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Technical note: A preliminary assessment of UV-C imaging using the Full Spectrum Imaging System (FSIS-II) for the detection of latent fingermarks

Will Stoddart [a], Kyprianos Georgiou [b], Paul Deacon [c], Leisa Nichols-Drew [a], Kevin J. Farrugia [a,*]

[a] Faculty of Health and Life Sciences, Leicester School of Pharmacy, De Montfort University, The Gateway, Leicester LE1 9BH, UK
[b] School of Human and Social Sciences, University of West London, St Mary's Rd, London W5 5RF, UK
[c] Independent Researcher, Dundee, UK

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ABSTRACT

The Full Spectrum Imaging System (FSIS-II) was assessed for the detection of latent fingermarks on a variety of substrates, specifically focusing on UV-C imaging for untreated marks and those that have been treated with cyanoacrylate (CA). The use of UV-C was effective at the detection of latent fingermarks on a variety of substrates and UV-C imaging may be effective when UV-A does not provide any fingermark detections on thermal paper. A Phase 2 and a small Phase 3 trials on aluminium cans were carried out with a detection sequence of UV-C imaging, CA fuming, UV-C imaging, UV-A imaging and BY40. For Phase 2 laboratory trials, the use of initial UV-C reflection was effective at removing the background and was a useful tool for initial screening. The use of UV-C was superior to UV-A after CA fuming and provided the highest overall number of high-quality marks. For phase 3 trials, the results showed that BY40 fluorescence was marginally more effective than UV-C imaging of CA-treated marks. This preliminary study shows that the FSIS-II and UV-C imaging can complement other methods for the detection of latent fingermarks.

1. Introduction

The use of UV radiation has been used in forensic science since the early 20th century for the analysis of various types of evidence such as documents, glass, body fluids and drugs [1]. Research in the 1970s then focused into the use of UV for the visualisation of latent fingermarks [2–11]. Imaging and visualising evidence with UV (UV-C 100–280 nm; UV-B 280–315 nm; UV-A 315–400 nm) can take place by absorption, reflection or fluorescence to create a contrast with the background. The majority of UV imaging systems developed by the London Metropolitan Police and Israel National Police were laboratory-based before further work by the US Army Crime Laboratory developed portable and then commercially-available systems, such as the Reflected Ultraviolet Imaging System (RUVIS) [12]. Several studies have assessed these commercially-available systems, identifying advantages against busy backgrounds of cyanoacrylate-treated marks [13] as well as crime scene applications [14].

A comparison study comparing UV-A, UV-B and UV-C showed that UV-C was the most effective wavelength range for the detection of latent fingermarks on both paper and glass [15]. Another comparative study of three UV-C systems by the UK Home Office showed that the most high-quality marks were obtained with a DEUS (digital enclosed ultraviolet imaging system) consisting of a UV-C-sensitive, back-thinned CCD and camera system housed in a lightproof chamber custom built by the Home Office [16]. The use of UV-A is able to detect different types of evidence, including the detection of latent fingermarks on thermal paper [17] and cyanoacrylate developed marks [18,19]. Bramble et al. [20] reported a fingermark detection rate of 69% with UV-C compared to 23% with an argon-ion laser at 514 nm. The UV fluorescence intensity decreased considerably when the mark was exposed to the 266 nm laser light for 20 min; however, this exposure did not have an effect on subsequent chemical treatment with ninhydrin and DFO [20]. A pseudo-operational trial for the detection of latent marks on plastic packaging found that all cyanoacrylate-treated marks detected by reflected longwave UV-A were also detected by BY40 fluorescence as well as new marks that UV-A had not detected [19]. Currently, there are limited studies in the literature assessing and comparing the use of both UV-A and UV-C on cyanoacrylate treated marks on a variety of substrates, although a recent study [21] reported that UV-C was superior to UV-A reflection for suppressing the background of cyanoacrylate treated marks on Israeli polymer banknotes.

Both longwave UV-A and shortwave UV-C reflection methods are

* Corresponding author.
E-mail address: kevin.farrugia@dmu.ac.uk (K.J. Farrugia).

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listed as Category A processes in the Fingermark Visualisation Manual, defined as "standard processes for routine operational use. They must be used in preference to other category processes where possible" [22]. UV-C has to be used with caution due to health and safety issues and damage to skin and eyes; however, this can be used safely with the appropriate training, PPE and risk management [1]. The use of shortwave UV-C can be destructive to the subsequent recovery of DNA [1,23,24]. Several types of forensic equipment, such as cyanoacrylate chambers, employ UV-C processes for avoiding cross-contamination in between casework samples; however, further research such as the effect of exposure time, is necessary. For example, the use of longwave UV-A (315–400 nm) was reported as non-destructive to DNA for exposures of up to 30 min [25]. The use of longwave UV-A carries a lower risk but may not be as effective as UV-C for certain applications.

The latest generation of the Full Spectrum Colour Imaging System (FSIS-II), launched in 2021 by Arrowhead Forensics and distributed in the UK by ForenteQ Ltd., allows for the imaging and capture of evidence from 254 nm up to 1100 nm and can capture a full handprint at 1000 PPI or smaller areas up to 4800 PPI. This study presents a preliminary assessment of the FSIS-II suitability for the detection of latent fingermarks with UV-C before and after cyanoacrylate fuming by assessing a variety of substrates and by means of a Phase 2 laboratory trial and a Phase 3 pseudo-operational trial as recommended by the UK Home Office [26] and the International Fingerprint Research Group (IFRG) [27].

2. Methodology

A variety of substrates, such as thermal papers, envelopes, shell casings, aluminium cans, food items and plastic, was obtained through recycling bins and from work colleagues. The items were then analysed by the FSIS-II system by means of UV-C imaging. This was followed by initial Phase 2 laboratory trials focusing only on aluminium cans and a small Phase 3 laboratory trials of 15 cans with a main focus of comparing the use of UV-A and UV-C after cyanoacrylate fuming. The appropriate PPE, including a full-face shield, long-sleeved lab coat and gloves, was used.

2.1. Preliminary trials

For this part of the study, a diverse range of objects from work colleagues and family members were collected for examination which included white and brown envelopes, a baby food pouch, a coke can, flowerpots (exposed to adverse weather conditions such as rain and snow over a 3-month period), plastic toys, faux leather, bubble wrap, polystyrene, shell casings of two different calibres (.38 mm and .70 mm), and various food items (apple, banana, tangerine, grapefruit, lemon, and egg). The examined items were handled carefully with gloves with no deliberate planting of fingermarks to assess the viability of UV-C imaging using the FSIS-II system. A single deposited natural fingermark on an aluminium can was imaged under UV-C regularly for 30 days to monitor the effect of ageing.

2.2. Phase 2 laboratory trials

This part of the study focused on a variety of aluminium cans that were obtained from recycling bins. Aluminium cans were selected for this study due to their non-porous nature, multi-patterned backgrounds, curvature and availability. The items were washed with warm soapy water and then ethanol "so that most types of pre-existing contaminant will be removed" and ready for fingermark deposition by donors [26]. Six donors of various ages and sex deposited a depletion series of six natural fingermarks across the curvature of 32 cans with ageing periods of 1,7,14 and 21 days for a total of 720 natural fingermarks. For smaller cans (volume of 330 mL), the six donors deposited their fingermarks across two cans (three donors on each can) whereas only one can was required for larger cans (volume of 500 mL). For fair comparisons, the type of can (size, brand, colour) across each ageing period was kept consistent (Fig. 1).

After the ageing period, the items were imaged by means of UV-C imaging (FSIS-II), followed by cyanoacrylate (CA) fuming, then imaged again under UV-C and UV-A reflection and finally treated with fluorescent BY40 dye. Depletions one and six from each donor and ageing period were imaged and graded at every step of the sequence.

2.3. Phase 3 pseudo-operational trials

Fifteen aluminium cans, with a variety of colour, style and shapes, were again obtained from recycling bins; however, the items were not cleaned in preparation for the detection and imaging of any latent fingermarks that may be present. Any information related to the donor, fingermark ageing or depletion was unknown. Each can was examined by the same sequence of fingermark detection techniques as for phase 2 laboratory trials, noting any developed fingermarks by each technique.

2.4. Fingermark detection and imaging techniques

2.4.1. Shortwave Reflected UV (SWRUV)

SWRUV was carried out by means of a 254 nm mercury lamp and imaged using the Full Spectrum Imaging System II (FSIS-II). Unlike previous systems, there is no image intensifier or an eyepiece and the FSIS-II uses a CMOS imager that has a spectral response in the UV part of the spectrum together with a quartz input window, a quartz lens and a 254 nm bandpass filter. Any captured evidence is displayed in real-time on a computer monitor.

2.4.2. Cyanoacrylate fuming

The articles under examination were fumed with cyanoacrylate (Cyanobloom, Foster and Freeman UK) in a FumeCare (model number CA-90-PRO-CF) fuming chamber with a volume of 0.665 m^3. The chamber is fitted with a hot plate (temperature set to 125 °C) and a humidifier (set to 80%), which are checked and calibrated regularly by means of a RS52 digital thermometer/thermocouple (RS 123–3216) and a psychrometer kit (Extech Instruments RH305). The process consisted of weighing 2.5 g of CA in a foil dish with a fuming cycle of 50 min and a purge cycle of 40 min. The foil dish was then weighed again to ensure that $>$ 95% of the CA had evaporated. A total of four fuming cycles were performed, one for each ageing period. The aluminium cans were then viewed under white light and any developed fingermarks were noted and photographed.

2.4.3. Longwave Reflected UV (LWRUV)

LWRUV was carried out by means of a UV Crime-lite 82 S (350–380 nm, Foster and Freeman) and a Baader-Venus UV bandpass filter (330–385 nm). A glass lens rather than a quartz lens was used during the detection, imaging and photography process [19].

2.4.4. Basic Yellow 40 (BY40)

The use of the fluorescent dye BY40 was the final step of the sequence. The BY40 solution was prepared by dissolving BY40 (2 g, WA Products) in 99% ethanol (1 L, Fisher). The items to be tested were then immersed in the BY40 solution for 15 s followed by thorough rinsing under running water and left to dry at room temperature overnight before fluorescence examination. A period of at least 24 h after fuming had elapsed before BY40 staining took place. BY40 fluorescence was observed with a blue Crime-lite 82 S (420–470 nm, Foster and Freeman) and viewed with a yellow long-pass 476 nm filter (1% cut on point).

2.5. Photography and grading of marks

Photography, apart from UV-C imaging, was performed using a modified Nikon D850 with a full-spectrum conversion (Advanced Camera Services, U.K.) and equipped with a Nikon 105 mm f/2.8 Micro

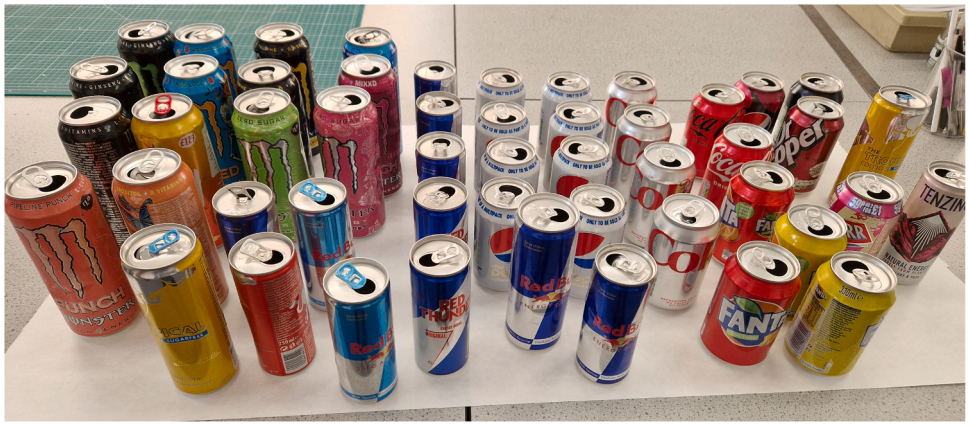

Fig. 1. Examples of aluminium cans used in the study for Phase 2 and Phase 3 trials.

Nikkor lens. The camera was set at aperture priority, f/8, ISO 400, and a ratio of 1:1. The number and quality of latent marks developed was assessed after each technique in the sequence. For Phase 2 trials, depletions one and six were photographed for each donor, item and ageing period and graded 0 to 4 as per the UK Home Office CAST guidelines [26]. The same person (not an identification expert) did all the grading of developed marks from colour images; however, this grading system is subjective. This grading scheme is used by researchers who may not be identification experts and therefore does not only rely on the detection and counting of minutiae but has a "relation to the qualities of the fingermark that an identification expert would use, namely the extent and clarity of the ridge detail that has been developed" [26,28]. The number and percentage of marks graded 3 or 4 aided the assessment of each enhancement sequence in this study. For Phase 3 trials, developed marks with continuous ridge detail and an area greater than 64 mm^2 were counted [26]. Marks detected by each enhancement technique were noted in addition to unique marks found by each technique.

3. Results and discussion

3.1. Preliminary trials

A variety of substrates were tested for the detection of latent fingermarks using UV-C imaging of the FSIS-II system. Fig. 2 shows an example of latent fingermarks on thermal paper (handled the day before) without any treatment and viewed with longwave UV-A and shortwave UV-C. The use of UV-C imaging may be effective when UV-A does not provide any fingermark detections. Other substrates, such as plastics and aluminium cans were examined under UV-C, before and after CA fuming (Fig. 3). A deposited fingermark on an aluminium can was imaged under UV-C regularly for 30 days to monitor the effect of ageing and the detection by the FSIS-II system. Fig. 4 shows that that the detection of the latent fingermark is still possible after 30 days; however, the fingermark ridges appear to migrate and diffuse, as a consequence of ageing [29]. Only one natural fingermark was assessed and monitored over the 30-day ageing period during preliminary trials; however, additional fingermark donors and ageing periods were then considered in phase 2 trials.

UV-C imaging with the FSIS-II also successfully imaged fingermarks on the matt baby food pouch and on the tangerine (possible due to contaminants) but was less or not effective on the shell casings, items exposed to adverse weather conditions (children's toys, plastic ball, flowerpots), faux leather, bubble wrap and various food items. Unlike thermal paper, no ridge detail was detected on the rough surface of generic paper and envelopes. The difference between the smooth thermal paper and the rough porous substrates was expected as the increased roughness also increases the UV-C scattering from the surface making any scattering from the ridge detail difficult to distinguish [22]. The accumulation of water, condensation and dirt on the surfaces exposed to adverse weather conditions provided further challenges to image any latent marks that may have been present. In summary, these preliminary observations identified some of the potential factors to consider in using the FSIS-II system for the detection of latent fingermarks, which include the type of surface (shiny/matt/metal/plastic), exposure conditions and the presence of any contaminants.

3.2. . Phase 2 laboratory trials

Fig. 5 represents a summary of the percentage of marks graded 3 or 4 for each enhancement method in the sequence. Although the use of UV-C

Fig. 2. Detection of latent fingermarks on thermal paper by (a) longwave UV-A and (b) shortwave UV-C.

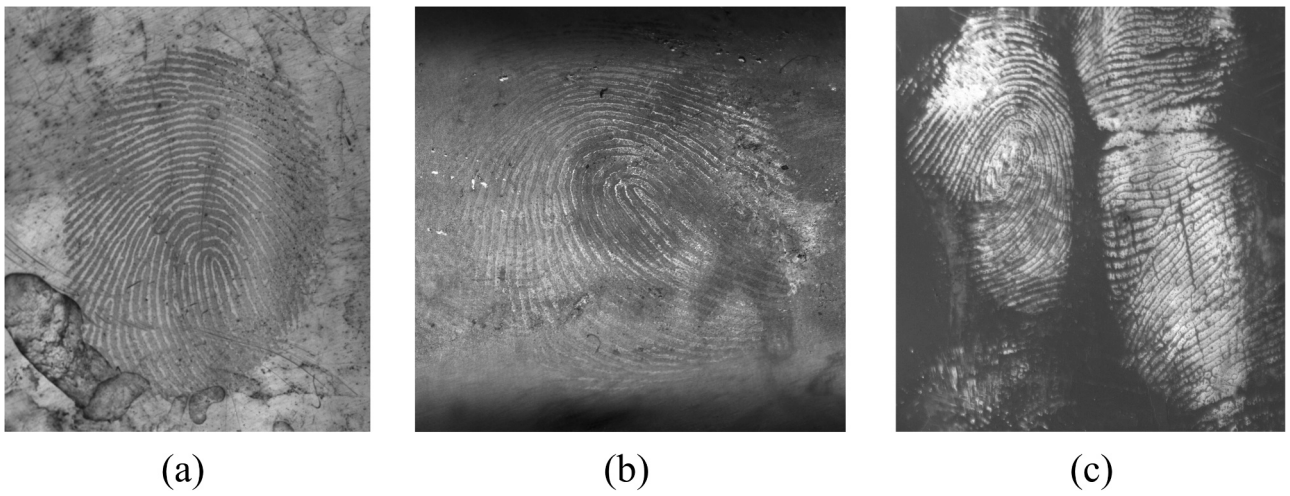

Fig. 3. UV-C imaging of latent fingermarks before chemical treatment on (a) plastic safety goggles; (b) aluminium can and after CA fuming (c) soft plastic.

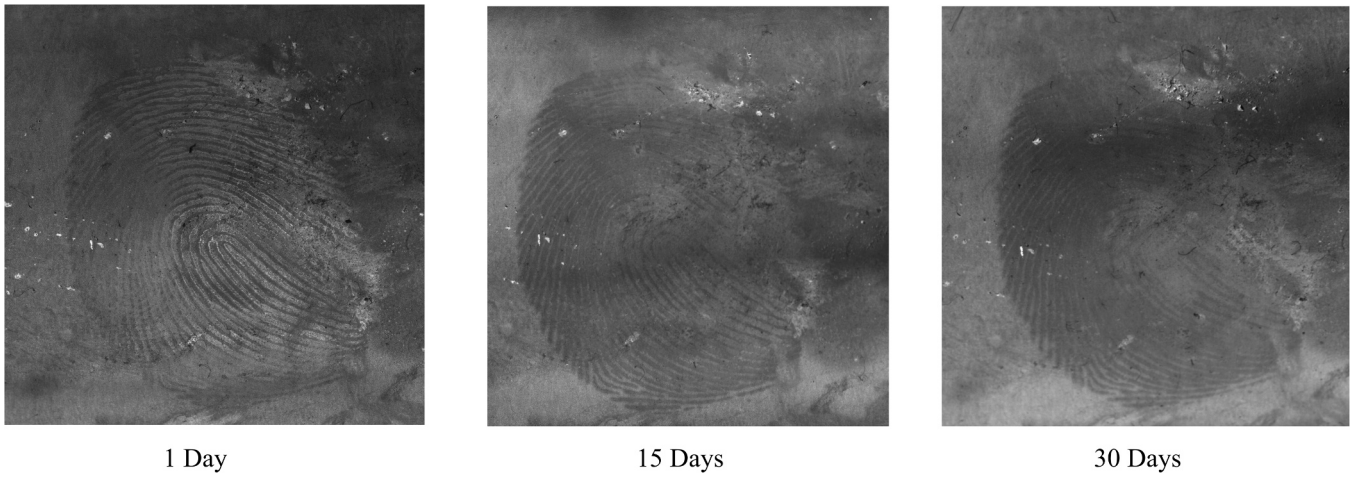

Fig. 4. UV-C imaging of a latent fingermark on an aluminium can at different ageing periods.

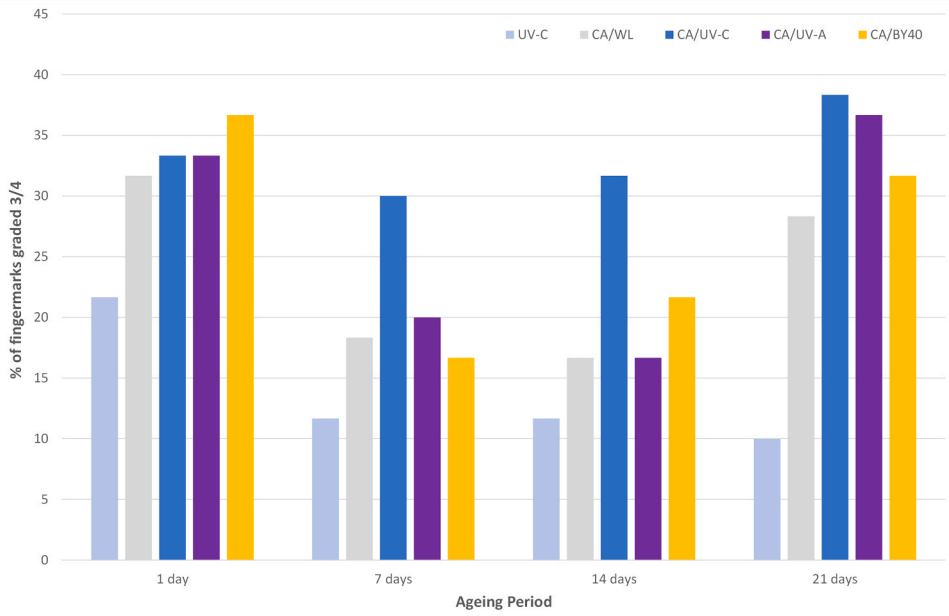

Fig. 5. Percentage of detected fingermarks by each technique in Phase 2 trials.

imaging was effective at improving the contrast, sometimes completely suppressing the background (Fig. 6), the use of CA fuming provided a higher number of marks that were graded 3 or 4. On certain cans, such as those with an unsmooth or ribbed finish, the use of UV-C imaging was not effective; however, CA fuming and UV imaging or BY40 resulted in higher quality marks (Fig. 7). Reflective UV-C imaging of CA treated marks yielded the highest number of marks graded 3 or 4 across all ageing periods and donors, except for 1 day ageing where BY40 was marginally better. Furthermore, after CA fuming, the use of reflective UV-C was equal to UV-A for 1 day ageing, marginally better for 21 days ageing and considerably better for 7 and 14 days ageing. The use of UV-C imaging after CA fuming provided superior contrast as UV-C reflected and scattered from the developed CA polymer on the ridges. Marks that were graded 3 and 4 were also obtained for longer ageing periods at 14 days (Fig. 8) and 21 days (Fig. 9). The results also highlight the importance of recording and photography of developed marks after each enhancement process in the sequence as the quality of the mark may decrease or even be obliterated. BY40 fluorescence provided good contrast for most cans tested in this study; however, background fluorescence can have an effect on the overall quality of the mark. Phase 2 trials can have a number of limitations such as the deposition of fingermarks under controlled conditions, which can vary considerably to those encountered in case work, and the fact that the researchers know where the actual fingermarks have been deposited. Nonetheless, these trials provide an insight into the effectiveness of enhancement techniques that can be further followed with Phase 3 pseudo-operational trials and Phase 4 full-operational trials.

3.3. . Phase 3 pseudo-operational trials

Fig. 10 shows the number of detected fingermarks by each technique in the pseudo-operational trial. For this small Phase 3 trial and contrary to the phase 2 trial, BY40 performed marginally better than UV-C after CA fuming which may depend on the background of where the mark was present. The use of the UV-C initial searching was also more effective than CA fuming and white light, which is the opposite of what was observed in laboratory trials with deposited fingermarks, suggesting that UV-C imaging at the start of the sequence can be useful in operational casework, while assessing the impact on other types of evidence such as DNA. In a number of operational forensic laboratories, DNA swabbing precedes fingermark detection methods and so the effect of UV-C on DNA is not as relevant [21]. Furthermore, CA fuming detected some

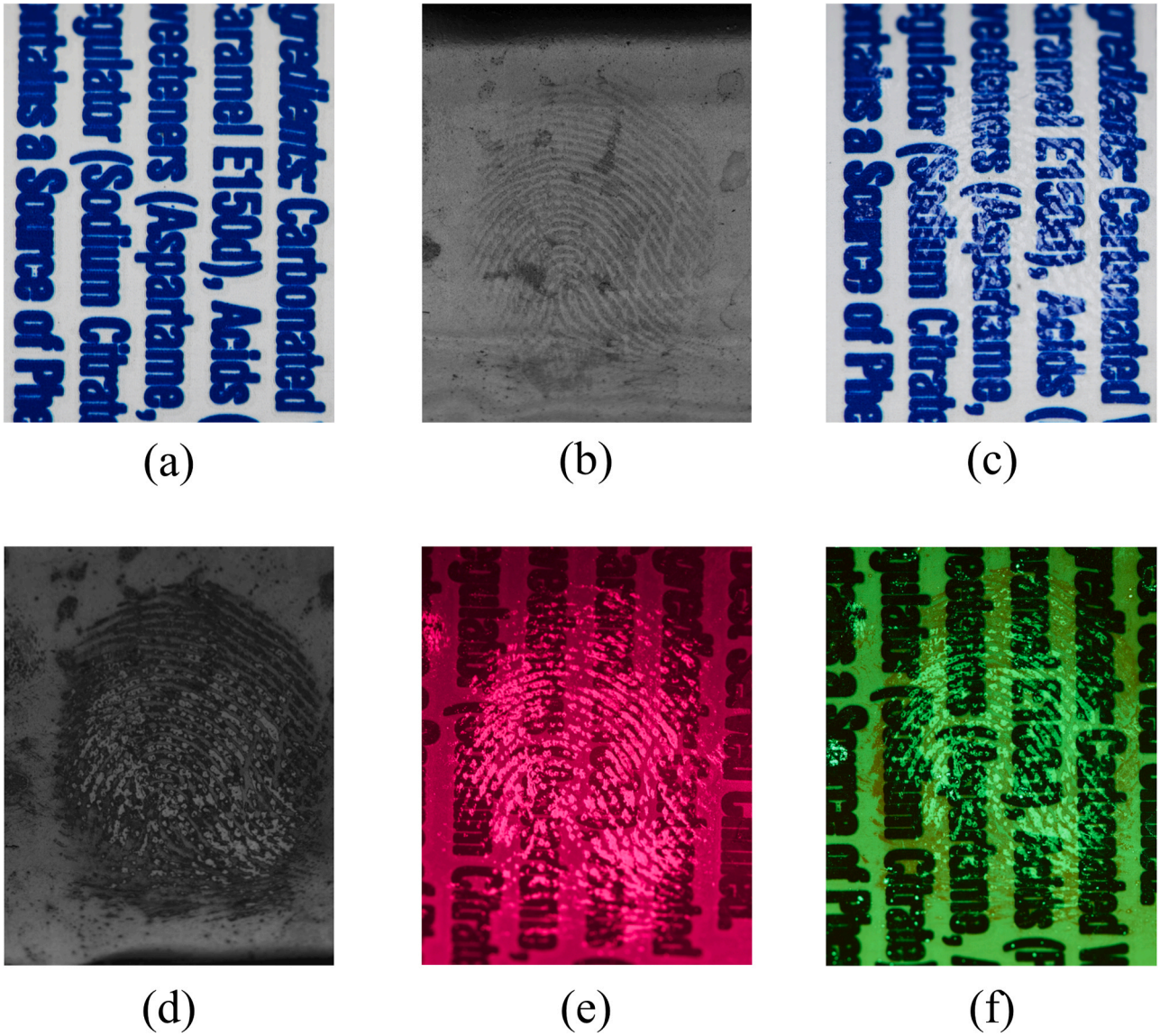

Fig. 6. Development of a latent mark on a Diet Pepsi aluminium can, donor 1, depletion 1 and 1-day ageing: (a) white light; (b) UV-C; (c) CA fuming and post fuming (d) UV-C; (e) UV-A; (f) BY40.

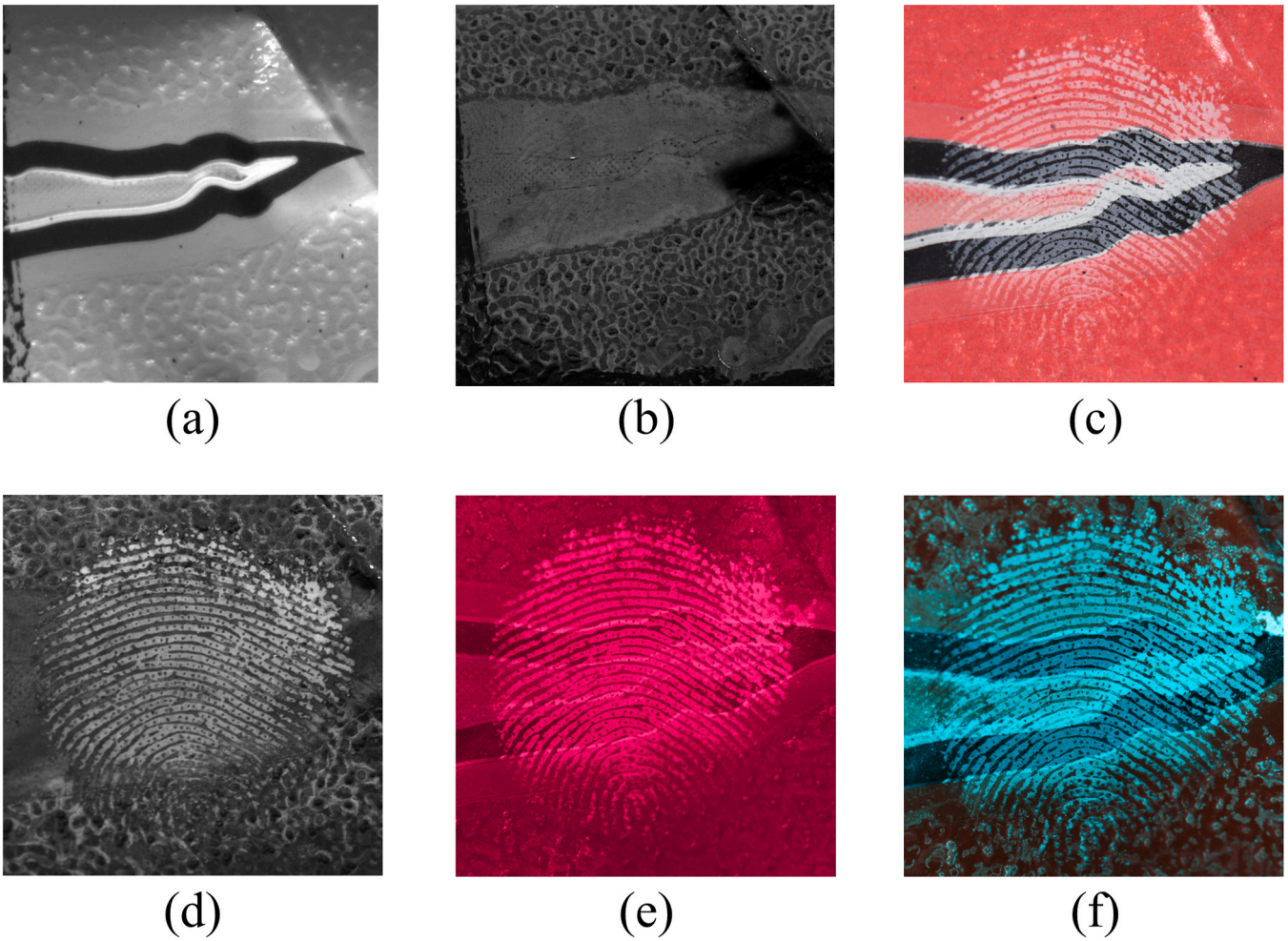

Fig. 7. Development of a latent mark on a Monster Energy Pipeline Punch aluminium can, donor 4, depletion 6 and 7-days ageing: (a) white light; (b) UV-C; (c) CA fuming and post fuming (d) UV-C; (e) UV-A; (f) BY40.

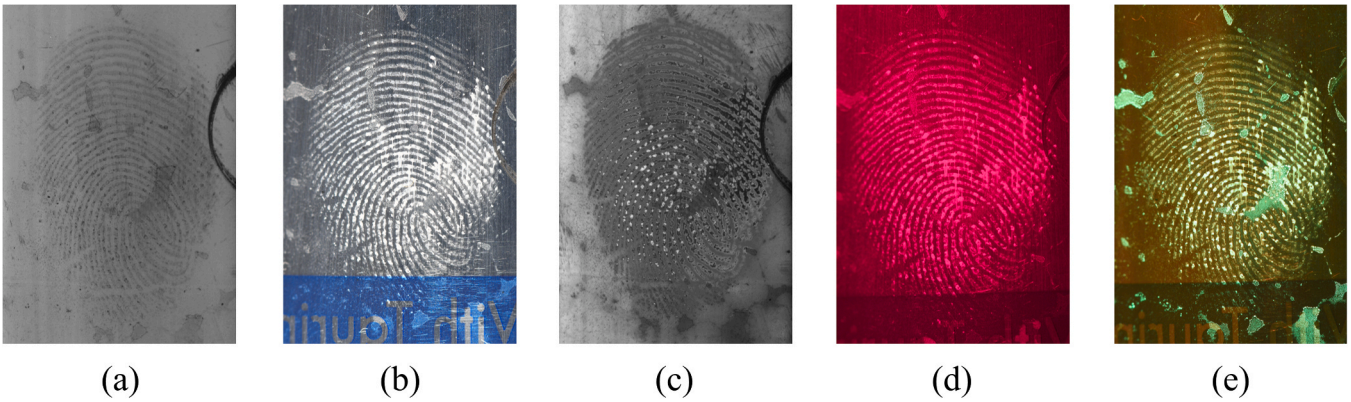

Fig. 8. Development of a latent mark on a Red Bull Sugar Free aluminium can, donor 3, depletion 1 and 14-days ageing: (a) UV-C; (b) CA fuming and post fuming (c) UV-C; (d) UV-A; (e) BY40.

marks that initial UV-C imaging did not and vice-versa. As for Phase 2 trials, the use of UV-C after CA fuming detected all the marks that UV-A detected and some additional ones as well, indicating that UV-C may be more effective than UV-A for imaging CA treated marks (Fig. 11). The use of BY40 detected twice as many marks than UV-A reflection of CA treated marks and, as reported in another study, if BY40 is omitted from the sequence, then marks could potentially be missed [19]. Recording, assessing and photographing marks should be done at every stage of the sequence.

3.4. . Limitations of the study

This study aims to offer some insight into the use of shortwave UV-C with the FSIS-II for the detection of latent fingermarks before and after development with cyanoacrylate. Both Phase 2 and Phase 3 trials in this study used a small number of variables, such as only one type of

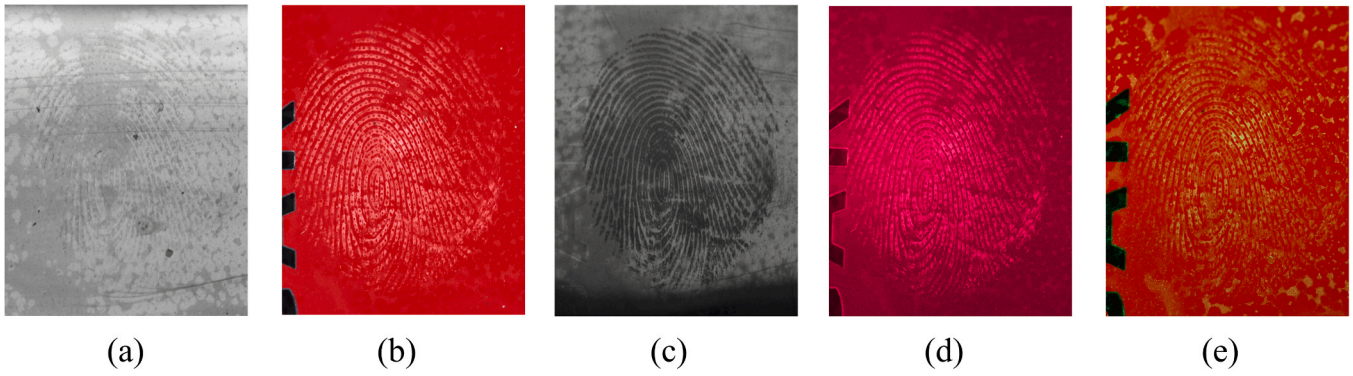

Fig. 9. Development of a latent mark on a Coca Cola aluminium can, donor 5, depletion 6 and 21-days ageing: (a) UV-C; (b) CA fuming and post fuming (c) UV-C; (d) UV-A; (e) BY40.

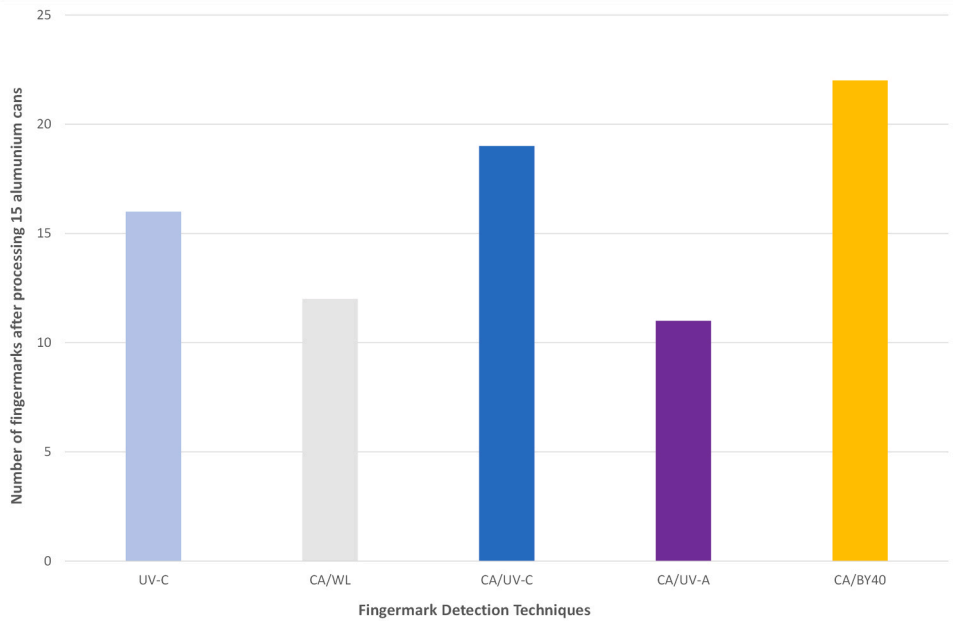

Fig. 10. Number of detected fingermarks in the small pseudo-operational trial.

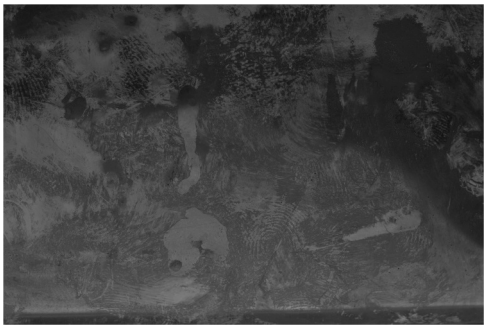

Fig. 11. Several areas of ridge detail of CA-treated marks on a Monster Energy Original can under UV-C imaging.

substrate (aluminium cans). Furthermore, Phase 3 trials only used 15 items and caution is required before reaching any firm conclusions from the results.

4. . Conclusion

This preliminary study shows that UV-C imaging can complement other methods for the detection of latent fingermarks. This study highlighted the importance of recording, assessing and photographing marks at every stage of the sequence, since the quality of the marks may change after treatment with CA fuming or BY40. Keeping in mind the small scale of the study, the use of BY40 during Phase 2 trials was, in general, less effective than UV-C reflection for the detection of CA-treated fingermarks; however, in Phase 3 trials, BY40 performed marginally better than UV-C and detected twice as many marks than UV-A imaging. This demonstrates that BY40 fluorescence is still important in the overall sequence for the detection of marks on non-porous surfaces.

Users of the FSIS-II must take into consideration the cost of the system as well as the effects of UV-C on subsequent forensic analysis such as DNA. The main strength of the FSIS-II and UV-C imaging was the detection of additional marks post CA fuming and before BY40 treatment which can reduce the investigative time for police forces.

CRediT authorship contribution statement

Paul Deacon: Conceptualization, Data curation, Methodology,

Resources, Visualization, Writing – original draft, Writing – review & editing. **Leisa Nichols-Drew:** Data curation, Investigation, Resources, Supervision, Visualization. **Will Stoddart:** Data curation, Formal analysis, Investigation, Resources, Visualization. **Kyprianos Georgiou:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing – review & editing. **Kevin J. Farrugia:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Kevin Farrugia reports equipment, drugs, or supplies was provided by Arrowhead Forensics and ForenteQ.

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