

# 1 **A forensic investigation on the secondary transfer of organic gunshot** 2 **residues**

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8

## 9 **Abstract**

10 Gunshot residues (GSR) are an important forensic trace in firearm-related events. Currently,  
11 routine GSR analyses focus on the detection and characterisation of the inorganic  
12 components (IGSR). The increasing prevalence of heavy metal-free ammunition challenges  
13 these current protocols and there is significant interest in how the organic components of  
14 GSR (OGSR) can provide complementary information. OGSR compounds, originally  
15 deposited on the shooter during the firing process, may further be transferred onto another  
16 individual or surface, ultimately generating a pollution. Hence, the aim of this study was to  
17 provide additional information regarding the risk of a secondary transfer of OGSR. Two  
18 scenarios were investigated, the first one related to the arrest process and the possibilities of a  
19 secondary transfer arising between a shooter onto a non-shooter (e.g. between a police officer  
20 and a person of interest (POI)). The second scenario concerned the transfer of OGSR onto the  
21 non-shooter after handling a firearm for few minutes without discharging it. One calibre was  
22 chosen, the .40 S&W calibre, used by the Australian State Police Force involved in this  
23 study. A secondary transfer was observed in all cases for the two scenarios investigated, for  
24 three compounds of interest: ethylcentralite (EC), diphenylamine (DPA), *N*-  
25 nitrosodiphenylamine (*N*-nDPA). The firearm handling scenario resulted in a larger  
26 secondary transfer to that of the arrest scenario. Overall, the amounts of OGSR detected on  
27 the non-shooter were generally lower than that detected on the shooter and controls after the  
28 arrest scenario. The results of this study provide complementary knowledge about OGSR,  
29 which can be further used to improve the current practice and the interpretation of OGSR  
30 evidence. In particular, it highlights that the secondary transfer proposition must be  
31 considered during the interpretation, especially when small amounts of OGSR target  
32 compounds are detected.

33 **Keywords:** Firearm discharge residues, FDR, OGSR, arrest, firearm handling, UPLC-MS/MS

## 34        **1. Introduction**

35        Gunshot residues (GSR) are an essential trace in firearm-related events. In practice, GSR  
36        analyses currently focus on the detection and characterisation of the inorganic components  
37        (IGSR) which are mainly metallic particles composed of lead, barium and antimony known to  
38        be associated with the primer mixture. IGSR protocols are challenged by the increasing  
39        probability of encountering casework involving heavy metal-free (HMF) ammunition [1].  
40        Furthermore, given the quantity of propellant present in firearm cartridges, significant traces  
41        of OGSR may be deposited during a shooting. This may provide GSR examiners with an  
42        opportunity to obtain information that is complimentary to IGSR examination, potentially  
43        enhancing the forensic evaluation process in regards to a shooting. This necessitates further  
44        research into improving our knowledge of OGSR generated through the combustion of  
45        propellant powder, its characterisation, its transfer and persistence. Several studies already  
46        considered the question of OGSR analysis [2-9] and this study focused on the secondary  
47        transfer, beyond such analytical aspects.

48        While the primary transfer of IGSR and OGSR to the shooter occurs during and after the  
49        firing process, it is also important to assess further transfer of these residues from the shooter  
50        to an uncontaminated individual. Indeed, detecting GSR on an individual does not confirm  
51        the person has discharged a firearm [10, 11]. Secondary transfer of GSR traces can happen  
52        when, for instance, a non-shooter makes contact with a firearm (without discharging it) or  
53        with another individual who recently discharged a firearm.

54        Several studies have approached secondary transfer of IGSR. Charles and Geusens [12]  
55        investigated the secondary transfer of inorganic particles from police officers onto non-  
56        shooters. They concluded that the risk of transfer is heavily dependent of the technique of  
57        arrest [12], the more vigorous the arrest, the higher is the risk of transferring particles from  
58        one surface to another. They also emphasised that special unit forces officers who have a  
59        higher degree of contact with firearms, resulted in larger quantities of GSR transferred [12].  
60        French et al. [13] examined the secondary transfer of IGSR particles via a handshake between  
61        a shooter and non-shooter, as well as during the exchange of a firearm between a shooter and  
62        non-shooter [13]. They concluded that the average number of particles transferred via  
63        handshakes were found to be high (>80 characteristic particles in average) while an exchange  
64        of firearm resulted in a lower number of particles (40 characteristic particles in average)  
65        transferred [13]. The experiments were carried out immediately after the firearm was  
66        discharged, resulting in the maximum amount of GSR being present on the shooter and the

67 firearm [13]. French et al.'s study was further extended to explore the tertiary transfer by  
68 performing two consecutive handshakes [14]. A reduction in inorganic particle transfer was  
69 observed, however IGSR particles were still detectable following the tertiary transfer scenario  
70 [14]. Similar observations were made by Girvan et al. [15], where the transfer of inorganic  
71 particles during the arrest of a non-shooter by a police officer who had previously discharged  
72 a firearm was studied [15]. It was found that particles were detectable from specimens taken  
73 from the hands of the non-shooter [15]. Studies into the secondary transfer of OGSR,  
74 however, are limited. Arndt et al. [16] investigated the secondary transfer of OGSR after a  
75 handshake between the shooter and non-shooter [16]. The specimens were analysed by Ion  
76 Mobility Spectrometry (IMS) with no OGSR detected. However, several limitations,  
77 including a high limit of detection of the instrumentation, were highlighted, which could have  
78 contributed to this results [16]. Gassner et al investigated three different scenarios just after  
79 discharge involving handshakes, transporting a firearm and arrests [17]. The secondary  
80 transfer of OGSR was observed for all scenarios when a more sensitive analytical method  
81 was utilised. The firearm displacement scenario resulted in the lowest amount transferred,  
82 followed by handshaking with the arrest scenario resulting in highest amount of OGSR  
83 transferred. These studies emphasised that the risk of a secondary transfer of both IGSR and  
84 OGSR is significant. Therefore, precautions are essential to avoid a transfer of GSR when a  
85 contact between police officers and non-shooters occurs.

86 The aim of the current study was to extend the body of knowledge regarding the secondary  
87 transfer of OGSR as only two studies tackled such questions, and only one analysed  
88 specimens with a highly sensitive instrument. This study is focussing on an Australian  
89 perspective. The current ammunition used in Australia is the calibre .40 S&W and has never  
90 been studied in the context of secondary transfer. Generally, police officer(s) carry their  
91 service firearms while on duty and may potentially come in contact with non-shooter(s)  
92 during police investigations and operations. It is, therefore, essential to assess the degree of  
93 transfer, which could potentially take place if physical altercations such as an arrest  
94 procedure occurs between police officer(s) and non-shooter(s). This study considered two  
95 scenarios: the first one related to an arrest scenario between the shooter (i.e. Police officer)  
96 and a non-shooter (i.e. POI). The aim of this first scenario was to study the potential

97 pollution<sup>1</sup> of POI by police officers during the arrest process. The second scenario involved a  
98 non-shooter handling a firearm without discharging it. The aim of the second scenario was to  
99 determine the amount of OGSR transferred by handling the firearm when compared to a  
100 person who discharged it. Four compounds of interest, known to be part of propellant powder  
101 and OGSR composition, were investigated: ethylcentralite (EC), methylcentralite (MC),  
102 diphenylamine (DPA) and  
103 *N*-nitrosodiphenylamine (*N*-nDPA) [19-21].  
104

## 105 **2. Material and method**

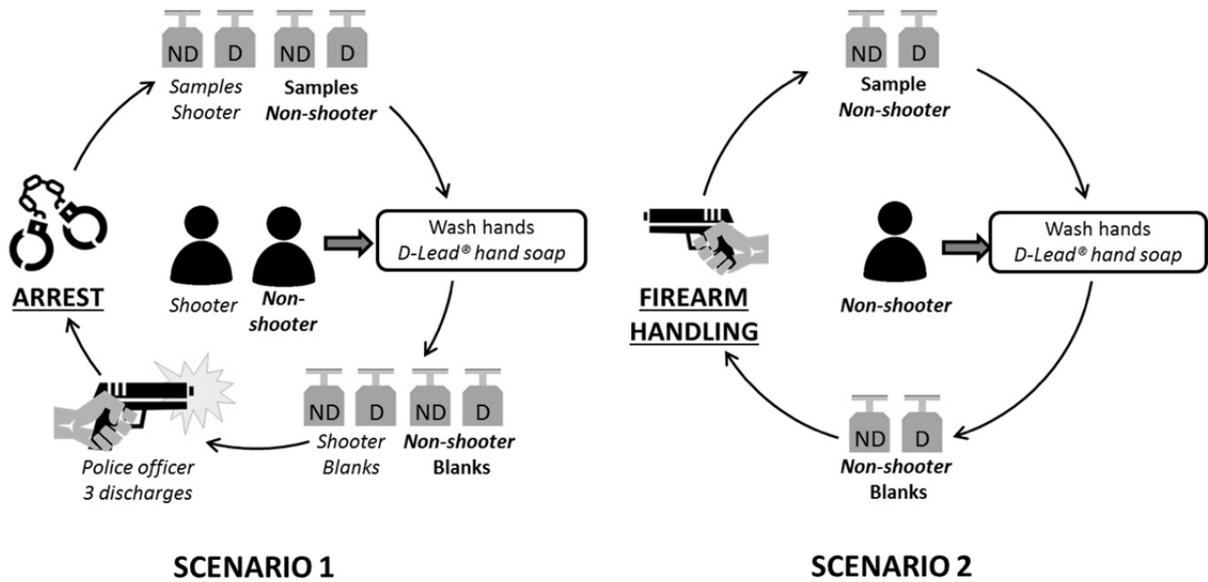
### 106 2.1 Secondary transfer: Shooting experiment procedure

107 For this study, one authorised personnel in an Australian State Police Force facility  
108 performed the firearm discharges in an indoor shooting range. The different transfer scenarios  
109 were performed outside of the firing range to minimise the risk of polluting the hands of the  
110 non-shooter from the environment. One calibre and firearm was selected: A Glock 22<sup>®</sup>  
111 calibre .40 S&W. This was chosen as it is the service weapon and calibre of the Australian  
112 police forces. The lead-free Winchester WinClean<sup>®</sup> (180Gr. Brass Enclosed Base)  
113 ammunition was chosen. The thumb-forefinger part of the palm and back of both dominant  
114 and non-dominant hand (right and left respectively) as well as the wrists were sampled  
115 separately.

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<sup>1</sup> According to Schwendener et al [18], “pollution” refers to the addition of some material due to a lack of precautions, while “contamination” refers to non-pertinent traces present before any investigation and cannot be avoided [18]. Pollution is therefore more suitable in the context of a secondary transfer study.

116 The methodology for both scenarios is presented in



117

118 Figure 1. This involved both participants (one shooter and one non-shooter) thoroughly  
119 washing their hands prior to the blanks being collected. The next step required the shooter to  
120 discharge three rounds of ammunition with the Glock® 22 held with two hands. To avoid  
121 pollution, the non-shooter did not enter the range at any point during the scenario. Following  
122 the firearm discharge, the shooter left the firing range and conducted the arrest scenario: the  
123 non-shooter put their hands on the top of their head before the shooter gripped the hands of  
124 the non-shooter and put them behind their back before they were handcuffed (Figure 1,  
125 scenario 1). The handcuffing procedure simulated a typical arrest procedure. The non-shooter  
126 was also asked to resist the arrest during the handcuffing process in order to simulate a  
127 realistic scenario.

128 After 1-2 minutes, the shooter removed the handcuffs and the specimens were collected from  
129 both hands of the non-shooter, as well as the shooter. The collection of OGSR was performed  
130 with GSR stubs (Ted Pella Inc, USA). The thumb-forefinger region of the palm and back of  
131 the hand, as well as the wrist, were thoroughly sampled until the stub surface was no longer  
132 sticky [21-23]. Each hand was sampled using an individual stub with the collected specimens  
133 packaged separately by sealing with the cover and placed in their respective boxes. The  
134 specimens were stored at 4 °C until extraction. The extraction was performed within 24 hours  
135 of collection to avoid degradation of the specimens [24].

136



158 [21]. Additionally, a 5 point calibration standard curve (0.01-1 ppm) was prepared and  
159 analysed with every run of specimens for quality control purposes

160

**Table 1. Compounds of interest. IS = internal standard.**

Compounds	Provider	Concentration	Solvent
EC	Novachem Pty Ltd	100 µg/mL	Methanol Acetonitrile (1:1)
MC		100 µg/mL	Methanol Acetonitrile (1:1)
DPA		1000 µg/mL	Methanol
<i>N</i> -nDPA		1000 µg/mL	Methanol
d10-DPA (IS)	C.D.N Isotopes Inc.	Solid	-

161 d10-DPA has been previously utilised as a suitable internal standard (IS) by [21, 25]. Stock  
162 solutions of internal standard were prepared at a concentration 1000 µg/mL in  
163 methanol:acetonitrile (1:1) v/v and added to each specimen at a final concentration of 20  
164 ppm [19].

165 Analysis of specimens was conducted per Maitre et al. [21]. The method was validated using  
166 the ICH Guidelines [26], and found fit for OGSR qualitative analysis purposes. The  
167 specimens were extracted using the protocol described in Taudte et al. [19, 21, 27].

168 The chromatographic separation was performed on a Waters UPLC ACQUITY® system. An  
169 Agilent ZORBAX RRHD Eclipse XDB 80Å C18, 3.0 x 100 mm, 1.8 µm was used coupled to  
170 a ZORBAX Eclipse XDB 80Å C18, 3.0 x 5 mm, 1.8 µm UHPLC guard. The mobile phase  
171 used is presented in Table 2, both solvent were filtered through 0.2 µm membrane filters  
172 (Table 2). The starting conditions of the chromatographic method is 70% water and 30%  
173 methanol. The method used a gradient which includes a 4.6% increase of methanol per  
174 minute for 12 minutes [19, 21], followed by 5 minutes of flushing and equilibrium before the  
175 next run. The column temperature was thermostatically maintained at 43 °C and an injection  
176 volume of 2 µL was used throughout.

177

178

**Table 2. UPLC mobile phase composition.**

Mobile phase components	Solvent grade	Additive	Membrane filters
Methanol	Hypergrad Lichrosolv®, Merck KGaA	+ 0.1% (v/v) formic acid	0.2 µm PTFE (47mm, Advantec, grade J020A047A)
ultrapure Milli-Q® Water	18.2 MΩcm, Q-POD®, Merck KGaA		0.2 µm mixed cellulose ester (47 mm, Advantec, grade A020H047A)

179

180 The QqQ-MS conditions were as follow: the desolvation temperature was set at 250 °C and  
181 the detection was performed using Multi-Reaction-Monitoring (MRM) from 0 to 12 minutes  
182 with electrospray ionisation (ESI) source set at 140 °C [21].

183 The results were extracted and processed in order to provide a normalised response: the  
184 detected peaks were integrated using QuanLynx® (Waters software). The presence of  
185 precursors to both product ion transitions was a required condition in an abundance above the  
186 limits of detection (LOD) for considering the compounds as present. The detected  
187 compounds underwent a blank subtraction (hand blank collected before the each experiment)  
188 before being normalised to the internal standard (IS). The square root of the ratio was then  
189 calculated and represent the normalised peak area [21, 28, 29].

190

### 191 3. Results and discussion

192 During this study, calibration curves were analysed along with the specimens and showed  
193 consistent and stable responses across each analytical analysis with the calibration curves  
194 found to be linear during each analytical run (average  $R^2 > 0.99$ ).

195 All the targeted compounds were considered detected when the abundance was found above  
196 the limit of detection (LOD). The LODs were found as follow: *N*-nDPA: 5.64 ppb, MC: 0.17  
197 ppb, DPA: 2.09 ppb and EC: 0.38 ppb [21]. Blank subtractions were performed on every  
198 specimen from each of the shooter and the non-shooter to account for possible  
199 contaminations. The blank specimens arising from the non-shooter where found to be clean,  
200 i.e. with none of the OGSR compounds detected. However, it was surprising that even after  
201 hand washing, some blanks from the shooter were found to contain OGSR. Hand washing has  
202 previously been studied [16] and indicated a complete removal of OGSR traces. The  
203 difference in results might arise from the use of different soap and sanitisers. Arndt et al have  
204 studied different soap containing alcohol [16], which might be more efficient in the removal  
205 of OGSR. In this study the soap used was a D-lead<sup>®</sup> hand soap used to decontaminate the  
206 hands of heavy metals, such soap might not be sufficient enough to remove OGSR. In  
207 addition, different instrumentation were used, which differ in sensitivity [16]. Arndt et al.  
208 have analysed specimens by IMS which typically produces high LODs [16]. Conversely,  
209 highly sensitive UPLC-QqQ-MS instrumentation was used in this study, and it was found  
210 that hand washing was not sufficient to remove completely OGSR traces. If the hand blank  
211 was found to contain a larger amount of OGSR than that of its corresponding specimen from  
212 the experimentation, that particular specimen was considered negative for OGSR traces to  
213 avoid skewing the results.

214

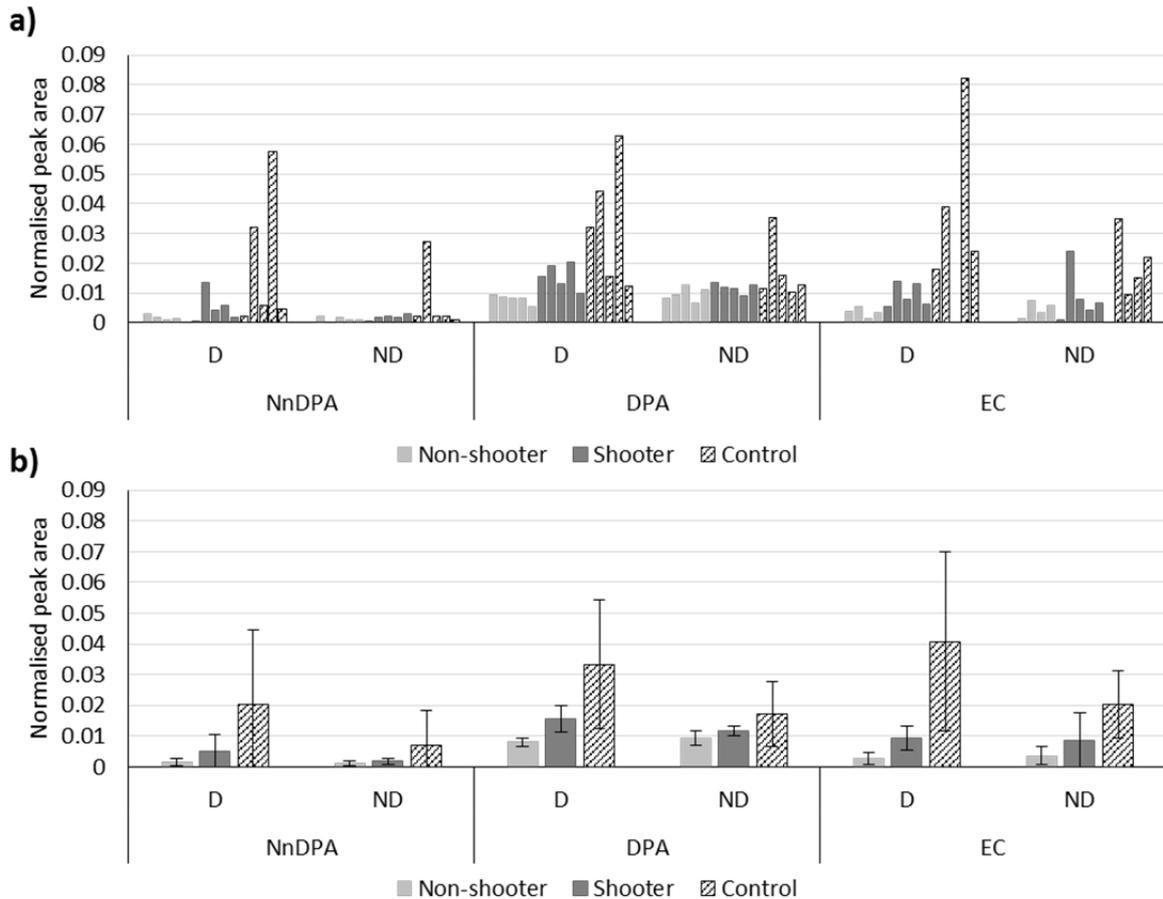
#### 215 3.1 Scenario 1: Arrest process

216 During their duties, police officers may come into contact with a potential POI for a  
217 particular investigation. When it occurs, there is a question of potential pollution of the non-  
218 shooter by the police officer. In order to assess this, an arrest scenario was performed and  
219 investigated. The results from the UPLC-QqQ-MS analysis are reported as a normalised  
220 response (section 2.2) [21]. Three of the four target compounds were detected (EC, DPA and  
221 *N*-nDPA). The manufacture of propellant powder typically involves the addition of a single  
222 centralite, either EC or MC but rarely both. Figure 2 represents the amount detected

223 (normalised response) for the three compounds of interest collected from both hands  
224 (dominant and non-dominant) of the shooter and non-shooter in the context of the arrest  
225 scenario. Figure 2a represents the details of the replicates, each bar-plot represents the  
226 amount detected on each hand. Figure 2b represents the averaged amount detected from each  
227 set of replicate specimens.

228 It was observed that the three compounds of interest were successfully identified in each of  
229 the five replicates of the arrest scenario. The amount detected of these compounds followed  
230 the same trend across each of the dominant and non-dominant hands, with a lower amount  
231 detected on the latter when compared to the dominant hand. As expected, the largest amount  
232 was detected in the control (Figure 2a and b), which relates to the detection of OGSR on the  
233 hands of the shooter immediately after the firearm discharges. The second largest amounts  
234 detected were from specimens arising from the hands of the shooter after they arrested the  
235 non-shooter. Finally, a secondary transfer was observed for the three compounds of interest  
236 on the non-shooter after being handcuffed by the shooter (Figure 2). The non-shooter did not  
237 have any prior contact with any potential source of OGSR, and their blanks were found free  
238 of OGSR. This emphasises the fact that the OGSR found on the non-shooter arose primarily  
239 from the transfer of OGSR from the shooter during the arrest. It must be noted that the wrists  
240 were also sampled. Hence, the handcuffs might also have contributed to the secondary  
241 transfer of OGSR onto the hands of the non-shooter in addition to the transfer from the  
242 shooter during the duration of the arrest process.

243 The results observed in Figure 2b on the hands of the shooter also suggest the presence of a  
244 secondary transfer as the amount detected on the hands of the shooter is lower than the  
245 amount detected in the controls. The only difference between the control specimens and the  
246 shooter specimens was the arrest scenario. Hence, the responses detected, for each of the  
247 compounds on both hands of the shooter, were found to be lower than the controls. Such a  
248 result is likely due to the transfer of OGSR onto the hands of the non-shooter while  
249 performing the arrest simulations. However, losses to the environment or redistribution of the  
250 OGSR onto surfaces that were not collected may also have contributed to the results. An  
251 exception is regarding DPA on the non-dominant hand (Figure 2 and Table 3), where it can  
252 be observed that adding the shooter and non-shooter resulted in a larger amount than the  
253 control. Such a result may be the consequence of the high variability observed between  
254 specimens as illustrated by the error bars in Figure 2b.



255

256 **Figure 2. Scenario 1: Arrest process. Level of OGSR detected (normalised response) from both hands of**  
 257 **each participant. D= dominant hand, ND= Non-dominant hand. a) Each replicates separately (n=5);**  
 258 **b) Averaged amount; the error bars represent the standard deviation. The “non-shooter” represents the**  
 259 **individual being arrested who did not have any contact with the firearm; the “Shooter” is the police**  
 260 **officer who arrested the non-shooter after discharging the firearm. “Controls” represent the amount**  
 261 **detected from the shooter immediately after three discharges, without having entered in contact with any**  
 262 **other surfaces.**

263

264 Different trends were observed between the non-shooter when compared to the shooter and  
 265 the controls when comparing the dominant and non-dominant hand (Figure 2b). It was found  
 266 that the detection of compounds was more consistent between both hands on the non-shooter  
 267 while larger differences between hands was seen in the shooter and control specimens.  
 268 Greater amounts of OGSR were detected on the dominant hand of the shooter and control  
 269 when compared to the amount detected on the non-dominant hand. The deposition of GSR is  
 270 highly dependent on the type of firearm, however, the position of the hands while holding the  
 271 grip of the gun causes the dominant hand to be positioned closer to the ejection port. In this  
 272 case the ejection port of the firearm was on the right. As a result, a greater amounts of GSR  
 273 are deposited on the dominant hand (right hand) [23]. The difference in the amount is

274 consequently high due to the activity of holding and discharging a firearm. Whereas on the  
 275 non-shooter, the result related to the handcuffing scenario for which both hands of the non-  
 276 shooter were usually clutched in the same manner in order to put them behind the back. This  
 277 led to a lower and more consistent level of OGSR being transferred across both hands of the  
 278 non-shooter than that seen in the shooter and control specimens. The large variability was  
 279 also observed in Figure 2b (as demonstrated by the error bars) for both shooter and control.  
 280 This variability reflects the numerous factors influencing the primary transfer of OGSR  
 281 compounds such as the firearm, the ammunition, the plume dispersion at the muzzle and the  
 282 ejection port, the shooter position, skin conditions and environmental conditions. Such  
 283 variations were also observed previous studies [9, 17, 21].

284 Table 3 represents the percentage when the detected responses were normalised to the  
 285 control. The controls represent the largest amount of residue available as they were collected  
 286 immediately after discharging the firearm (100%). A large difference was observed between  
 287 the specimens (Table 3), with the amount detected on the shooter post arrest ranging between  
 288 23% (EC, D) and 68% (DPA, ND). Conversely, that of the non-shooter ranged between 9%  
 289 (N-nDPA, EC, D) up to 55% (DPA, ND).

290

291 **Table 3. Scenario 1: Average percent of the level of OGSR detected when normalised to Control.**  
 292 **D= dominant hand, ND= non-dominant hand.**

	N-nDPA		DPA		EC		AVERAGES
	D	ND	D	ND	D	ND	
Control	100%	100%	100%	100%	100%	100%	100%
Shooter	25.7%	27.3%	46.9%	68.1%	22.8%	42.5%	38.9%
Non-shooter	8.6%	21.0%	24.1%	55.4%	8.4%	22.4%	23.3%

293

294 When comparing the overall averages (Table 3), it was observed that after the arrest scenario  
 295 an amount corresponding to 39 % of the control were still observable from the shooter, while  
 296 on the arrested non-shooter, the amount detected after secondary transfer was about 23 %,   
 297 suggesting that a pollution of a non-shooter from shooter who proceeded to the arrest was  
 298 significant.

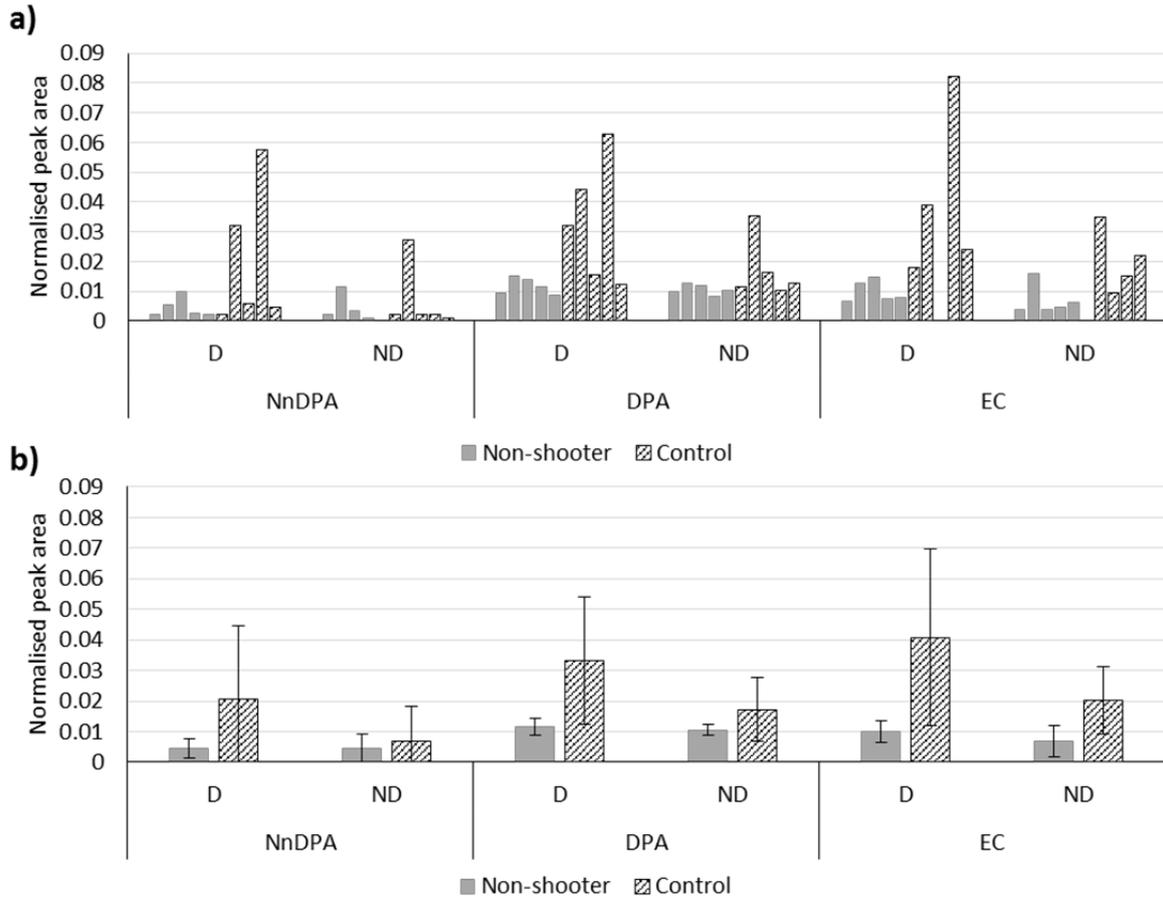
299 Similar trends were observed by Gassner et al. [17] with detection of OGSR on a  
300 non-shooter after an arrest scenario. The study involved the use of a different calibre  
301 (9 mm Luger) with the arrest scenario conducted differently as the non-shooter was  
302 handcuffed on the ground and then helped to get back up. They identified that a significant  
303 amount of OGSR (41.9% for *N*-nDPA) was transferred during an arrest simulation. As they  
304 sampled both hands on the same GSR stub [17], the results from the present study (e.g. D and  
305 ND) were summed together for comparison purposes, and a secondary transfer of 29.6% for  
306 *N*-nDPA was found. Considering the large variability observed between discharges, the  
307 difference in the observed secondary transfer is likely to arise from the simulations and the  
308 way the arrests were conducted. In [17], the fact that the non-shooter was lying down and  
309 helped to get back up may result in a longer and more vigorous contact, which may  
310 ultimately lead to a larger amount of OGSR being transferred.

311

### 312 3.2 Scenario 2: Firearm handling

313 In Scenario 2, a firearm was discharged three times and then handled by a non-shooter for  
314 about 10 minutes without further discharges. The holding activity was not restricted and the  
315 non-shooter also manipulated the firearm by opening and closing the breech. In Figure 3a and  
316 b, it was observed that *N*-nDPA, DPA and EC were successfully detected on the hands of the  
317 non-shooter, confirming that secondary transfer was possible through handling of the firearm,  
318 with OGSR detected in all 5 replicates. The amount detected was consistently lower than that  
319 of the control (Figure 3a). Figure 3b represents the average amount (normalised response) for  
320 each participant (non-shooter and shooter) and the error bars reflect the standard deviations.

321 After discharges, OGSR traces might deposit onto the body of the firearm, generating an  
322 accumulation of residues on its surface. Furthermore, the firearm is typically not cleaned  
323 frequently, favouring the accumulation of GSR on its outer part. The source of the OGSR  
324 traces detected on the non-shooter hands is, therefore, likely to arise from the OGSR  
325 background present on the firearm during the holding contact and manipulations.



326

327 **Figure 3. Scenario 2: Firearm handling. Level of OGSR detected (normalised response) from both hands**  
 328 **of each participant. D= dominant hand, ND= Non-dominant hand. a) Each replicates separately (n=5);**  
 329 **b) Averaged amount; the error bars represent the standard deviation. The “non-shooter” represents the**  
 330 **individual who handled the firearm; “Controls” represent the amount detected from the shooter**  
 331 **immediately after three discharges, without having entered in contact with any other surfaces.**

332

333 It is interesting to observe that for *N*-nDPA on the non-dominant hand of the non-shooter  
 334 (Figure 3), handling the firearm resulted in a similar amount of OGSR being transferred to  
 335 the amount detected in control specimens. Due to the construction of the firearm, the position  
 336 of the ejection port (on the right) and the position of the hands while discharging the firearm,  
 337 the non-dominant hand is often less exposed to the GSR plume than the dominant hand.  
 338 Therefore, a significant portion of the total amount of OGSR transferred onto the non-  
 339 dominant hand might arise from the contact with the grip of the firearm as it usually acts as a  
 340 support when holding the firearm.

341 Consequently, the secondary transfer of OGSR when handling a firearm might be a main  
 342 contributor to the deposition of OGSR on the non-dominant hand. However as the non-  
 343 shooter held the firearm without any restriction, it happened that the firearm was passed

344 between the two hands and such actions made the firearm to be held with the non-dominant  
 345 hand. Such manipulations usually do not occur while discharging as the weapon is held by  
 346 the dominant hand and supported by the non-dominant hand. This activity might have likely  
 347 contributed to the secondary transfer on the non-dominant hand. Furthermore, the duration of  
 348 the contact was longer during the scenario (about 5-10 minutes) to that of the controls, where  
 349 the specimens were collected immediately after discharge. A prolonged contact would also  
 350 impact the level of OGSR transfer onto the surface of the hands.

351 When comparing the trends, Table 4 illustrates the percentage of OGSR detected on both  
 352 hands of the non-shooter normalised to the control. On the dominant hand, an average  
 353 between 22% and 35% was detected. While on the non-dominant hand, an average amount  
 354 ranging between 33% and 65% was detectable (Table 4). On average, an amount of 40 %,  
 355 when compared to the control specimens, was still detected after handling the firearm. The  
 356 results emphasise that handling a firearm for several minutes, without discharging it, is  
 357 sufficient to successfully transfer OGSR traces in a substantial amount.

358

359 **Table 4. Scenario 2: average Percent of the level of OGSR detected when normalised to Control.**  
 360 **D= dominant hand, ND= non-dominant hand.**

	N-nDPA		DPA		EC		AVERAGE
	D	ND	D	ND	D	ND	
Control	100%	100%	100%	100%	100%	100%	100%
Non-shooter	21.7%	65.2%	35.1%	61.3%	24.1%	33.4%	40.2%

361

362 Gassner et al. also observed a secondary transfer of OGSR by only touching the surface of a  
 363 firearm when displacing it [17]. They observed that the amount detected after touching the  
 364 firearm was lower than after the arrest, while in this study the opposite trend was observed.  
 365 The different conditions of the firearm manipulation and the timeframe of the experiment is  
 366 likely the source of the different trends observed between the two studies. Indeed, their  
 367 experiment involved displacing a firearm without any further handling, whereas in the  
 368 present study, the non-shooter was allowed to manipulate the firearm, including opening and  
 369 closing the breech. Opening and closing the breech provides access to additional sources of  
 370 OGSR inside the weapon, leading to a potentially higher secondary transfer. The second  
 371 substantial factor is the contact duration. In their study, contact was about 10 seconds [17],

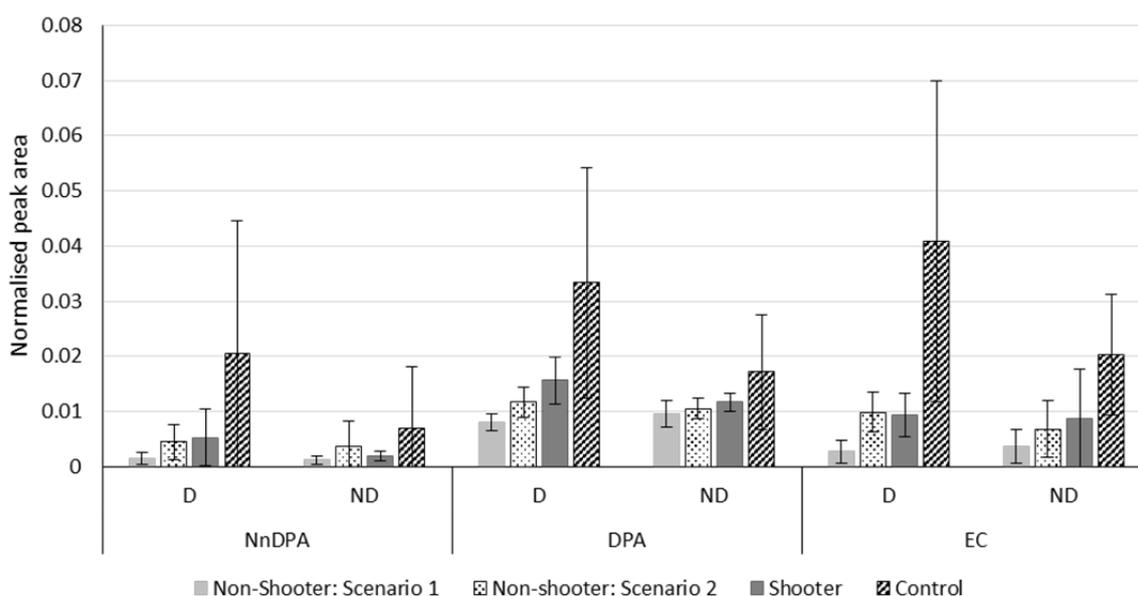
372 while here the non-shooter held the weapon 5-10 minutes. Such difference in the duration of  
373 the contact with the firearm may greatly influence the amount of OGSR transferred. A longer  
374 contact may result in a larger amount of OGSR transferred.

375

### 376 3.3 Scenarios comparison

377 Figure 4 illustrates the amount detected across the two scenarios performed in this study. It  
378 was found that a secondary transfer of OGSR occurred following both the arrest and firearm  
379 handling experiments, with similar trends observed across the three compounds detected. A  
380 substantial reduction of the response detected between the controls and the non-shooter after  
381 the arrest was observed (Figure 4).

382



383

384 **Figure 4. Comparison between scenario 1 and 2. D= dominant hand, ND= non-dominant hand.**

385

386 It was also observed that handling a firearm resulted in a higher degree of secondary transfer  
387 (Table 4, average of 40% observed) than being arrested by the shooter (Table 3, average of  
388 23% observed). The amount detected on the shooter after the arrest scenario is similar to the  
389 non-shooter after having handled a firearm (Figure 4, Table 3 and Table 4, 38.9% and 40.2%  
390 respectively). Minor exceptions were seen for DPA (D) for which a larger response was  
391 observed on the shooter when compared to the non-shooter (firearm handling). The opposite  
392 results was observed with N-nDPA on the non-dominant hand, of which a difference of

393 almost 38% was observed between the two scenarios (27% in Table 3 and 65% in Table 4).  
394 This is due to a high amount detected on the hand of the non-shooter after handling the gun  
395 and a low amount detected on the shooter after the arrest. These results emphasise the  
396 influence of the shooting process and the associated variability in the amount of OGSR  
397 recovered and detected. Finally, on average, the largest responses detected arose from  
398 specimens taken from the controls, which were taken from the shooter immediately after the  
399 firearm discharges and without any contact with any other surfaces.

400 In summary, the results of this study demonstrate that the risk of secondary transfer is  
401 significant. From an investigation and interpretation perspective, it is recommended that  
402 precautions be taken to minimise or detect instance of secondary transfer to avoid false  
403 positive results. Because of the numerous factor involved in the formation, deposition and  
404 analysis of OGSR, as well as the unique sequence of activities that may lead to different  
405 extent of secondary transfer, it is essential to consider assessing every investigation following  
406 a  
407 case-by-case approach in order to ensure to interpret OGSR results in an appropriate manner  
408 in view of the circumstances surrounding the investigation [11, 30].

409 The results suggest that practice procedures should include documentation of contacts  
410 between officers, firearms and the POI(s). Further, the results suggest that officers' firearm,  
411 handcuffs, clothes and other equipment should be cleaned and decontaminated regularly. It  
412 would be valuable for contact records to be provided to the forensic scientist for the  
413 evaluation of the OGSR evidence. This will allow forensic scientists to approach the  
414 interpretation of the results with a better understanding of the context in which the specimens  
415 were obtained. For instance, a police officer who discharged a firearm shortly before or  
416 during an intervention should not enter into contact with POI(s) in order to restrict possible  
417 pollution. If such situation occurs and is unavoidable, sampling the police officer who  
418 arrested the POI might be valuable. Such specimens could be used as controls to assess the  
419 degree of OGSR pollution of the police officer as soon as possible. Indeed detecting early in  
420 the investigative process the possibility that specimen analysis results may arise from a  
421 pollution would allow forensic scientists to interpret the results in the appropriate manner, by  
422 taking into account the possibility of a secondary transfer. It may ultimately reduce the risk of  
423 false positive, which would have a considerable impact on the outcomes of the forensic  
424 investigation.

425

426 In the global context of GSR, no direct comparison can be performed between IGSR and  
427 OGSR because of the different formation process, composition as well as transfer and  
428 persistence mechanism. Several studies have examined the secondary transfer of IGSR [12-  
429 15]. In the context of an arrest scenario, Charles and Geusens [12] have studied two separate  
430 simulations involving a low and high level of contamination of the police officers. For the  
431 low contamination simulation, in average, 2 characteristic particles (Pb-Ba-Sb) were detected  
432 on the shooter while only 1 was detected on the non-shooter, resulting in 33% of transfer  
433 [12]. For the high simulation, however, an average of 66 particles were found on the shooter,  
434 while only 3 on the non-shooter (4% of transfer) [12]. Girvan et al [15] have also studied the  
435 secondary transfer of IGSR through the arrest process. They found a secondary transfer of  
436 40% for the characteristic Pb-Ba-Sb particles [15]. Such studies highlight the inherent  
437 variability of IGSR deposition and analysis, which was also observed for OGSR in this study.

438 Despite the differences in the formation, transfer and analysis between IGSR and OGSR. The  
439 studies on the secondary transfer of IGSR [12, 15] have shown similar trends when  
440 compared to the results observed for OGSR presented in this study, emphasising that a  
441 secondary transfer of both IGSR and OGSR is possible in the context of an arrest. The  
442 differences are likely to arise from the different retention and transfer properties of IGSR  
443 when compared to OGSR. Consequently, such results stress on the cautiousness that have to  
444 be kept in mind when interpreting GSR evidence, especially when a low number of particles  
445 of IGSR or a low amount of OGSR are detected. This study has emphasised the necessity and  
446 the importance of assessing the secondary transfer of OGSR. Such results might be used in  
447 order to improve the interpretation of such traces in the context of forensic investigations. An  
448 interpretative model can be developed through the use of the Bayesian theorem. Such  
449 probabilistic framework would enable forensic scientists to assess the likelihood ratio (LR)  
450 for OGSR outcomes in the light of the propositions of interest as well as the case  
451 circumstances. The advantages of the Bayesian theorem approach is that it allows forensic  
452 scientists to take into account the possibility of a secondary transfer as well as the persistence  
453 when calculating the LR.

454

#### 4. Conclusion

455  
456 This study evaluated and explored critical questions regarding the secondary transfer of  
457 OGSR between a shooter, who previously discharged a firearm, and a non-shooter, with no  
458 immediate prior contact with a firearm. Two scenarios were investigated, one relating to the  
459 arrest of the non-shooter by the shooter, the second one approach the handling of a firearm by  
460 the non-shooter without discharging it. A secondary transfer occurred during both scenarios,  
461 with OGSR detected in each specimen collected from the non-shooter following an arrest  
462 process. OGSR was also detected when a non-shooter handled a firearm with similar levels  
463 of OGSR detected when compared to a shooter who discharged their firearm followed by  
464 conducting an arrest scenario. In average, the amount of OGSR detected did not exceed the  
465 amount identified on the shooter who was sampled immediately after discharge. It is essential  
466 to assess such scenarios in order to develop a better understanding of OGSR behaviour. In  
467 addition, such research provides complementary information to forensic scientists in order to  
468 improve the interpretation process. When approaching the assessment of traces such as  
469 OGSR, questions such as secondary transfer and persistence become essential.

470 In practice, standardised protocols restricting or mitigating contact between police officers  
471 who discharged a firearm and the POI are advisable as well as recommending that firearms  
472 are cleaned on a regular basis to limit the accumulation of OGSR. Additionally, this  
473 information and the context of the arrest should be documented and provided to the forensic  
474 scientist for the evaluation of OGSR results. Such information allows the results of the  
475 analysis to be included into the global context of the case, to be combined with other findings  
476 such as IGSR particles. It also allows to take into account the chronology of the event, the  
477 time of sampling and potential sources of pollution such as an arrest process undertaken by  
478 contaminated officers.

479 In addition, the results presented in this study can inform the evaluative framework. The  
480 secondary transfer can be included in the interpretation process of OGSR in order to provide  
481 a more meaningful assessment of such traces. Doing so, this would allow to have a better  
482 understanding of such findings by including them in the global context of the case under  
483 investigation.

484

## 485        **5. Ethics**

486        UTS Human Research Ethics Committee (HREC) approved the presented research  
487        (application number 2015000480).

488

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496

## 497        **7. References**

- 498        [1] Avery D, Watson RT. Regulation of lead-based ammunition around the world. Ingestions  
499        of lead from spent ammunition: implications for wildlife and humans. 2009;161-8.  
500        [2] MacCrehan WA, Smith KD, Rowe WF. Sampling protocols for the detection of  
501        smokeless powder residues using capillary electrophoresis. *Journal of forensic sciences*.  
502        1998;43:119-24.  
503        [3] Laza D, Nys B, Kinder JD, Kirsch-De Mesmaeker A, Moucheron C. Development of a  
504        Quantitative LC-MS/MS Method for the Analysis of Common Propellant Powder Stabilizers  
505        in Gunshot Residue. *Journal of Forensic Sciences*. 2007;52:842-50.  
506        [4] Benito S, Abrego Z, Sánchez A, Unceta N, Goicolea MA, Barrio RJ. Characterization of  
507        organic gunshot residues in lead-free ammunition using a new sample collection device for  
508        liquid chromatography–quadrupole time-of-flight mass spectrometry. *Forensic Science*  
509        *International*. 2015;246:79-85.  
510        [5] Cascio O, Trettene M, Bortolotti F, Milana G, Tagliaro F. Analysis of organic  
511        components of smokeless gunpowders: High-performance liquid chromatography vs. micellar  
512        electrokinetic capillary chromatography. *Electrophoresis*. 2004;25:1543-7.  
513        [6] Jane I, Brookes P, Douse J, O'Callaghan K. Detection of gunshot residues via analysis of  
514        their organic constituents. *Proceedings of the international symposium on the analysis and*  
515        *detection of explosives*1983. p. 29-31.  
516        [7] Leggett LS, Lott PF. Gunshot residue analysis via organic stabilizers and nitrocellulose.  
517        *Microchemical Journal*. 1989;39:76-85.  
518        [8] Lloyd JBF. High-performance liquid chromatography of organic explosives components  
519        with electrochemical detection at a pendant mercury drop electrode. *Journal of*  
520        *Chromatography A*. 1983;257:227-36.  
521        [9] Gassner A-L, Weyermann C. LC–MS method development and comparison of sampling  
522        materials for the analysis of organic gunshot residues. *Forensic Science International*.  
523        2016;264:47-55.  
524        [10] Lindsay E, McVicar MJ, Gerard RV, Randall ED, Pearson J. Passive Exposure and  
525        Persistence of Gunshot Residue (GSR) on Bystanders to a Shooting: Comparison of Shooter

526 and Bystander Exposure to GSR. Canadian Society of Forensic Science Journal. 2011;44:89-  
527 96.

528 [11] Maitre M, Kirkbride KP, Horder M, Roux C, Beavis A. Current perspectives in the  
529 interpretation of gunshot residues in forensic science: A review. Forensic Science  
530 International. 2017;270:1-11.

531 [12] Charles S, Geusens N. A study of the potential risk of gunshot residue transfer from  
532 special units of the police to arrested suspects. Forensic Science International. 2012;216:78-  
533 81.

534 [13] French J, Morgan R, Davy J. The secondary transfer of gunshot residue: an experimental  
535 investigation carried out with SEM-EDX analysis. X-Ray Spectrometry. 2013;43:56-61.

536 [14] French J, Morgan R. An experimental investigation of the indirect transfer and  
537 deposition of gunshot residue: Further studies carried out with SEM-EDX analysis. Forensic  
538 Science International. 2015;247:14-7.

539 [15] Girvan J. The Transfer of Gunshot Residue Surrounding Suspect Apprehension  
540 [Bachelor]: Canberra Institute of Technology; 2011.

541 [16] Arndt J, Bell S, Crookshanks L, Lovejoy M, Oleska C, Tulley T, Wolfe D. Preliminary  
542 evaluation of the persistence of organic gunshot residue. Forensic Science International.  
543 2012;222:137-45.

544 [17] Gassner A-L, Manganelli M, Werner D, Rhumorbarbe D, Maitre M, Beavis A, Roux CP,  
545 Weyermann C. Secondary transfer of organic gunshot residues: Empirical data to assist the  
546 evaluation of three scenarios. Science & Justice; 2018.  
547 <https://doi.org/10.1016/j.scijus.2018.08.007>

548 [18] Schwendener G, Moret S, Cavanagh-Steer K, Roux C. Can □contamination□ occur in  
549 body bags?□ The example of background fibres in body bags used in Australia. Forensic  
550 Science International. 2016;266:517-26.

551 [19] Taudte RV, Roux C, Bishop D, Blanes L, Doble P, Beavis A. Development of a UHPLC  
552 method for the detection of organic gunshot residues using artificial neural networks.  
553 Analytical Methods. 2015;7:7447-54.

554 [20] Gassner A-L, Ribeiro C, Kobylinska J, Zeichner A, Weyermann C. Organic gunshot  
555 residues: Observations about sampling and transfer mechanisms. Forensic Science  
556 International. 2016;266:369-78.

557 [21] Maitre M, Horder M, Kirkbride KP, Gassner A-L, Weyermann C, Roux C, Beavis A. A  
558 forensic investigation on the persistence of organic gunshot residues. Forensic Science  
559 International. 2018;292:1-10.

560 [22] Hofstetter C, Maitre M, Beavis A, Roux CP, Weyermann C, Gassner A-L. A study of  
561 transfer and prevalence of organic gunshot residues. Forensic Science International.  
562 2017;277:241-51.

563 [23] Maitre M, Kirkbride K, Horder M, Roux C, Beavis A. Thinking beyond the lab: organic  
564 gunshot residues in an investigative perspective. Australian Journal of Forensic Sciences.  
565 2018:1-7.

566 [24] Taudte RV, Roux C, Beavis A. Stability of Smokeless Powder Compounds On  
567 Collection Devices. Forensic Science International. 2016;270:55-60.

568 [25] Ali L, Brown K, Castellano H, Wetzel SJ. A Study of the Presence of Gunshot Residue  
569 in Pittsburgh Police Stations using SEM/EDS and LC-MS/MS. Journal of Forensic Sciences.  
570 2016;61:928-38.

571 [26] ICH. Harmonised Tripartite Guideline. Validation of analytical procedures: text and  
572 methodology Q2 (R1). International Conference on Harmonization, Geneva, Switzerland  
573 2005. p. 11-2.

- 574 [27] Taudte RV, Roux C, Blanes L, Horder M, Kirkbride KP, Beavis A. The development  
575 and comparison of collection techniques for inorganic and organic gunshot residues.  
576 Analytical and Bioanalytical Chemistry. 2016;408:2567-76.
- 577 [28] Brereton RG. Chemometrics for pattern recognition: John Wiley & Sons; 2009.
- 578 [29] Varmuza K, Filzmoser P. Introduction to multivariate statistical analysis in  
579 chemometrics: CRC press; 2016.
- 580 [30] Romolo FS, Margot P. Identification of gunshot residue: a critical review. Forensic  
581 Science International. 2001;119:195-211.

582