Science & Justice 65 (2025) 101310

Contents lists available at ScienceDirect

Science & Justice

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

Short Communication

Using fingermark powders and lifters on rhino horn to support anti-poaching efforts

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ARTICLE INFO

Keywords:
Fingermarks
Wildlife forensics
Trafficking
Rhino poaching
Rhino Horn

ABSTRACT

Wildlife poaching and the trade of wildlife items is a large area of illegal business that is alleged to be worth hundreds of billions of dollars. However, wildlife forensics remains an understudied field even though the consequences of poaching are catastrophic and can lead to the spread of zoonotic disease and a decrease in biodiversity. Even though fingermark analysis is cost-effective, easy to deploy in the field and has a long history of securing criminal convictions in court, wildlife forensics is mainly limited to DNA-based techniques. Rhinos are one of the most trafficked animals in the world, with some species being hunted to near extinction.

To reduce rhino poaching and tackle the trade of rhino horn, this research used various fingerprint powders, including standard and fluorescent powders, to visualise fingermarks deposited on rhino horn. Eight fingermark powders were tested, including four traditional powders (i.e., magneta-flake, aluminium, and reduced scale black and white powders) and four fluorescent powders (i.e., red-and-green-fluorescent powders, along with Foster + Freeman's fpNatural® 1, and fpNatural® 2,). The rhino horn sample used in this study was cut in half, and latent fingermarks were enhanced on both the rough and smooth sides of the rhino horn. Lifting tape and black gelatine were employed to lift enhanced fingermarks, and fingermarks were photographed on Foster + Freeman's DCS®4 (for standard powders) and DCS®5 (for fluorescent powders).

Black gelatine was found to be significantly superior to tape in preliminary trials, and therefore, only black gelatine was used to lift powdered fingermarks after initial experiments. This study highlights that metallic powders (namely aluminium and magneta flake), and all fluorescent powders are effective options to enhance latent fingermarks on rhino horn, yielding marks suitable for comparison and search on fingermark databases. These fingermarks can be lifted using black gelatine without significant loss of fingermark detail. Due to the rough nature of the surface, fingermarks were significantly inferior in quality on the rough outer surface than the smooth inner cut section of the rhino horn. The recommendations made in this study can have an impact on the illegal wildlife trade when deployed in the field, providing more tools to assist front line anti-poaching agents and leading to an increase in convictions.

1. Introduction

The illegal trade of wildlife is an industry (alleged to be worth billions of USD annually [1]) that relies on the exploitation and relocation of protected animal and plant species [2]. The consequences of exploiting protected wildlife include loss of biodiversity, the spread of disease, human injury, a decline in animal welfare, and cultural loss [1,3–8]. Poaching can also result in severe environmental consequences, including deforestation and the disruption of carbon stocks [9]. Demand and subsequent supply of wildlife items often reach unsustainable and damaging levels [10]. The pain and suffering inflicted on animals has become an increasing concern among the public [11]. Animals predominantly affected by wildlife trafficking and exploitation include wild birds [12,13], elephants [14], reptiles [15–17], rhinoceroses [18], amongst other victims. Protected plant species can also be victims of wildlife trafficking [19].

Illegal wildlife trafficking takes place globally in urban, suburban and rural environments, particularly in geographical regions of high biodiversity, such as Asia, Africa and Australia [20,21]. Wildlife items are lucrative on the black market, and often worth more by weight

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https://doi.org/10.1016/j.scijus.2025.101310
Received 13 January 2025; Received in revised form 30 June 2025; Accepted 23 July 2025
Available online 31 July 2025
1355-0306/

compared to drugs and weapons [22]. Unfortunately, irreparable damage can be caused by wildlife trafficking syndicates over a relatively short timescale, and these syndicates are often also involved in money laundering, complex fraud, and corruption [23]. Despite the damage these organisations cause, wildlife forensics remains understudied.

Rhinoceroses are megaherbivore ungulates and are one of the most common victims of illegal wildlife trafficking, despite conservation efforts [24]. All extant species of rhino are considered near-threatened, vulnerable or endangered [25]. The overall gross illicit income generated by rhino horn trade at the wholesale level from 2012 to 2021 was estimated to be between USD 874 million – 1.13 billion [26].

Rhino horn is used and consumed in Traditional Chinese Medicine (TCM) and is still being used to treat fever, rheumatism, gout, and other disorders, but it is also used as a symbol of wealth and success [27]. Traditionally, rhino horns were also used to treat other afflictions, such as heart disease and cancer; even though rhino horns were banned for use in TCM by the Chinese government in 1993, people still believe that rhino horn is an effective pharmaceutical ingredient [28]. This is despite biomedical evidence not supporting many of the medical capabilities of the rhino horn (some individuals have also reported negative effects) [29]. In addition to its use in TCM, rhino horn is sold on the black market as carved fine art. Horns are carved into both utilitarian items (such as dishware and cups) and decorative items, like hair accessories and jewellery, all of which can be found in black market auctions [28].

Traditional forensic methods that are typically used in forensic standard procedures have been employed to prevent poaching and catch poachers. Mass spectrometry, infrared spectroscopy and DNA-based identification techniques have been attempted on wildlife samples, but not necessarily validated [25]. Human fingermarks have been visualised from the surface of various wildlife samples for anti-poaching purposes, to varying degrees of success [8]. A variety of powders have been employed to visualise latent fingermarks from the surfaces of feathers and eggs of protected birds, elephant ivory, live snakes, and gelatine lifters have been used to lift fingermarks from samples including crocodile skin and pangolin scales [8].

It is important to note that forensic methods used on wildlife samples under laboratory conditions must be validated under environmental conditions, in order to be useful in a practical operational context. For example, the provision of fingerprinting kits and training to crime scene practitioners may not be sufficient alone, and additional resources such as scanners may need to be employed to build forensic databases [30]. Powders and lifting tools are ideal for practical use on remote wildlife crime scenes, as they are small, portable and inexpensive forensic solutions that can be used to obtain forensic evidence when there is limited access to laboratory resources.

Methods for obtaining forensic evidence from trafficked rhino horn have not yet been explored, although fingermark visualisation techniques have been applied to similar substrates. Cyanoacrylate fuming with dye staining and Leucocrystal Violet have been used on big game antlers and horns, while chemical techniques and fingerprint powders have been trialled on deer antlers, with magnetic powder proving most successful [31,32]. As fingerprint powders have not yet been tested on rhino horn specifically, this study aims to identify the most effective fingerprint analysis technique for rhino horn, therefore addressing a critical knowledge gap for wildlife forensic investigations.

2. Materials and methods

The rhino horn (species unknown) used in this experiment was donated by the Museum of Life Sciences for research purposes. This horn was split in two prior to donation to the museum, with a vertical clean cut starting from the tip of the horn down to the base, revealing one rough exterior side and one smooth interior side (Figs. 1 and 2). In this work, both sides were used to determine how the roughness of the surface would impact the quality of the fingerprints deposited and which fingerprint powder would be most effective on both types of surfaces.

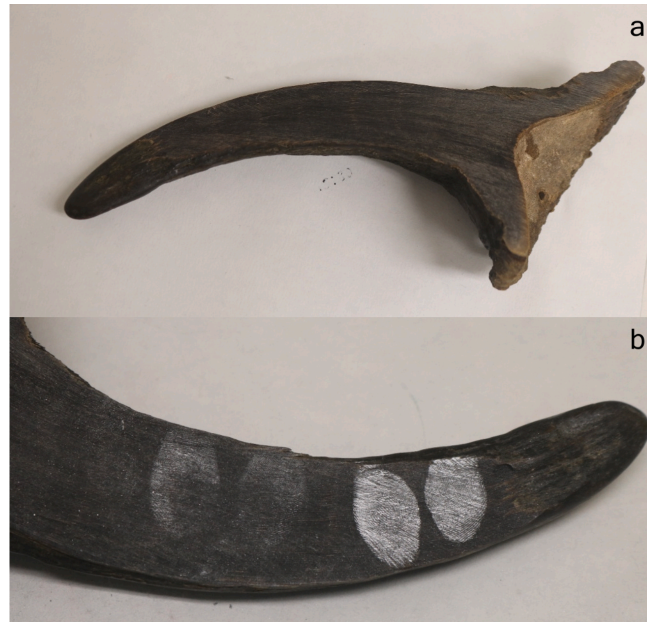

Fig. 1. Pictures displaying one half of the cut rhino horn that was used throughout these experiments with no fingermark enhancement (a) and fingermarks visualised with aluminium powder on the interior surface of the cut rhino horn (b).

The species and the origin of the horn being unknown is a limitation of this experiment and work should be done to validate successful methodologies across different species of rhino's horn. This was an important aspect as rhino horn is often cut into pieces to generate more profit, or into discs or blanks during the trafficking process to make transport of the exhibits easier and less conspicuous [33]. Altering the size and shape of the rhino horn exposes the interior regions.

Two reduced-scale powders (SupraNano black and white powders) and two metallic powders (aluminium and magneta flake) were obtained from SceneSafe™ (Burnham-on-Crouch, England). Red and green-fluorescent powders were acquired from Crime Scene Investigation Equipment Ltd (Milton Keynes). fpNatural 1 and 2® (referred to as fp 1 and fp 2 respectively) were obtained from Foster + Freeman® (Evesham). A zephyr fibreglass fingermark brush was acquired from Forensics Source™ (Jacksonville), and the magnetic wand was bought from FingerPrintPads.com (Santa Ana). Squirrel brushes were from SceneSafe™, as was a Marabou feather brush. Forensic lifting tape (crystal tabs) and gelatine lifters (black) were purchased from SceneSafe™.

2.1. Fingermark collection

Fingermarks can vary due to a number of factors such as age, ethnicity, activity of the donor, and sex [34]; to account for these variables, ten fingermark donors over the age of 18 (five males and five females) were recruited for fingermark deposition to mitigate these factors. Ethical clearance for the collection and storage of fingermarks was granted by the Biomedical Sciences, Dentistry, Medicine and Natural & Mathematical Sciences Research Ethics Subcommittee (Reference Number: HR/DP-21/22-23072). All research was conducted in accordance with the Human Tissue Act 2004 and all donors signed consent forms before depositing fingerprints.

Donors were asked to refrain from washing their hands one hour prior to fingermark deposition. They were then instructed to rub their hands to evenly distribute oils and contaminants before depositing two thumbprints on the rhino horn with three seconds of contact and moderate pressure using both their thumbs. Thumbprints alone were chosen due to limitations of the available surface area of the horn to deposit

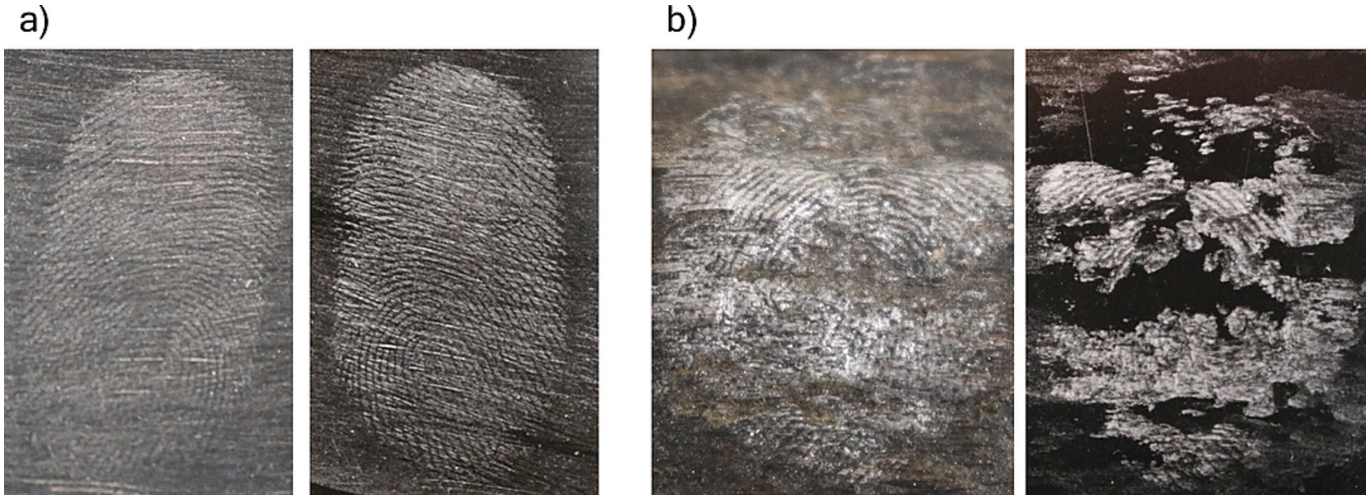

Fig. 2. Pictures displaying fingermarks enhanced with aluminium powder (a successful standard powder) on the smooth a) and rough b) sides of rhino horn, pre (left) and post (right) lifting with black gelatine lifter.

fingermarks. Marks were powdered 30 mins after deposition, similar to the method used by Weston-Ford et al. [35] in their fingerprint research on ivory.

2.2. Powdering and lifting

Fingermarks were powdered in a laboratory environment and under a fume hood. Prints developed with standard powders were then photographed using a Canon DSLR DS126571 EOS 750D. These were subsequently lifted with black gelatine lifters and lifting tape before being secured onto acetate using tape. Gelatine lifters were cut to approximately 2 × 2 cm for precise application to the fingermark deposited on the rhino horn. Experiments included a preliminary trial of eight powders and two lifters (using three fingermark donors), and successful treatments were taken forward to trials with ten fingermark donors.

2.2.1. Fingermark grading

To accommodate the needs of both researchers and operational workers, fingermarks were graded via two different grading schemes. The Home Office recommends a 0–4 grading scheme for studies involving fingermarks (Table 1).

The second "operational" grading scheme is used by police forces practically and determines whether it is possible to search for the mark on fingermark databases, and/or compare a fingermark with a mark visualised e.g. at a crime scene (Table 2).

The quality of a fingermark has also been shown to be influenced by the individual grading the fingermark, which can cause introduce bias in these types of experiments [34]. Therefore, fingermark grades were verified by fingermark experts in the City of London Police.

2.2.2. DCS®4 imaging and enhancement

Once fingermarks were visualised with a conventional powder, they were lifted with a forensic lifting tool (either crystal tabs tape or black gelatine lifter) and were then visualised using the DCS®4 imaging system. Lifts were photographed on the DCS®4 system whilst being illuminated by white light. These marks were then photographed against an ISO accredited and calibrated 30 cm ruler for scale and graded using both grading systems (Tables 1 and 2) with automatic enhancements applied to correct image brightness, contrast, and gamma.

Table 1
Commonly used fingermark grading chart recommended by the Home Office [36]. This grading scheme is utilised by researchers and academics in scientific studies [37].

Grade	Level of Detail
0	No Mark Evidence Found
1	Evidence of Contact but no Mark Detail
2	Less than 1/3 of Print Showing Clear Ridge Detail
3	Between 1/3 and 2/3 of Print Showing Clear Ridge Detail
4	More than 2/3 of Print Showing Clear Ridge Detail

Table 2
Metric utilised operationally by police forces for grading fingermarks.

Grade	Level of Detail
Insufficient	Insufficient detail for comparison with another fingermark
Comparison	Sufficient detail for comparison with another mark, but not enough detail to conduct a search on fingermark databases
Comparison and Search	Sufficient detail for both comparison, and searching on databases

2.2.3. DCS®5 imaging and enhancement

All marks enhanced with fluorescent powders were visualized using the DCS®5 imaging system. The DCS®5 is the updated version of the DCS®4 and has the capability to visualise marks enhanced with fluorescent powders that require illumination in the non-visible light spectrum −namely UV (300–400 nm) and IR (700 nm to 1000 nm). The fluorescent powders were visualised under the conditions summarised in Table 3 and in in accordance with the manufacturer's recommendations.

Automatic image balancing was applied to the images on the DCS®5, which corrects the contrast, brightness and gamma of the image. Images were then calibrated against a validated ruler and then graded (as per Tables 1 and 2).

2.2.4. Rhino horn cleaning procedure

The rhino horn was cleaned with a small amount of dish soap and lukewarm water between each treatment to avoid cross-contamination

Table 3
Settings used for visualising marks enhanced with fluorescent powders on the DSC®5.

Powder	Excitation Wavelength	Filter	Camera Settings
fpNatural 1®	420 nm	Schott 780	1/1.3 F5.6
fpNatural 2®	640 nm	Sharp Cut 850	1/80 F5.6
Red/Green Fluorescent	365 nm	Schott 420	1/6 F11

between powders. This cleaning processes followed the protocol established by the Canadian Conservation Institute [38]. Cleaning was needed to allow all experiments to be conducted on the same horn. Soft blue roll paper was used to dry the horn after cleaning. This cleaning procedure was used on pangolin scales and was found to have negligible effects on subsequent marks deposited and enhanced using powders [39].

2.2.5. Data analysis

Results were analysed by using the Chi-Squared goodness of fit test in IBM SPSS v23 software to determine if there were any significant differences in the ability to visualise fingermarks deposited on rhino horn with different powders. Additionally, a Wilcoxon signed rank test was used to assess whether the use of gelatine lifters significantly improved or reduced the quality of fingermarks developed with standard powders.

3. Results

Both tape lifter and gelatine lifter were considered when lifting powdered fingermarks from rhino horn, as well as eight different fingermark powders, as part of preliminary experiments with three fingermark donors. The most effective lifting tool and powders were taken forward to experiments involving ten fingermark donors.

3.1. Comparison of lifting tools

The effectiveness of tape and gelatine lifts was evaluated in a preliminary screening stage to determine whether one was more suitable to lift fingermarks on the rhino horn, on both inside and outside surfaces. Fingermarks powdered with eight powders from three donors (two females, one male) were compared. The fingermarks were graded both before being lifted from the horn (pre-lift) and after being lifted from the horn (post-lift). Results seen in Table 4 are expressed using the Home Office grading (a) and operational grading (b) schemes.

The results indicate that there is a statistically significant difference between the quality of fingermarks lifted with gelatine and those lifted with tape in favour of gelatine when using the Home Office grading scheme ($X^2 = 4.449$, df = 1, p = 0.035). When these same fingermarks are graded with the operational grading system, comparing the frequency of both "comparison" and "comparison and search" there are no statistically significant differences between the gelatine and the tape ($X^2 = 1.714$, df = 1, p = 0.190). However, when comparing the frequency of excellent ("comparison and search" alone) black gelatine lifter was found to be statistically superior to crystal tab tape ($X^2 = 5.712$, df = 1, p = 0.017). For these reasons, black gelatine lifter was deemed more suitable for fingermark lifting on this wildlife sample. Crystal tabs have been shown to be a less flexible lifting tool, especially in comparison to black gelatine lifter [39]. When the less flexible tape lifter was used, the tape was unable to fully penetrate into the deeper grooves on the outside of the rhino horn, leading to the ridge detail becoming interrupted. The black gelatine lifter was better suited to the irregular topography of the surface of the rhino horn.

Table 4
Comparison of fingermark grades post-lifting with black gelatine and lifting tape using the Home Office grading scheme (a) and operational grading scheme (b).

a)			b)		
Home Office Grade	Gelatine (Post-Lift)	Tape (Post-Lift)	Operational Grade	Gelatine (Post-Lift)	Tape (Post-Lift)
0	35	43	**Insufficient**	81	87
1	11	24	**Comparison**	7	8
2	32	21	**Comparison and Search**	8	1
3	11	7			
4	7	1			
Total	**96**	**96**	**Total**	**96**	**96**

3.2. Preliminary Testing of standard powders

Standard powders (four in total) were compared pre- and post-lifting with black gelatine to determine promising powders for further experiments (Tables 5 and 6 respectively). Analysis was conducted using a Home Office grading scheme (Table 5) and an operational grading system (SI 1).

There is a statistically significant difference in the quality of powdered fingermarks on the rhino horn ($X^2 = 31.661$, df = 3, $p < 0.001$) according to the Home Office grading scheme. Aluminium and magnetic powder are not statistically significantly different from each other ($X^2 = 0$, df = 1, p = 1.000). SupraNano black powder generates significantly poorer results compared to aluminium ($X^2 = 22.756$, df = 1, $p < 0.001$) and magnetic ($X^2 = 22.756$, df = 1, $p < 0.001$) powders. SupraNano black powder has also shown significantly inferior performance when compared to SupraNano white powder ($X^2 = 5.4$ df = 1, p = 0.020). SupraNano white powder is also significantly less effective than both aluminium and magnetic powder ($X^2 = 8.333$, df = 1, p = 0.004). The operational grading scheme was in agreement with the Home Office grading scheme (SI Table 1).

There is a statistically significant difference in the quality of lifted powdered fingermarks on the rhino horn ($X^2 = 10.910$, df = 3, p = 0.012) according to the Home Office grading scheme. Aluminium and magnetic powder are not statistically significantly different to each other ($X^2 = 0.375$, df = 1, p = 0.540). SupraNano black powder generates significantly poorer results compared to aluminium ($X^2 = 8.195$, df = 1, p = 0.004) and magnetic ($X^2 = 11.077$, df = 1, $p < 0.001$) powers. SupraNano white powder is not significantly different from both aluminium ($X^2 = 0.444$, df = 1, p = 0.505) and magnetic powder ($X^2 = 1.613$, df = 1, p = 0.204). SupraNano black powder is also significantly inferior at visualising latent fingermarks on rhino horn when compared to SupraNano white powder ($X^2 = 5.581$ df = 1, p = 0.018). Since the two white powders were not consistently as effective as the metallic powders both pre-and post-lift and in particular across both grading schemes (SI Table 2), both SupraNano white and SupraNano black powders were discarded from further experiments.

Typically, SupraNano black and SupraNano white are used on either light-coloured (black powder) or dark-coloured (white powder) smooth non-porous surfaces to provide enhanced contrast, and they may be lifted with a black or white gelatine lifter. However, carbon-based powders have shown to be effective on rough and textured porous organic samples; black carbon powders were effective on mammalian skin [40], and both black and white carbon-based powders visualised latent fingermarks on snakeskin [15]. Despite this, these reduced-scale powders produced significantly inferior results compared to the other powders, indicating that these powders are not well suited for the rough, porous surface of the rhino. Even though both snakeskin and rhino horn are keratin-based organic materials, it is important to note that the topography of the rhino horn is highly irregular, whereas snakeskin is a lot flatter in comparison. Furthermore, snakeskin has been shown to have a nanometre-thin lipid layer on its epidermis, which could further influence how latent fingermarks interact with the wildlife sample [41].

Table 5
Tables displaying the number of fingermarks visualised with standard fingerprint powders pre-lifting at each Home Office grade per four powders. The total number of fingermarks for each powder is 24.

Grade	Aluminium	Magnetic	SupraNano White	SupraNano Black
0	0	0	0	18
1	0	0	3	1
2	7	7	14	4
3	4	5	1	0
4	13	12	6	1
Total	**24**	**24**	**24**	**24**

Table 6
Tables displaying the number of fingermarks visualised with standard fingerprint powders post-lifting at each Home Office grade per four powders. The total number of fingermarks for each powder is 24.

Grade	Aluminium	Magnetic	SupraNano White	SupraNano Black
0	0	1	5	24
1	4	7	8	0
2	13	7	6	0
3	3	7	3	0
4	4	2	2	0
Total	**24**	**24**	**24**	**24**

Nonetheless, similar powders remain useful for the enhancement of fingermarks on ivory, as Weston-ford et al. were able to lift fingermarks on elephant ivory using SupraNano black magnetic powder [35]. While ivory is a porous surface, it is significantly smoother than the rhino horn, particularly the rougher outside surface and made up of an outer layer of cementum and a core of dentine (dentinal tubules make up helicoidal arrays) [42]. Rhino horn frays into tubules and growth occurs in building up layers of hard, inert keratinised skin cells into lamellae [43]. These filaments are not homogenous but they are similar to the structure of hair [43], whereas dentine more closely resembles that of teeth [42].

3.3. Comparison of standard powders

The two most successful fingermark powders (aluminium and magneta flake powders) from the preliminary experiment (section 3.2) were carried forward for further experiments, where they were used to visualise fingermarks from ten donors, both pre- and post-lifting with black gelatine lifter.

The results shown in Fig. 3 indicate that the powders do not show any significant difference for fingermarks visualised and graded directly on the horn (pre-lift) ($X^2 = 0.051$, df = 1, p = 0.822). Aluminium and magnetic powders are equally effective for enhanced and lifted fingermarks (post-lift with black gelatine), when visualised under the DCS®4 ($X^2 = 0.050$, df = 1, p = 0.823). There was no significant difference in results pre-and post-lifting according to the Home Office ($X^2 = 1.227$, df = 1, p = 0.268) and the operational grading scheme (**SI Fig. 1**).

This suggests that black gelatine may be utilized directly in the field, as it is considerably more manageable to transport for subsequent analysis compared to rhino horn. It has been observed that the rough texture of rhino horn can result in a loss of detail when lifting gelatine, although these losses frequently account for less than one-third of the overall fingermark size. This could explain why these losses are not deemed significant when employing these grading schemes. It is important to note, however, that gelatine begins to melt above 40 °C [54], particularly when used on a hot substrate. Consequently, the use of gelatine lifters in the field necessitates caution, particularly if the substrate is suspected to be warm.

Aluminium and magnetic powders have been found to be significantly more effective at enhancing latent fingermarks on the rhino horn compared to other standard fingermark powders (namely SupraNano black and SupraNano white). Metallic powders have already been shown to be effective on some keratinous wildlife samples, including for instance pangolin scales [39]. Metallic powders have been effective at fingermark visualisation on multiple substrates, including wildlife samples [12,13], and are suitable for use on rough surfaces.

3.4. Comparison of fluorescent powders (Post-Lift)

The fluorescent powders tested were red and green fluorescent powders, and Foster + Freeman's fp 1 and fp 2. The data is shown in Fig. 4 **and** SI Fig. 2. When conducting a chi square test overall, the data indicates that there is no statistically significant difference in the performance of all fluorescent fingermark powders visualising fingermark detail on rhino horn, using both Home Office (a) ($X^2 = 5.242$, df = 3, p = 0.155) and operational scales (b) ($X^2 = 5.875$, df = 3, p = 0.118). However, when conducting pairwise analysis, fp 1 was found to be significantly less effective than red fluorescent powder ($X^2 = 4.713$, df = 1, p = 0.030 and $X^2 = 4.943$, df = 1, p = 0.026 using the Home Office and operational grading schemes respectively). These fingermarks were visualised with fluorescent powders, lifted with black gelatine lifter, and

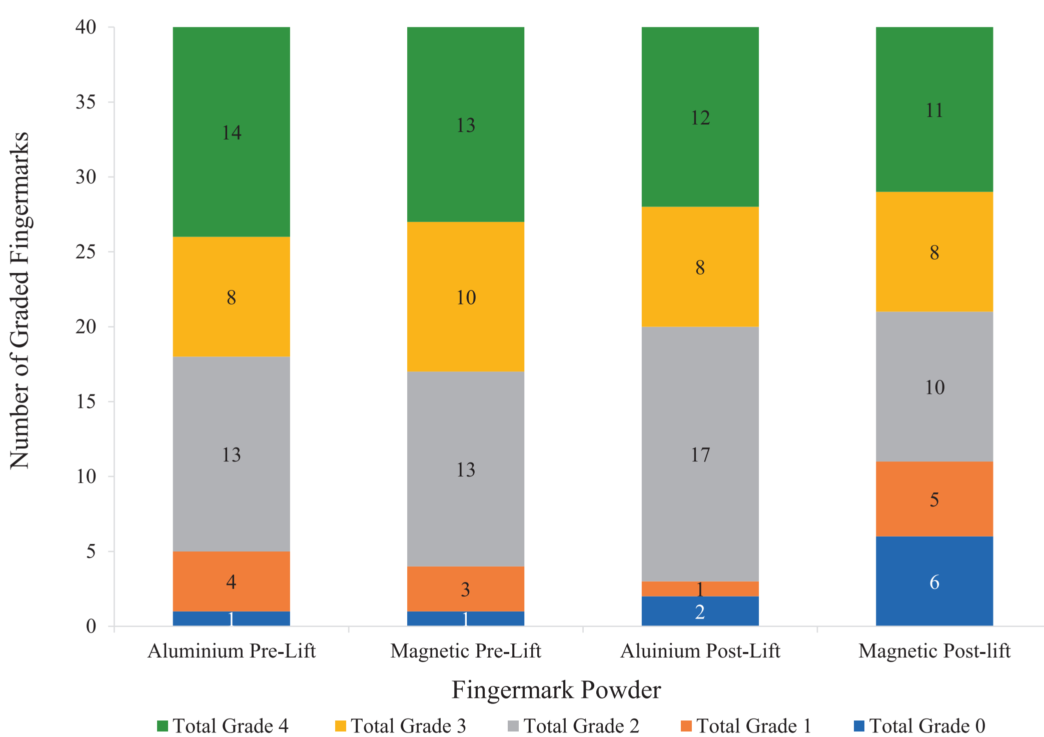

Fig. 3. A stacked bar chart displaying the number of fingermarks visualised with standard powders at each Home Office grade, pre and post lift, for aluminium and magneta flake powders. The total number of fingermarks for each powder was 40.

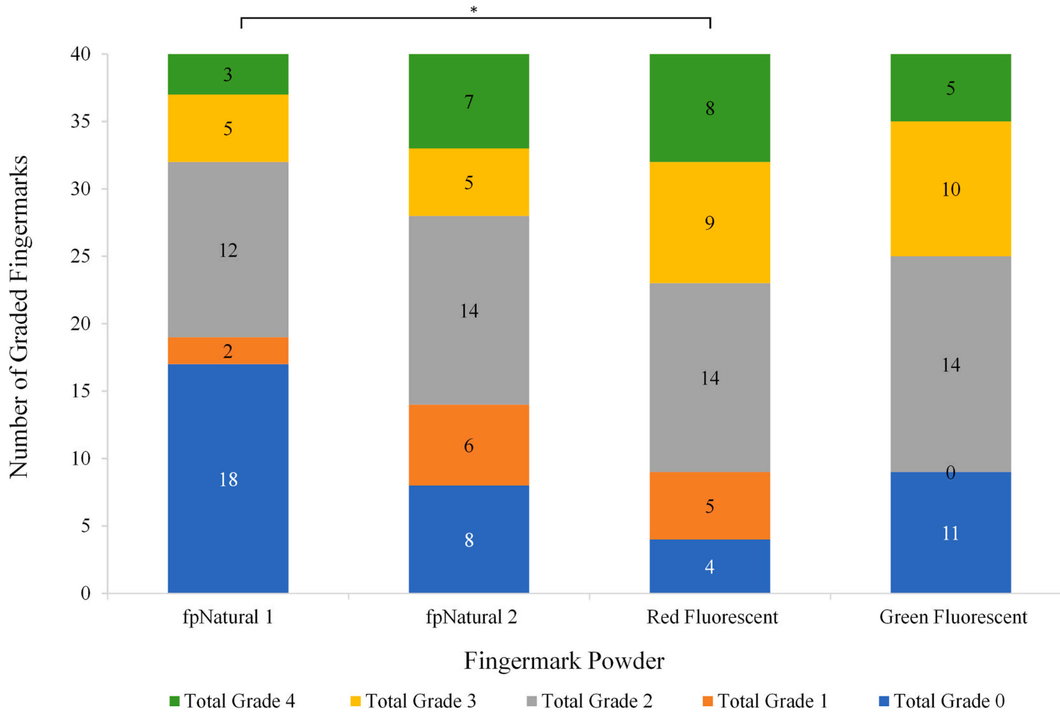

Fig. 4. A stacked bar chart displaying the number of fingermarks visualised with fluorescent powders at each grade, post lift, for fp 1, fp 2, and red and green fluorescent powders. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

visualised on the DCS®5. This means that, theoretically, all fluorescent fingerprint powders can be used to effectively enhance and lift latent fingermarks on rhino horn except fp 1 (Fig. 5).

It was hypothesised that fp 1 and 2 may be the most effective fluorescent powders because marks were visualised on compatible software. Furthermore, these powders were designed to eliminate background interference, and could have been effective at removing irregularities in colour of the wildlife sample and improving contrast between the mark and the surface [44]. However, fp 1 and 2 are excellent on smoother surfaces, such as polymer banknotes and glossy cards [44], and while the cut portion of the horn is flat and markedly smoother than the outside, the exterior of the horn is highly textured. This could explain why these powders were not significantly superior to red and green fluorescent powders and why fp 1 was significantly less effective.

No previous study has been conducted on rhino horn using these fingerprint powders, however previous studies on feathers of birds of prey by McMorris et al, found out that magnetic fluorescent red, and magnetic fluorescent green powders were found to be the most effective

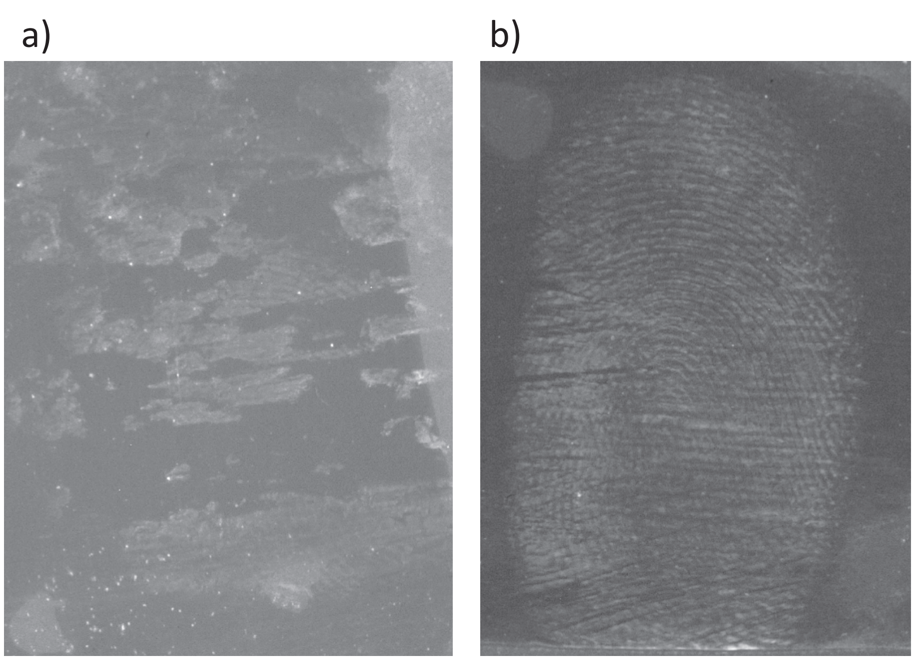

Fig. 5. Black and white pictures displaying fingermarks visualised with an example of a successful fluorescent powder, green fluorescent powder on the rough (a) and smooth (b) sides of rhino horn, post lifting with black gelatine lifter. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

fingermark powders at visualising latent fingermarks on the feathers of birds of prey [12,13]. However, this does not hold true for the rhino horn as no fluorescent powder was significantly better at enhancing fingerprints than aluminium and magnetic powders. The challenging surface may also partially explain why the same fingerprint powders that were found to be effective on the feathers of birds were not as effective on the rhino horn. Although the composition of both wildlife samples is keratin, feathers are made of beta-keratin [45], they are lighter and malleable, and possess a relatively more levelled surface [45]. The rhino horn in comparison is made of alpha keratin [46], which is more rigid, and while feathers are challenging to visualise fingermarks on due to the flexibility of the item and how often the weaves can be moved out of place.

In addition, these previous studies [12,13] deem a Home Office grade of 1 as a "successful mark", which is often an insufficient grade on an operational scale, however this paper only considers a grade of 3 or 4 a "forensically useful" on the Home Office scale, which can further explain this disparity. Unsurprisingly, the roughness of the rhino horn surface has a significant impact on the quality of the fingerprints, both before and after being lifted. Some fingermark ridge detail is lost in the recesses of the outside surface of the horn. This partly explains why gelatine is significantly more effective at lifting fingerprints compared to tape on this type of surface; the material is easier to bend and stretch, allowing it to reach deeper surfaces.

3.5. Comparing fingermarks on rough and smooth surfaces

Fingermark donors were asked to deposit their fingermarks on both the cut part of the horn (the smooth surface) and on the exterior side of the horn (rough surface) to determine if the surface roughness of the horn impacts the quality of the enhanced fingermarks.

When comparing powdered fingermarks on the rough and smooth sides of the horn (pre-lift) there was a significant difference in the quality of the fingermarks (Fig. 6 **and** SI Fig. 3). This set of experiments only considered the two most successful standard powders, aluminium and magnetic. In terms of the Home Office grading scheme, marks deposited on the smooth side of the horn were significantly more detailed than those on the rough side of the horn ($X^2 = 42.718$, df = 1, $p < 0.001$). On the smooth side, 37 out of 40 marks had ridge detail larger than one-third of the total mark area, making them forensically useful. On the rough side, only 8 out of 40 marks were forensically useful, compared to the 32 that were not. The same is true for the operational grading scheme ($X^2 = 37.0286$, df = 1, $p < 0.001$). On the smooth side, 36 marks were forensically useful, whereas 4 marks were not; on the rough side, only 9 marks were forensically useful, compared to the 31 that were not.

When comparing powdered fingermarks (with the same two powders) on the rough and smooth sides of the horn post lifting with gelatine lifter, there was a significant difference in the quality of the fingermarks (Fig. 6 **and** SI Fig. 3). Fingermarks lifted from the smooth side of the horn were significantly higher in quality than those on the rough according to the Home Office ($X^2 = 68.493$, df = 1, $p < 0.001$) and operational ($X^2 = 72.2$, df = 1, $p < 0.001$) grading schemes. 39 and 38 marks out of 40 were forensically useful on the smooth sides of the horn regarding the Home Office and operational grading scheme, respectively. No successful marks were lifted from the rough side of the horn post lift, according to either scheme.

Considering both unlifted and lifted fingermarks, aluminium and magnetic powder were equally effective on the smooth surface of the rhino horn, according to the Home Office ($X^2 = 0.721$, df = 1, $p = 0.396$) and operational ($X^2 = 2.883$, df = 1, $p = 0.090$) grading schemes. They were also equally effective on the rough side of the horn, according to both schemes (Home Office: $X^2 = 0.556$, df = 1, $p = 0.456$, and operational: $X^2 = 1.127$, df = 1, $p = 0.288$).

When comparing post-lift fingermarks enhanced with fluorescent powders (red, green, fp 1 and fp 2) on the rough and smooth sides of the horn, there was a significant difference in the quality of the fingermarks (Fig. 7 **and** SI Fig. 4). Fingermarks lifted from the smooth side of the horn were significantly higher in quality than those on the rough side according to the Home Office ($X^2 = 27.113$ df = 1, $p < 0.001$) and operational ($X^2 = 26.786$, df = 1, $p < 0.001$) grading schemes, when visualised on the DCS®5. 42 and 39 marks out of 80 were forensically

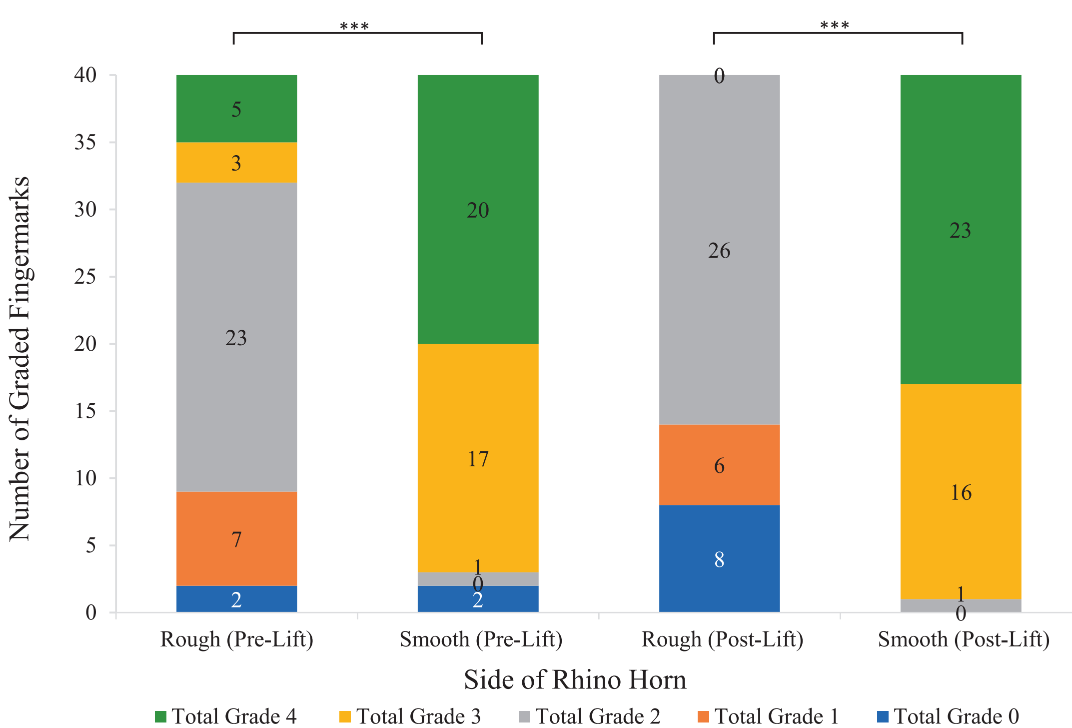

Fig. 6. A stacked bar chart displaying the number of fingermarks visualised with standard powders (aluminium and magnetic) on the rough and smooth sides of the rhino horn, both pre-and-post-lifting, at each Home Office grade. The total number of fingermarks for each powder is 40. *** conveys that $p < 0.001$.

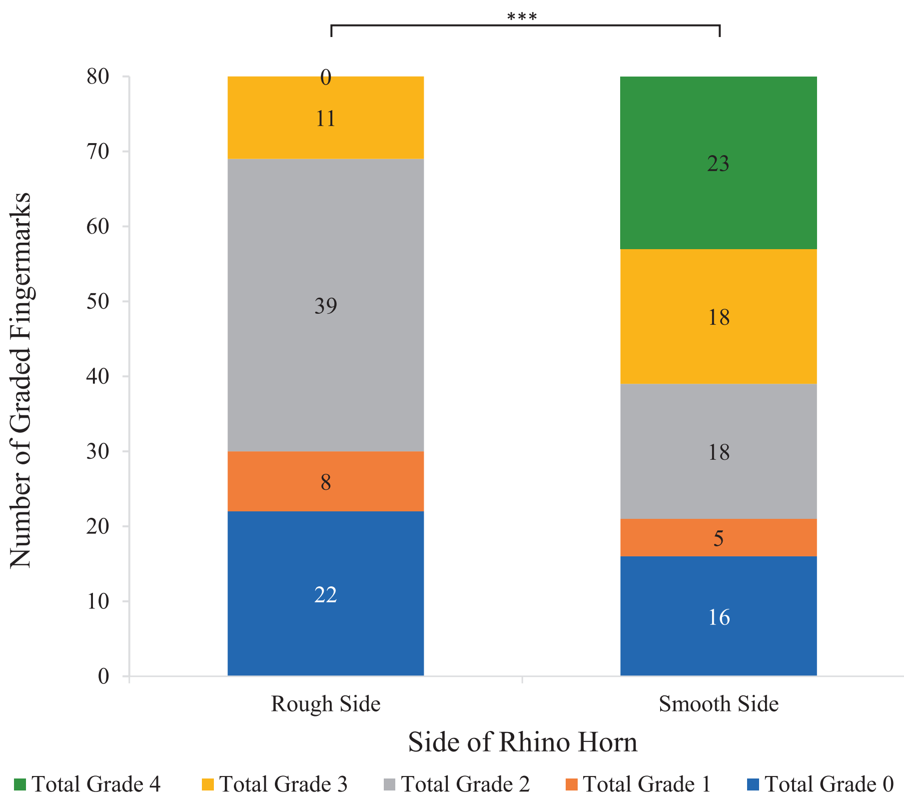

Fig. 7. A stacked bar chart displaying the number of fingermarks visualised with fluorescent powders on the rough and smooth sides of the rhino horn, post-lifting with black gelatine lifter, at each operational grade. The total number of fingermarks for each treatment is 80. *** conveys that $p < 0.001$.

useful on the smooth sides of the horn using the Home Office and operational grading scheme, respectively.

None of the powders were superior to each other when just considering the smooth side of the horn. This is true for the Home Office ($X^2 = 2.607$, df = 3, p = 0.456) and operational ($X^2 = 5.013$, df = 3, p = 0.171) grading schemes. Numerically, red fluorescent yielded the highest frequency of successful prints, where fingermarks were forensically useful 65 % of the time, and fp 1 yielded the lowest percentage of fingermarks suitable for comparison, at 37.5 %.

3.6. Recommendations and future work

This project is a preliminary investigation exploring the efficacy of eight different fingerprint powders and two lifting tools for visualising and lifting fingermarks from both the outer and inner exposed region of rhino horn. In order for this work to be operationally useful, a full validation would be required.

In this research, two thumbprints were deposited per powder and lifter, per donor. The available space to deposit fingermarks on the rhino horn was limited, and therefore, this approach allowed for accommodating as many donors as possible simultaneously and accounting for inter-donor variation (which is usually larger than intra-donor variation) [36]. Future studies, as part of method validation, could be expanded to include additional donors and the use of forefingers. Another important variable to explore is how fingermark visualisation on rhino horn is affected by time. Ageing experiments need to confirm that the method is operationally feasible as the composition of fingermarks can change over time [36]. Environmental validation should also be conducted, as exposure to sunlight, high temperatures, weather, and humidity can alter fingermark quality.

While the composition of rhino horns is generally the same across all species and keratin samples were found to be consistent across all five species of rhino [47], validation work should be done to confirm that successful methods are effective among rhino horns of different species.

Forensic tools employed in remote areas are vital for catching poachers and preventing illegal hunting, but limited resources, corruption, ineffective deterrents and the large scale of poaching are all barriers to the success of these tools [48]. Therefore, a more holistic approach to combatting illegal wildlife trafficking is recommended. Funding has been given to crime units, to enhance intelligence capabilities, so that they are better equipped to combat wildlife crime in rural areas, where crime has previously gone unpunished [49]. Another important strategy involves targeting the growing demand for wildlife items, and campaigns from large organisations leverage their social media platform to raise awareness and to change consumer behaviours [50]. Furthermore, local awareness campaigns have been launched as part of a larger anti trafficking frameworks, providing education programs and alternative livelihood training to combat unsustainable practices [50]. To address the root cause of wildlife trafficking, poverty and lack of education must be considered alongside improving law enforcement and deterrence.

4. Conclusion

This study aimed to identify optimal fingermark powders, both standard and fluorescent powders that can be employed to visualise latent fingermarks deposited on both the smooth and rough surfaces of rhino horn. Fingermark powders are inexpensive, effective for fingermark enhancement, and accessible, making them excellent tools to implement in remote locations while investigating wildlife crime. In addition to this, fingermark powders can be used on wildlife samples from/on whole live specimens. Visualising fingermark detail on rhino horn can be used to identify individuals from a specific wildlife crime, and other linked crimes such as complex fraud, gun crime, money laundering and corruption.

Out of the four conventional fingermark powders trialled, metallic powders (i.e. magneta flake and aluminium) were the most effective powders. Fp 2 and green and red fluorescent powders were not found to be significantly different from each other, although fp 1 was found to be significantly less effective than red fluorescent powder. Red fluorescent powder visualised a higher proportion of forensically useful fingermarks suitable for comparison with reference marks, and searching on fingermark databases. Additionally, different lifting tools were trialled to determine how best to preserve fingermarks found on rhino horns from wildlife crime scenes and black gelatine was found to be superior to tape, since gelatine is a more flexible lifting tool able to lift from the irregularity of the outside of the horn. Marks deposited on the smooth inside surface of the cut horn were significantly higher in quality than those on the outside surface, due to the less variable topography of the cut section.

This preliminary investigation offers useful insight into what conventional and fluorescent powders are most effective on this understudied wildlife sample, but further investigation should occur before these methods are used in the field. This study was conducted in a laboratory environment, however various factors, such as differing weather conditions and the introduction of soil or sand may affect the quality of the deposited fingermarks on the wildlife item studied – poached items are often buried in the ground to be retrieved later. Another area of interest includes the possibility of retrieving touch DNA from a latent fingermark deposited on the inside and outside surfaces of rhino horn.

This study is the first to demonstrate the effectiveness of metallic and fluorescent powders, and black gelatine lifter, in visualising and lifting fingermarks from rhino horn. The successful powders and lifters identified in this study should be studied further and validated under field conditions, to be deployed in areas where they are urgently needed to fight wildlife crime. When employed as part of a holistic approach to illegal wildlife crime, providing tools to forensic practitioners and working towards the deterrence of poaching can lead to a reduction in illegal hunting and the global issues associated with poaching.

Consent to participate

All research was conducted in accordance with the Human Tissue Act 2004 and all donors signed consent forms before depositing fingerprints.

Consent for publication

This article does not include any content for which consent would need to be obtained.

Availability of data and material

N/A

Code availability

N/A.

Authors' contributions

All authors contributed to the study conception and design. Practical work was conducted by Lauren Woodcock and Thomas Mancini. Initial manuscript preparation was performed by Lauren Woodcock and Thomas Mancini. Critical analysis and final approval of the manuscript was provided by Julia Ringe and Nunzianda Frascione.

CRediT authorship contribution statement

Lauren Woodcock: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing. **Thomas Mancini:** Methodology, Formal analysis, Writing – original draft. **Julia Ringe:** Methodology, Writing – review & editing, Supervision. **Nunzianda Frascione:** Conceptualization, Methodology, Writing – review & editing, Supervision.

Ethics approval

Ethical clearance for the collection and storage of fingermarks was granted by the King's College London biomedical Sciences, Dentistry, Medicine and Natural & Mathematical Sciences research Ethics Subcommittee (Reference Number: HR/DP-21/22-23072)

Funding

This research did not receive any specific funding.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank Tracy Alexander from the City of London Police for their advice and input on this research.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scijus.2025.101310.

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