were fully recovered. The sections comprised of both sides of the weapon and edge for the kitchen knife and sewing scissors whereas the screwdriver only required two sections of tape to each side due to its design. Each experiment was repeated 10 times for each weapon on each garment. After the fibres were recovered, the weapon was thoroughly cleaned using alcohol wipes and a new area of the garment, away from the site of any previous stabbings, was chosen for experimental repeats.

Reference tapings were created for each garment allowing easier target fibre recognition. The tapings produced from the experimentation were examined under x20 -x40 magnification using a GXM-XTL3 low power light microscope. The numbers of the target fibre that had been transferred to the weapon were counted and recorded for each experiment.

Results and Discussion

Fibres that corresponded in morphology and colour to the constituent target fibres were recorded for each experiment, any other fibres present were ignored and not included in the counting. The results from each experiment are shown in Table 1.

The results show a degree of variability within the same set of testing parameters; experimental conditions were kept constant with a solitary researcher carrying out an identical experimental procedure each time. It is appreciated that the researcher may naturally exert slightly greater pressure on one experimental run when compared to another, but the use of more realistic conditions was deemed to have primary importance. The results suggest there is a natural variability on the number of fibres transferred within the same set of conditions. This natural variability suggests that it would be impossible to predict a precise number of fibres transferred within a set of parameters and the forensic scientist would need to examine trends of transference rather than exact numbers. It can be seen within Table 1 that there are trends emerging for the relative amount of fibres transferred in a given scenario.

As outlined in the method, a shedability test was performed for each garment with the cotton garment exhibiting the highest shedability. It would therefore be expected that the cotton garment would contribute the highest number of transferred fibres to the weapon in comparison with the other two garments. Research investigating transfer of fibres to seats supports this proposition with cotton transferring more readily than polyester [20]. It can be seen in Table 1 that the knife-linen/viscose relationship yielded the highest amount of transfer despite not being the highest shedder. 2,279 fibres were counted over 10 repeats, providing an average of 227.9 fibres per repeat. It is worth noting that the standard error for this data is 25.305 showing that the numbers for each repeat fluctuate, resulting in a large range.

When considering this high transfer rate, it may be attributed to the knife having the largest surface area of the three weapons investigated thus causing the largest area of damage as well as the largest area for receiving fibres. The edge characteristics i.e. sharpness of the implement could have had a significant impact on the fibre transfer rate. A blunter instrument with rough features could provide more surface area for fibres to adhere to. The linen/viscose blend was ranked second in terms of shedability meaning the potential for fibre transfer is high. Conversely, if this was the cause, the cotton-knife relationship theoretically would have emerged as producing the highest levels of fibre transfer. The most noteworthy explanation of why the cotton-knife relationship did not yield the most fibres may be owed to the damage produced by the knife on the garment; after penetration by the knife, the linen/viscose garment possessed fraying at the site of the damage whereas the yarns at the site of the damage on the cotton were cleaner cut (Figure 3).

Puncture damage occurs in a fabric when an instrument penetrates the textile by shearing the yarn; evidenced by fraying at the site of the puncture. Fraying is defined as the displacement of the yarn from the weave of the fabric [38]. Fraying it therefore associated with irregular or damaged yarn ends and textile distortion [39]. When textiles tear, the yarns are displaced from the weave with the constituent fibres of the garment becoming loosened, creating conditions for the fibres to be transferred more readily as opposed to fibres that are held securely within the weave [39, 40]. The linen/viscose-knife puncture showed fraying at the site of the cut, as shown in Figure 3, and maybe therefore the most telling indication for the greater volume of fibre transfer.

Tensile energy absorption measures the characteristics of a material to absorb sudden high tension; such as in a tearing incident. When the fabric is subjected to tensile energy, the fabric may or may not tear depending on the force of the shock [41]. Tensile energy absorption properties may have an effect on the shedability of fibres due to the difficulty at which the fabric has been torn.

Crystallinity in this context refers to the degree of a structural order in a solid material. When considering the crystallinity of the fabrics in this study, the crystallinity is specified as the proportion of the material that is crystalline or amorphous in structure [42]. The degree of crystallinity in a fabric has an impact on the hardness of the material. As such, it is possible that the crystallinity of any specific material has an effect on the resistance of a fabric to a weapon, which could have an impact on the likelihood of fibres shedding.

According to Broadbent's study [32], linen has lower tensile energy absorption (0.35) than cotton (0.41), but higher than a linen/viscose 55:45 blend. A linen/viscose 55:45 blend has a lower tensile energy absorption (0.28) than cotton (0.41) [43]. The crystallinity in viscose is between 25-30%, whereas the crystallinity in cotton is 70% [31].

The knife-cotton relationship delivered a surprisingly low amount of transferred fibres for each repeat (73), with the average being augmented due to the anomaly of 540. If this outlier is ignored, the mean is a lowly 23.75 fibres per repeat. Pinpointing the reason for the low data is ambiguous with the lack of fraying being the most likely explanation. It does, however, demonstrate that the shedability of the garment is not the only factor that the forensic fibre examiner needs to take in to consideration when interpreting fibre evidence transferred in this manner.

The knife-polyester relationship delivered an ample amount of transference; a total of 1,671 fibres were transferred on to the knife from the polyester garment, creating an average of 167.1 fibres per repeat. A standard error of 26.384 reveals that the numbers for each repeat oscillate slightly. The knife, with a large surface area provides a platform for increased transference, yet it was not anticipated that the relationship would provide the second highest level of transfer, due to the polyester being the lowest shedder of fibres. The polyester featured fraying at the site of the damage (Figure 3) which may imply why the transfer was profuse. There appears to be a distinct correlation between degree of fraying and increased fibre transfer.

The relationship between the scissors and linen/viscose garment generated a high quantity of transfer with 1,056 fibres being counted creating an average of 105.6 per repeat. The standard error of 6.866 shows that the results are consistent; the range is small, therefore the numbers for each repeat are analogous. The damage to the linen/viscose garment displayed fraying at the yarns where the scissors had penetrated as shown in Figure 4. In comparison to the knife, the scissors have a much smaller surface area, resulting in a smaller area of damage and area for substrate fibre transfer. Therefore, a reduced surface area correlates with a reduced potential for fibre transfer. Another factor which may have contributed to the fibre transfer was the sharpness of the scissors' bladed edge. Data produced from the knife-linen/viscose association illustrates that a greater area of damage produced significantly higher transferred fibre numbers than the scissors-linen/viscose relationship.

The results obtained from the scissors-cotton relationship were surprising; with a reduced surface area, thus a smaller area of damage, a higher number of transferred fibres than the knife-cotton relationship defies the hypothesis. An average of 95 was recorded per repeat with a standard error of 12.408 showing that while there is some degree of discrepancy between the repeats, the numbers are similar. While the results for this relationship were surprising, perhaps they shouldn't be, given that across all three garments, scissors retained fibres at a high rate, with 105.6 on average for linen/viscose and 56.5 per repeat average for polyester. Though the site of damage inflicted by scissors on the polyester was small, when separated from the incision, the yarns featured fraying; this has an important impact on the amount of fibres transferred. The scissors are a blunter instrument than the knife, meaning the former is more likely to produce fraying [40].

The screwdriver ranked lowest for transferred fibres across all three garments. This is an expected result considering the surface area of the weapon is the smallest, thus the potential damage area is the smallest. As can be seen in the Table 1, linen/viscose fibres were transferred to the screwdriver the most, with cotton the second most and polyester the least.

Given that polyester sheds the least fibres, it is unsurprising that the average amount of fibres transferred on to the screwdriver is the least of the three garments. There was evidence of fraying on the polyester and linen/viscose garments, as shown in Figure 5, but given that more cotton fibres were retrieved from the screwdriver compared to polyester, the fraying appears to have been an insufficient amount and as such is an insignificant influence.

As seen in Figure 6, the tip of the knife contains a small blunted area of damage. This component was not a result of the experiment and existed before the commencement of the study. If an implement is sufficiently blunt it will pull some of the yarn out of the weave, as opposed to cutting cleanly through it and could produce a greater degree of fraying [26,44].

The overall results, to some extent, are unexpected. Given that the shedability test showed cotton as the highest shedding material, it is surprising that the linen/viscose garment transferred the most fibres. However, one of the key parameters encountered in this study is textile fraying; it appears to have a palpable effect on increasing fibre transfer.

The degree of fraying may be influenced by fabric structure, an open-weave structure is characterised by warped threads in fabric never coming together, leaving small intervals. A closed-weave structure has no spaces between the threads. The open-weave of the linen/viscose garment make it more susceptible to fraying in comparison to the closed-weave structure of the cotton and polyester garments. While literature supporting this notion is limited, it is possible that the more open weave of the garment allows the yarns to be displaced more readily, consequently influencing the volume of transfer [39,40,45]. Unsurprisingly, polyester was the lowest transferred fibre type, although a high amount of transfer occurred with the knife-polyester relationship. The larger area for fibre transfer coinciding with fraying perhaps satisfies why this relationship provided a high volume of transfer. Possibly the biggest obscurity, though, is the surprisingly small number of cotton fibres retrieved from the knife. Prior to the experiment, it was hypothesised that this relationship would produce the greatest transfer. However, the properties of cotton mean it produces little or no significant fraying.

Conclusions

This research has shown the potential for the transfer of fibres to a weapon during a singular stabbing incident, allowing for an association between the victim and the weapon. In nearly all the experimental repeats, fibres were transferred supporting the routine examination of weapons for fibres during a stabbing related incident. Recovery of such fibres would help establish a link between a weapon and the victim's clothing. It was anticipated that the highest shedding garment (cotton) would produce the highest degree of transference. This was not the case, suggesting that the degree of fibre transference to a weapon in stabbing incidents is a much more complex science. The degree of shedability of a garment is only one factor that influences the degree of transference with the surface area of the weapon and the potential for the garment to fray also playing a significant role in transference.

The larger the surface area of the weapon, the more opportunity there is for fibres to be collected. This was demonstrated in the experiments where the weapon with the smallest surface area, the screwdriver/garment relationships, produced the smallest number of transferred fibres for any weapon/garment relationship across all three garment types. In addition, the ability of the garment to tear is shown to be a major influence in the transference of fibres. Textiles that constitute components which produce fraying transfer more readily, as shown in the high transfer rate of the weapon-linen/viscose relationship.

This research suggests that the forensic scientist needs to consider factors such as the surface area of the weapon, the potential of the garment to tear and fray as well as its shedding properties when interpreting fibre transference in this manner.

References

[1] Wiggins, K., Drummond, P. & Hicks Champod, T. 2004, "A study in relation to the random distribution of four fibre types on clothing (incorporating a review of previous target fibre studies)", Science & Justice, vol. 44, no. 3, pp. 141-148.

[2] Wakefield, J.C., Skene, A.M., A. F. M. Smith & Evett, I.W. 1991, "The Evaluation of Fibre Transfer Evidence in Forensic Science: A Case Study in Statistical Modelling", Journal of the Royal Statistical Society. Series C (Applied Statistics), vol. 40, no. 3, pp. 461-476

[3] Suzuki, S., Higashikawa, Y., Sugita, R., & Suzuki, Y. 2009. “Guilty by his fibers: Suspect confession versus textile fibers reconstructed simulation”, Forensic Science International (Online), 189(1), e27-e32.

[4] Wells, S.L., Laing, R.M., Carr, D.J. & Niven, B.E. 2013, "Effect of laundering on visible damage to apparel fabric caused by sharp force impact", Forensic science international, vol. 233, no. 1-3, pp. 283-287.

[5] Cowper, E.J., Carr, D.J., Horsfall, I. & Fergusson, S.M. 2015, "The effect of fabric and stabbing variables on severance appearance", Forensic Science International, vol. 249, pp. 214-224.

[6] Pounds, C.A. & Smalldon, K.W., 1975. The Transfer of Fibres Between Clothing Materials During Simulated Contacts and their Persistence During Wear: Part I—Fibre Transference. *Journal of the Forensic Science Society*, 15(1), pp.17–27.

[7] Langford, A. et al., 2005. *Practical Skills in Forensic Science*, Pearson.

[8] Kemp, S.E., Carr, D.J., Kieser, J., Niven, B.E. & Taylor, M.C. 2009, "Forensic evidence in apparel fabrics due to stab events", Forensic Science International, vol. 191, no. 1, pp. 86-96.

[9] Karlsson, T. 1998, "Homicidal and suicidal sharp force fatalities in Stockholm, Sweden. Orientation of entrance wounds in stabs gives information in the classification", Forensic science international, vol. 93, no. 1, pp. 21-32.

[10] Wright, E., 2017. Focus on violent crime and sexual offences, England and Wales: year ending Mar 2016 Chapters in this compendium. *Office for National Statistics*, (March 2016).

[11] Palasinski, M. 2013, "Security, respect and culture in British teenagers' discourses of knife-carrying", Safer Communities, vol. 12, no. 2, pp. 71-78

[12] Apps, J.R., Williams, C., McGuinness, A., Gabbie, S. & Sutcliffe, A.G. 2013, "Stabbing and safeguarding in children and young people: a Pan-London service evaluation and audit", JRSM Short Reports, vol. 4, no. 7, pp. 1-7.

[13] Gilgan. 2018. "London murder rate beats New York as stabbings surge", The Times (online). Available at: https://www.thetimes.co.uk/article/london-murder-rate-beats-new-york-as-stabbings-surge-f59w0xqs0

[14] Ferllini, R. 2012, "Macroscopic and Microscopic Analysis of Knife Stab Wounds on Fleshed and Clothed Ribs", Journal of Forensic Sciences, vol. 57, no. 3, pp. 683-690.

[15] www.parliament.uk. (2017). Knife Crime Statistics. [online] Available at: http://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN04304#fullreport.

[16] Swann, I.J., MacMillan, R. & Watson, A.A. 1985, "A study of stab wounds", Archives of emergency medicine, vol. 2, no. 1, pp. 31-36.

[17] Di Maio VJ, Di Maio D, editors. 2001. "Wounds caused by pointed and sharp-edged weapons", Forensic Pathology. 2nd ed. Boca Raton, FL: CRC Press

[18] Nic Daéid, N., Cassidy, M. & McHugh, S. 2008, "An investigation into the correlation of knife damage in clothing and the lengths of skin wounds", Forensic Science International, vol. 179, no. 2, pp. 107-110.

[19] Taupin, J. 1999, "Comparing the Alleged Weapon with Damage to Clothing-The Value of Multiple Layers and Fabrics", Journal of Forensic Sciences, vol. 44, no. 1, pp. 205-207.

[20] Palmer, R., Sheridan, K., Puckett, J., Richardson, N. & Lo, W. 2017, "An investigation into secondary transfer-The transfer of textile fibres to seats", Forensic Science International (Online), vol. 278, pp. 334.

[21] Schnegg, M., Gueissaz, L., Rodriguez, J., Hess, S. & Massonnet, G. 2015, "Transfer of Fibres onto Knife Blades in Stabbing Events: Distribution and Determination of the Stabbing Sequence", Journal of Forensic Science and Medicine, vol. 1, no. 2, pp. 84-92.

[22] Causin, V., Marega, C. & Schiavone, S. 2005, "Cuts and tears on a paper towel: a case report on an unusual examination of damage", Forensic Science International, vol. 148, no. 2, pp. 157-162.

[23] Horsfall, I., Watson, C., Champion, S., Prosser, P. & Ringrose, T. 2005, "The effect of knife handle shape on stabbing performance", *Applied Ergonomics,* vol. 36, no. 4, pp. 505-511.

[24] Taff, M.L. & Boglioli, L.R. 1998, "Science and politics of cutting and stabbing injuries in the USA", Journal of Clinical Forensic Medicine, vol. 5, no. 2, pp. 80-84.

[25] Aming, A. & Chitaree, R., 2010. Physical analysis of damaged tissue simulant covered with textiles made by sharp knife stabbing. *Thai Journal of Physics*, Series 6.

[26] Benson, N., Robson Oliveria Dos Santos, Griffiths, K., Cole, N., Doble, P., Roux, C. & Blanes, L. 2017, "The development of a stabbing machine for forensic textile damage analysis", Forensic Science International (Online), vol. 273, pp. 132.

[27] Patel, F. 1998, "Vasovagal death from screwdriver stabbing of the neck", Journal of Clinical Forensic Medicine, vol. 5, no. 4, pp. 205-206.

[28] Zhang, X. & Yang, Y. 2016, "Scissors stab wound to the cervical spinal cord at the craniocervical junction", The spine journal: official journal of the North American Spine Society, vol. 16, no. 6, pp. e403-e406.

[29] Hainsworth SV, Delaney RJ, Rutty GN. 2008, "How sharp is sharp? Towards quantification of the sharpness and penetration ability of kitchen knives used in stabbings", Int J Legal Med;122(4):281–91.

[30] Biermann, T.W. & Grieve, M.C., 1998. A computerized data base of mail order garments - A contribution toward estimating the frequency of fibre types found in clothing. Part 3: The content of the data bank - Is it representative? *Forensic Science International*, 95(2), pp.117–131.

[31] Palmer, R. & Oliver, S. 2004, "The population of coloured fibres in human head hair", Science & Justice, vol. 44, no. 2, pp. 83-88.

[32] Broadbent, A.D., 2001. Basic principles of textile coloration. *Color Research & Application*, 28(3), pp.230–231.

[33] Kate Fletcher, Sustainable Fashion and Textiles: Design Journeys, (UK, Earthscan, 2008) p.6

[34] Watt, R., Roux, C. & Robertson, J. 2005, "The population of coloured textile fibres in domestic washing machines", Science & Justice, vol. 45, no. 2, pp. 75-83.

[35] Auerbach, P.S., 2012. *Wilderness medicine*, Elsevier.

[36] Palmer, R. & Burch, H.J. 2009, "The population, transfer and persistence of fibres on the skin of living subjects", Science & Justice, vol. 49, no. 4, pp. 259-264.

[37] Grieve, M. & Wiggins, K. 2001, "Fibers Under Fire: Suggestions for Improving Their Use to Provide Forensic Evidence", Journal of Forensic Sciences, vol 46, no. 4, pp 835-843

[38] Carr, D., 2017. *Forensic Textile Science.*, Elsevier

[39] Robertson, J., Roux, C. & Wiggins, K.G., 2018. *Forensic examination of fibres* 3rd ed., CRC Press.

[40] Taff, M.L. & Boglioli, L.R. 1998, "Science and politics of cutting and stabbing injuries in the USA", Journal of Clinical Forensic Medicine, vol. 5, no. 2, pp. 80-84.

[41] Adanur, S., 1995. Wellington Sears Handbook of Industrial Textiles. Technomic.

[42] Herman, M.F., 2007. Encyclopedia of polymer science and technology, 3rd ed. Wiley.

[43] Bilal, B.K., 2007. Comfort and handle behaviour of linen-blended fabrics. *Autex Research Journal*, 7(1), pp.33–47. Available at: ww.rrf.com.

[44] Bostock, E. Parkes, G. Williams, G. 2013, “A novel method for the analysis of slash cuts to clothing”, Journal of Forensic Research, vol. 4, no. 4, pp. 195-197.

[45] Hearle, J.W.S., Lomas, B., Cooke, W.D. & Textile Institute (Manchester, E. 1998, *Atlas of fibre fracture and damage to textiles,* 2nd edn, CRC, Cambridge;Boca Raton.

Figure 1. Weapons used for simulations; top: kitchen knife, centre: scissors, bottom: screwdriver.

Figure 2. Garments used for stabbing simulations; top: cotton T-shirt; bottom left: polyester T-shirt; bottom right: linen/viscose trousers

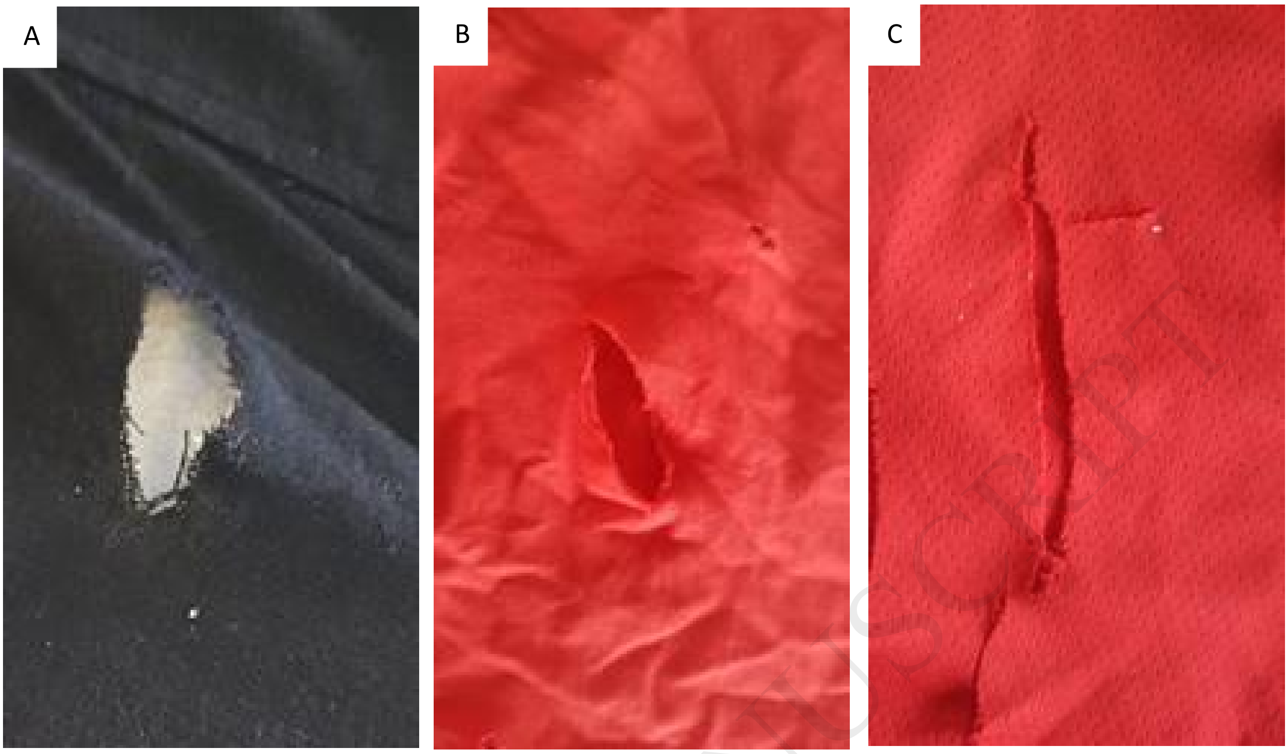

Figure 3. Damage inflicted by knife to A: linen/viscose, B: cotton, C: polyester.

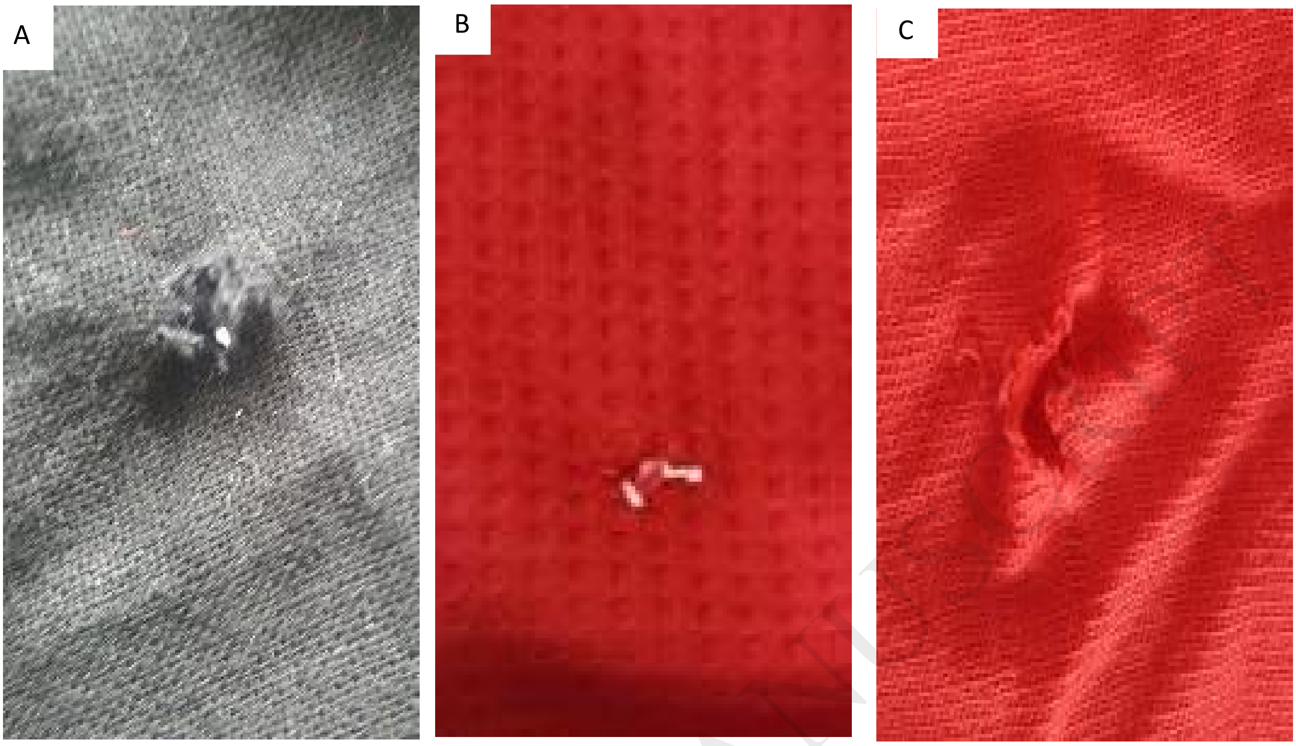

Figure 4. Damage inflicted by scissors to A: linen/viscose, B: polyester, C: cotton.

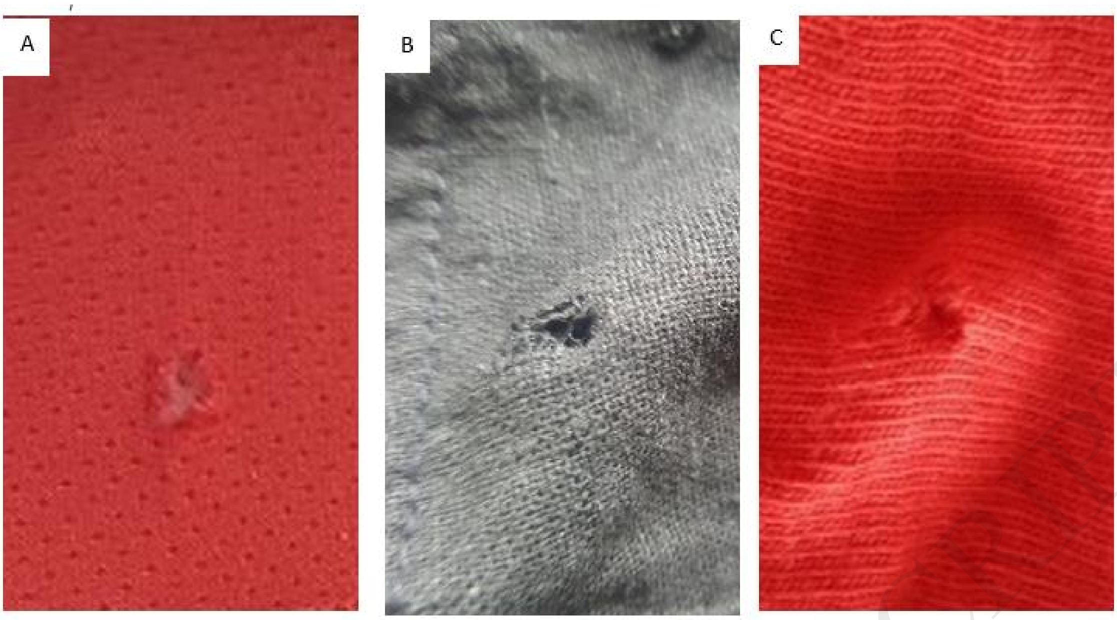

Figure 5. Damage inflicted by screwdriver to A: polyester, B: linen, C: cotton


A
B

Figure 6. A: pre-sustained damage to tip of knife used in this study; B: image of 'A' under 400x high-powered microscopy.

Table 1. Results showing number of fibres transferred to a weapon during a single stabbing.

	Cotton			Polyester			Linen/Viscose		
	Knife	Scissors	Screwdriver	Knife	Scissors	Screwdriver	Knife	Scissors	Screwdriver
Repeat 1	**35**	**154**	**26**	**292**	**81**	**37**	**134**	**105**	**79**
Repeat 2	**21**	**74**	**13**	**327**	**50**	**56**	**175**	**147**	**72**
Repeat 3	**30**	**58**	**17**	**221**	**49**	**29**	**176**	**109**	**55**
Repeat 4	**28**	**75**	**44**	**85**	**71**	**35**	**242**	**102**	**55**
Repeat 5	**0**	**69**	**53**	**113**	**50**	**24**	**199**	**94**	**55**
Repeat 6	**22**	**41**	**21**	**109**	**68**	**19**	**383**	**91**	**26**
Repeat 7	**24**	**170**	**30**	**120**	**32**	**19**	**319**	**112**	**31**
Repeat 8	**540***	**111**	**51**	**129**	**65**	**27**	**145**	**74**	**74**
Repeat 9	**22**	**109**	**18**	**130**	**52**	**39**	**223**	**88**	**33**
Repeat 10	**8**	**89**	**73**	**145**	**47**	**35**	**283**	**134**	**75**
Total	**730**	**950**	**346**	**1,671**	**565**	**320**	**2,279**	**1,056**	**555**
Mean	**73**	**95**	**34.6**	**167.1**	**56.5**	**32**	**227.9**	**105.6**	**55.5**
Standard Deviation (STDEV)	**164.413**	**39.238**	**18.714**	**83.434**	**14.401**	**11.075**	**80.021**	**21.711**	**19.789**
Standard Error (STDER)	**51.990**	**12.408**	**5.918**	**26.384**	**4.554**	**3.502**	**25.305**	**6.866**	**6.258**