Forensic Science International 247 (2015) 14–17

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

An experimental investigation of the indirect transfer and deposition of gunshot residue: Further studies carried out with SEM–EDX analysis

James French [a,b,*], Ruth Morgan [b]

[a] Department of Security and Crime Science, University College London, 35 Tavistock Square, London WC1H 9EZ, United Kingdom
[b] JDI Centre for the Forensic Sciences, University College London, 35 Tavistock Square, London WC1H 9EZ, United Kingdom

ARTICLE INFO

Article history:
Received 6 June 2014
Received in revised form 13 October 2014
Accepted 15 October 2014
Available online 24 October 2014

Keywords:
Gunshot Residue (GSR)
Secondary transfer
SEM–EDX

ABSTRACT

Experiments were undertaken in order to explore the potential for gunshot residue (GSR) particles to undergo tertiary transfer, and to be deposited on individuals in the vicinity of a firearm discharge. Samples were taken from hands following a series of test-firings. SEM–EDX with automated detection and analysis software was used to determine the presence of GSR on these samples. As many as 22 particles were found to have undergone tertiary transfer via a series of handshakes following a firearm discharge. In one run, a particle measuring 49.19 μm was recovered from a tertiary transfer recipient. Significant numbers of particles were also recovered from bystanders, with as many as 36 being detected on a sample taken from an individual who was in the proximity of a firearm discharge. The implications of these observations for forensic investigations are considered. In particular, the need to prevent unwanted transfer during the collection phase is highlighted, and the importance of acknowledging the possibility of secondary and tertiary transfers when reconstructing firearms incidents is also stressed. Experimental studies offer a means of improving our understanding of the dynamics of GSR transfer and deposition, and assisting the forensic reconstruction of firearms incidents.

1. Introduction

Gunshot residue (GSR) is produced during a firearm discharge. It consists of spherical and irregular particles composed of material from the priming compound, propellant, cartridge and firearm [1]. These particles typically have diameters of 1–10 μm, but can measure in excess of 30 μm, 50 μm, or 100 μm [2]. When a firearm is discharged, GSR is deposited on the shooter and on surfaces in the vicinity of the firearm discharge and GSR is frequently employed as a form of trace evidence during the reconstruction of firearms incidents. The literature on GSR analysis and identification has been comprehensively reviewed by Romolo and Margot [3] and Dalby et al. [4].

It has been established that the presence of GSR does not necessarily indicate that a suspect has fired a gun. Rather, material can be acquired as a result of contact with a surface bearing GSR, or via proximity to a firearm discharge [5]. GSR may also be deposited on an individual who has entered a room in which a firearm was recently discharged [6,7]. However, there are few published empirical investigations of these mechanisms of GSR transfer and deposition, and fewer that consider secondary (and further) transfers. Further empirical study of these mechanisms will contribute to our understanding of the dynamics of GSR evidence and allow the implications and ramifications for forensic investigations to be explored. In particular, results from such studies will inform the interpretation of GSR evidence.

A study by French et al. [8] concerning the secondary transfer of GSR reported the occurrence of secondary transfers of GSR to subjects who had made contact with a shooter, and to subjects who had handled a recently discharged handgun. Importantly, these transfers involved significant quantities of GSR and as many as 129 particles were detected on a subject who had shaken hands with a shooter. The results of the study indicated that tertiary transfers might also be possible. Analysis of the particle size data revealed the possibility of very large GSR particles (>40 μm, >60 μm and >100 μm) undergoing secondary transfer. The study also highlighted the need for further experimentation aimed at enhancing our understanding of the dynamics of GSR and transfer mechanisms to enable accurate and empirically-supported interpretation.

* Corresponding author at: Department of Security and Crime Science, University College London, 35 Tavistock Square, London WC1H 9EZ, United Kingdom. Tel.: +44 020 3108 3109.
E-mail addresses: james.french@ucl.ac.uk (J. French), ruth.morgan@ucl.ac.uk (R. Morgan).

http://dx.doi.org/10.1016/j.forsciint.2014.10.023
0379-0738/

This paper develops the French et al. [8] study by presenting the results of two experimental scenarios in which tertiary transfers and depositions on a bystander were simulated. The tertiary transfer of different forms of trace evidence has previously been observed (see Taupin [9] for an example regarding fibres and hair). However, explicit consideration of the tertiary transfer of GSR is currently absent in the published literature. Knowledge of the potential for tertiary transfer and of the sizes of particle involved can be incorporated in the assessment of GSR evidence under competing propositions about its deposition. This paper contributes to our understanding of GSR transfer by comparing tertiary and secondary transfers in terms of their efficiency and of the sizes of particles involved. The French et al. study [8] compared the quantities of GSR deposited on shooters to those recovered from secondary transfer recipients. It is not known how these quantities of GSR compare to those that undergo tertiary transfer, or those that are deposited on bystanders. By simulating further transfer and deposition scenarios under the same conditions as the French et al. study [8] and by building a more comprehensive picture of GSR transfer and deposition, this present study allows such comparisons to be made. Experimental scenarios were intended to mimic, firstly, a forensic scenario in which a subject who was not present at the scene of a shooting made contact with an individual (perhaps an accomplice) who had previously made contact with a shooter. Secondly, an experiment was designed in which an individual was standing 1 m behind the shooter during a firearm discharge.

2. Materials and methods

The first experiment was designed to extend a transfer scenario simulated in the previous study [8] in order assess the potential for tertiary transfer. The second enabled measurement of the quantity of GSR deposited on a bystander under the same conditions.

In both scenarios, a SIG Sauer P226 self-loading pistol was used to fire five rounds of 9 mm Luger 95 grain jacketed soft point 9P1 ammunition (manufactured by FEDERAL Ammunition). Subjects were sampled in the manner outlined by French et al. [8]: 1/2 in. aluminium SEM stubs, covered in self-adhesive carbon discs (TAAB Laboratories, UK), were dabbed onto the entire surface of the hands 50 times, focusing particularly on the webbed area between thumb and forefinger (following Rosenberg and Dockery [10]). Sampling took place immediately after the completion of each experiment at a distance of 15 m from the site of the discharge and samples were placed within individual, sealed storage tubes (TAAB Laboratories, UK). These measures limited the potential for contamination. Prior to each experiment, participants were instructed to wash their hands thoroughly with soap and water before control samples were taken (following Andrasko and Maehly [11]).

2.1. Scenario one

Having discharged five rounds, the shooter was instructed to shake hands with a participant who had not been present at the scene of the discharge. This participant then shook hands with a third individual (thus forming a chain of two handshakes). All three individuals were sampled according the procedure outlined above. Sampling in this way enabled the collection of any GSR that underwent tertiary transfer, as well as the quantification of GSR that remained at the donor surfaces. This experiment was run three times.

2.2. Scenario two

During the firearm discharge, a participant stood 1 m behind the shooter with their hands by their sides. The hands of this bystander were sampled using the same procedure as experiment one, enabling the collection of the GSR that was deposited on his hands. This experiment was run three times.

2.3. Analysis

The samples were carbon coated and then analysed for the presence of GSR using SEM–EDX. Analysis was carried out using a JEOL JSM-6480LV scanning electron microscope fitted with an Oxford Inca X-sight Energy Dispersive Spectrometer and automated GSR detection and analysis software (INCAGSR). GSR particles were identified according to the latest ASTM standard [12].

3. Results

3.1. Scenario one

In each of the three runs of scenario one GSR particles were recovered from the third participant in the transfer chain. These particles had initially been deposited on the hands of the shooter during the discharge, before being secondarily transferred to the first transfer subject. These particles then underwent a tertiary transfer from this participant to the third individual in the chain. The number of particles recovered after the tertiary transfer was considerable in each run (18, 22 and 12 particles).

Following each experimental run and successive handshakes, much greater levels of GSR were recoverable from the shooters than from the other participants, despite the ‘loss’ of some particles as a result of transfer. The quantity of initially deposited GSR varied greatly across the three runs. Following runs one and two, more particles were recovered from the secondary transfer recipient (26 and 29) than from the third participant (18 and 22). Following run three, however, the reverse was true as 12 particles were recovered from the tertiary transfer recipient and 9 were detected on the sample taken from the secondary transfer recipient (the tertiary transfer donor).

Examination of the particle size data reveals that the majority of particles recovered from the hands of the tertiary transfer recipient in each of the three runs measured <10 μm. In run three the largest particle that was recovered, measuring 49.19 μm in diameter, was significantly larger than any of the particles detected on the three samples. It is emphasised that this large particle was primarily deposited, before being transferred twice more via successive contacts. The presence of this particle increased the average particle size for run three (8.82 μm), relative to the previous runs (3.92 μm and 3.25 μm, respectively).

In order to generate an estimate of the efficiency of the transfers, the particle counts of reciprocal samples were combined. For example, for run one the number of particles initially deposited on the shooter was calculated by combining the three samples taken during this run ($647 + 26 + 18 = 691$). Meanwhile, the quantity of particles that were initially transferred to the secondary transfer recipient was calculated by combining the samples from the second and third participants ($26 + 18 = 44$). Reconstructing particle counts in this manner is likely to underestimate the true values, but owing to the uniformity of the sampling strategy, any error was considered to be consistent across the three runs.

The estimated counts suggest that the secondary transfers, during which 6.4%, 11.0% and 9.5% particles underwent transfer, were less efficient than the tertiary transfers during which 40.9%, 43.1% and 57.1% of particles were transferred. The similarity of the efficiency of the three secondary transfers is notable, while the three tertiary transfer events were also similar in terms of their efficiency. This is despite variation in the initial quantities of material available for transfer in the three runs.

Table 1
Number of GSR particles recovered from each individual following the handshakes in scenario one.

Run	GSR particles recovered from shooter after contacts	GSR particles recovered from secondary transfer recipient after contacts	GSR particles recovered from tertiary transfer recipient after contacts
1	647	26	18
2	411	29	22
3	200	9	12

Table 2
Particle size data for the GSR particles recovered from each individual following the handshakes in scenario one.

	Run 1	Run 2	Run 3
	GSR particles recovered from tertiary transfer recipient after contacts	GSR particles recovered from tertiary transfer recipient after contacts	GSR particles recovered from tertiary transfer recipient after contacts
0–0.99 μm	4	5	0
1–2.99 μm	7	10	2
3–4.99 μm	2	2	4
5–9.99 μm	3	4	5
10–29.99 μm	2	1	0
30–99.99 μm	0	0	1
100 + μm	0	0	0
Total number of particles	18	22	12
Average particle size (μm)	3.92	3.25	8.82
Largest particle (μm)	15.69	13.25	49.19

Table 3
Transfer efficiency data for the transfers simulated in scenario one.

Run	Original GSR particles on shooter	Original GSR particles on secondary transfer recipient	Secondary transfer efficiency (%)	Original GSR particles on Secondary transfer recipient	GSR particles recovered from tertiary transfer recipient	Tertiary transfer efficiency (%)
1	691	44	6.4	44	18	40.9
2	462	51	11.0	51	22	43.1
3	221	21	9.5	21	12	57.1

3.2. Scenario two

Considerable numbers of GSR particles were recovered from the hands of the bystanders in the three runs of scenario two. 21, 36 and 28 particles were recovered following the firings in runs one, two and three, respectively.

The mean size of the recovered particles varied across the three runs (1.88 μm, 3.67 μm and 7.27 μm in runs one, two and three, respectively). The largest particle recovered from the hands of the bystander in runs one and two (7.47 μm and 12.90 μm) was smaller than that which was recovered in run three (32.35 μm)

Table 4
Number of GSR particles recovered from bystanders in scenario two.

Run	GSR particles recovered from bystander
1	21
2	36
3	28

Table 5
Particle size data for the GSR particles recovered from bystanders in scenario two.

	Run 1	Run 2	Run 3
	GSR particles recovered from bystander	GSR particles recovered from bystander	GSR particles recovered from bystander
0–0.99 μm	7	4	2
1–2.99 μm	12	18	9
3–4.99 μm	1	6	4
5–9.99 μm	1	4	7
10–29.99 μm	0	4	5
30–99.99 μm	0	0	1
100 + μm	0	0	0
Total Number of Particles	21	36	28
Average Particle Size (μm)	1.88	3.67	7.27
Largest Particle (μm)	7.47	12.90	32.35

4. Discussion

The results of experimental scenario one provide empirical confirmation that GSR particles may undergo tertiary transfer by means of successive handshakes following a firearm discharge. Importantly, the quantity of GSR recovered following these simulated transfers was considerable. In a manner similar to the transfers that were simulated during a previous study [8], the experimental transfer scenarios of this present study represent an "extreme case" in which any contacts (in this case, the handshakes) were made immediately following the discharge. Meanwhile, samples were taken from the hands of subjects without delay, meaning that the maximum extent of GSR deposition was captured. While this may limit the possibility of using the counts to determine an expected level of deposition in casework scenarios, the aim of this study was to assess the potential for alternative means of GSR deposition in order to inform the reconstruction of events.

It is important to consider the potential implications of these experimental findings for forensic investigations that involve GSR evidence.

4.1. Collection and processing

The findings demonstrate the potential utility of sampling from multiple individuals who may be suspected of having been involved in a firearms incident. The possibility of establishing a link (albeit an indirect one) between an individual and an incident is likely to be assisted by sampling from multiple suspects. While maximising the reconstructive potential of GSR evidence, expedient sampling will limit the further loss or redistribution of evidence that could result from further contacts and transfers.

The capacity of GSR to undergo transfers as a result of direct and indirect contacts gives rise to the potential for contamination during the handling and processing of suspects and evidence. Conceivably, contacts made by law enforcement officers with the hands of suspects could result in a transfer of material from suspect to officer. While reducing the quantity of GSR on the hands of the suspect, such a transfer would result in a population of GSR particles that could be transferred to a second suspect via the hands of the officer. Meanwhile, the results of this study highlight the potential for officers (especially those who regularly work with firearms) to bring GSR to a crime scene and conceivably, to transfer material to suspects or exhibits. Procedures and protocols aimed at managing these risks are necessary. For example, control sampling from responding officers is advised, and where practicable, encouraging hand-washing and the wearing of disposable gloves are also recommended. Furthermore, assigning one suspect per officer, where possible, would limit the potential for indirect transfer and would ensure that evidence was preserved.

4.2. Interpretation

Alternative means of GSR deposition must be acknowledged when interpreting the presence of GSR on a surface or suspect. This is underlined by the results of this study, which demonstrate the possibility of tertiary transfers of GSR and depositions in the vicinity of a firearm discharge. When considering the probability that GSR recovered from a suspect was deposited as a result of firing a gun, alternative causes such as secondary and tertiary (indirect) transfer mechanisms, as well as radial deposition, should be considered. Indeed, the experimental data that have been presented may be referred to when estimating the probability that a particular mechanism was responsible for the deposition of GSR that has been recovered from a suspect. The results of the present study highlight the potential for misinterpretation if alternative transfer mechanisms are not acknowledged. The efficiency of the observed tertiary transfers suggests that further contacts (and extension of the transfer chains) would be effective in initiating further transfers of GSR. In terms of the size of particles involved in transfer, the results of the present study build on previous findings [8], indicating that transfers of GSR are not restricted to the involvement of small GSR particles. Rather, large particles (such as the particle measuring 49.19 μm recovered in run three of scenario one) may undergo successive transfers. Thus, caution is advised when attempting to draw inferences from GSR evidence and taking particle sizes into consideration.

These results contribute to our understanding of the transfer properties of GSR. However, distinguishing between means of GSR deposition in casework situations will necessitate the incorporation of variables such as the timeframe between transfer/deposition and sampling, and the effect of persistence. The results of case-specific experimental work and test-firings will also assist in the interpretation of this form of particulate evidence in particular contexts.

5. Conclusions

This experimental study furthers our understanding of the dynamics of GSR evidence. Through experimental scenarios, it has been demonstrated that GSR particles may undergo tertiary transfer and that they can be deposited on the hands of an individual who is standing in the proximity of a discharge, but who has not fired a weapon. The results of these experiments also indicated that it is possible for large GSR particles ($>$10 μm) to undergo successive transfers. In the interest of recovering the greatest possible quantities of GSR, and enabling accurate crime reconstructions, multiple transfer mechanisms should be acknowledged when sampling from suspects following an incident. Meanwhile, the need for measures to guard against unwanted transfer and contamination during collection and processing is underlined. Crucially, these results present empirical evidence that highlights the importance of acknowledging alternative means of evidence deposition when interpreting the presence of recovered GSR. Further empirical research into the transfer and persistence of GSR that is produced by different ammunition and investigations that explore the effects of particle shape and chemical composition will contribute to the drawing of accurate, empirically-supported interpretations of the presence of GSR evidence.

Acknowledgements

The authors acknowledge that this research was funded by the Engineering and Physical Sciences Research Council of the UK through the Security Science Doctoral Research Training Centre (UCL SECReT) based at University College London (EP/G037264/1). The authors also acknowledge the support of officers from the Surrey/Sussex Joint Command Tactical Firearms Unit, the support of Oxford Instruments, UK and the assistance of James Davy (Department of Earth Sciences, UCL).

References

[1] B. Heard, Handbook of Firearms and Ballistics: Examining and Interpreting Forensic Evidence., 2nd ed., Wiley, Chichester, 2008.

[2] S. Basu, Formation of gunshot residues, J. Forensic Sci. 27 (1) (1982) 72–91, http://dx.doi.org/10.1520/JFS11453J.

[3] F. Romolo, P. Margot, Identification of gunshot residue: a critical review, Forensic Sci. Int. 119 (2) (2001) 195–211, http://dx.doi.org/10.1016/S0379-0738(00)00428-X.

[4] O. Dalby, D. Butler, J. Birkett, Analysis of gunshot residue and associated materials – a review, J. Forensic Sci. 55 (4) (2010) 924–943, http://dx.doi.org/10.1111/j.1556-4029.2010.01370.x.

[5] E. Lindsay, M. McVicar, R. Gerard, E. Randall, J. Pearson, Passive exposure and persistence of gunshot residue (GSR) on bystanders to a shooting: comparison of shooter and bystander exposure to GSR, Can. Soc. Forensic Sci. J. 44 (3) (2011) 89–96, http://dx.doi.org/10.1080/00085030.2011.10768144.

[6] V. Matricardi, J. Kilty, Detection of gunshot residue particles from the hands of a shooter, J. Forensic Sci. 22 (4) (1977) 725–738, http://dx.doi.org/10.1520/JFS10411J.

[7] L. Fojtášek, T. Kmjec, Time periods of GSR particles deposition after discharge – final results, Forensic Sci. Int. 153 (2–3) (2005) 132–135, http://dx.doi.org/10.1016/j.forsciint.2004.09.127.

[8] J. French, R. Morgan, J. Davy, The secondary transfer of gunshot residue: an experimental investigation carried out with SEM–EDX analysis, X-ray Spectrom. 43 (1) (2014) 56–61, http://dx.doi.org/10.1002/xrs.2498.

[9] J. Taupin, Hair and fiber transfer in an abduction case – evidence from different levels of trace evidence transfer, J. Forensic Sci. 41 (4) (1996) 697–699, http://dx.doi.org/10.1520/JFS13982J.

[10] M. Rosenberg, C. Dockery, Determining the lifetime of detectable amounts of gunshot residue on the hands of a shooter using laser-induced breakdown spectroscopy, Appl. Spectrosc. 62 (11) (2008) 1238–1241, http://dx.doi.org/10.1366/000370208786401473.

[11] J. Andrasko, A. Maehly, Detection of gunshot residues on hands by scanning electron microscopy, J. Forensic Sci. 22 (2) (1977) 279–287, http://dx.doi.org/10.1520/JFS10589J.

[12] American Society for Testing and Materials, ASTM, E1588-10e1. ASTM Standard Guide for Gunshot Residue Analysis by Scanning Electron Microscopy/Energy Dispersive X-Ray Spectrometry, ASTM International, West Conshohocken, PA, 2010, http://dx.doi.org/10.1520/C0033-03.