Comparison of NIR powders to conventional fingerprint powders

Keywords

Luminescence; Near-infra red; background suppression; patterned background; fingermark detection; powder dusting.

Highlights

- NIR powders were compared to conventional black and luminescent powders
- Black and GREENcharge™ powders are the most effective powders on the surfaces tested
- NIR powders do not offer significant advantage on conventional substrates
- Universal Powder outperformed fpNATURAL 1® in NIR luminescent conditions

Abstract

Fingerprint powders remain one of the most common detection techniques used at the crime scene. However, powder efficiency and contrast can be hindered when applied to highly patterned backgrounds. This problem can be overcome using powders that are luminescent in the near-infrared (NIR) region of the electromagnetic spectrum. Despite being commercially available, those powders have been the focus of only a small number of studies, limited to a few substrates or donors. Their performance and advantages over common techniques are still to be thoroughly investigated.

This study aims at assessing the performances of two NIR powder (fpNATURAL 1® and Universal Powder an in-house developed powder) against two conventional powders, a black and a luminescent powder (Sirchie Black, GREENcharge™) under various optical conditions (white light, luminescence and NIR). The powders were compared on four substrates using fingermarks of four different ages from five donors. A total 900 fingermarks were collected for each pairwise comparison.

NIR imaging provided good background suppression and a high contrast, however it was shown that conventional powders remained the most effective powdering methods on the substrates tested as sufficient contrast could be achieved under white light or in luminescent mode in the visible region. The results showed that Universal Powder performed similarly to conventional powders, but poor performances were obtained on most substrates with fpNATURAL 1®. Based on the results obtained, it is recommended to use NIR powders only on substrates or conditions where traditional powders are known to perform poorly.

Introduction

Powdering is one of the oldest and most common methods of latent fingermark detection for non-porous substrates [1]. Fingerprint powders originally relied on absorption to produce contrast between the mark and the substrate [1]. While these powders are suitable for most substrates, if the substrate is patterned or has a high contrast background (i.e. a barcode) the effectiveness of traditional powders is diminished. Luminescent powders can reduce substrate interferences and have been shown to be effective in providing superior contrast when compared to traditional powders [1]. However, some difficult substrates such as polymer banknotes or soft drink cans still produce background interferences, which can prevent a developed fingermark from being visualised. Recently, there has been an increased interest in visualisation in the near-infrared region (NIR) for latent fingermark development. Previous studies have shown that imaging in the NIR can reduce the potential interferences from a substrate [2-4]. NIR imaging of developed fingermarks is broken down into two main areas, upconverters and NIR luminescence. Upconverters rely on anti-stokes illumination where the upconverter is excited with NIR radiation (usually a high powered laser) and emission is visualised in the visible region [5-11]. Despite the sustained interest in upconverter powders [6] there are significant limitations when it comes to producing the luminescence and imaging the powders in an operational context. A high powered laser is usually required to produce luminescence, those lasers are expensive and their use involve hazard if not wearing appropriate goggles. Upconverter materials are not commercially available and required specialised synthesis procedures. Moreover, the performances of upconverters are yet to be validly compared against conventional techniques. As a result very few upconverter powders have made it past the pilot stage and none are currently used in practice. NIR luminescence involves the excitation of a NIR luminescent dye with either visible light or NIR radiation to produce enhancement, while observation is located in the NIR region of the electromagnetic spectrum (700nm to 2500 nm) [2, 12-18]. NIR luminescence methods can provide similar levels of background suppression, while still using standard forensic imaging equipment. NIR imaging was first applied to traditional fingermark methods and found that while the background interferences were supressed, the NIR luminescence of conventional methods was weak [2, 3]. Based on this NIR luminescent laser dyes were then applied as cyanoacrylate stains with varied success, while the NIR alternatives can provide superior background suppression, the improvement when compared to conventional methods remains minimal [2, 4].

NIR luminescent methods have since focussed on fingerprint powders, where most of the research is currently being conducted. A study performed by Chadwick et al, combined a NIR luminescent laser dye (Styryl 11) with Rhodamine 6G and coated it onto an aluminium oxide nanopowder. The combination of the two dyes allowed for a visualisation in both the NIR and visible regions and was found to provide better development on older marks and marks on textured surfaces [12]. Since the initial studies on NIR powders, two commercial products have become available, Foster+Freeman currently sell fpNATURAL 1® and fpNATURAL 2® which use Spirulina and Egyptian blue respectively as the base for these NIR powders[15, 16]. Previous studies have shown these powders to provide excellent contrast on difficult substrates such as polymer banknotes and aluminium cans, however the studies have been quite limited in their scope and a full comparison to conventional methods has not been performed [15, 16]. fpNATURAL 2®, also allows for NIR-NIR imaging, where the powders are illuminated with NIR light (730-800 nm) and observed with a 815 nm filter, this has been shown to be effective in visualising fingermarks for this powder. However NIR imaging does have some drawbacks, specialised lighting and imaging equipment is needed, alternatively existing DSLR equipment can be used after removal of the IR filter which can make scene imaging difficult. At this point NIR imaging is primarily performed in the laboratory.

While these new products have come onto the market, the studies into their effectiveness have been quite limited to either a single surface, powder or limited donor pool. The aim of this study is to determine the effectiveness of two NIR powders; Universal Powder (a further development of the powder published by Chadwick et al.) [12] and fpNATURAL 1® when compared to two conventional powders; Black and GREENcharge™ on a range of common surface types. While fpNATURAL 2® has been shown to be a very effective NIR luminescent powder, this study will only focus on the NIR powders that are excited using visible light and give NIR luminescence. Since the excitation of fpNATURAL 2® requires a dedicated NIR light source, it was not included in this study.

Materials and Methods

General Overview:

In order to understand the effectiveness of each powder, three commercially available powders Sirchie Black, GREENcharge™ and fpNATURAL 1® were compared to an in-house developed powder Universal Powder. All powders were applied to natural fingermarks and compared to each other under white light and their respective optimal luminescent conditions. Developed split marks were then digitally stitched back together and scored by three independent assessors using a modified University of Canberra scale [19].

Materials

Substrates

Four substrate types were selected for the study (Figure 1). All substrates were cleaned with ethanol and allowed to air dry prior to fingermark deposition in order to remove any potential contaminating fingermarks.

Table 1: Substrates used in this study

Substrate
Livingstone Premium Pathology Grade Glass Microscope Slides
Aluminium Soft Drink Cans
Coles Snap Seal Polyethylene Bags
Johnson Storm Grey Ceramic Tiles

Powders

Four powders were used in this study. Black and GREENcharge™ (magnetic) were Sirchie products, fpNATURAL 1® was purchased through Foster+Freeman. Universal Powder is a combination powder of the STaR 11 powder published in [12] and GREENcharge™ magnetic fingerprint powder. The powders are mixed in a 1:20 ratio of STaR 11 aluminium oxide powder and GREENcharge™ magnetic powder. The combination of these powders, allows for visualisation in the NIR region, but also extends across the majority of the visible spectra. This provides the examiner with a wider range of visualisation options than other powders currently available. All purchased powders were used as per the current manufacturer instructions and appropriate type of brush or magnetic applicator.

Methods

Fingermark Deposition

Five donors (two female, three male aged 20-35) were asked to deposit three natural marks on each of the substrates listed in Table 1 in a three series depletion. *For the glass and ceramic substrates, two slides or tiles were placed side by side and donors were instructed to deposit with their middle finger on the seam between the two surfaces. For the plastic and aluminium substrates, three fingers were placed on the substrate and were cut in half prior to development.* Following deposition, the marks were aged for five time periods (fresh, one, three, seven and fourteen days). This led to a total of 900 fingermarks collected for each pairwise comparison. Marks were kept in a controlled laboratory environment for the period of ageing. After ageing, marks were split in half and each side was powdered with a different powder.

Fingermark Imaging

All developed marks were first imaged under white light and for the luminescent powders they were also imaged at their optimal visualisation conditions (Table 2**Error! Reference source not found.**). All white light imaging was conducted using a *Video Spectral Comparator (VSC) 6000 (Foster+Freeman Pty Ltd)* to provide a controlled and consistent image for all substrates. While luminescent powders are not marketed for their contrast under white light, it was decided as part of this study to assess how visible the developed marks were under white light to make an assessment on how easily these powders could be used at a large crime scene. All luminescent imaging was conducted using a *Poliview® IV forensic imaging system (Rofin Australia Pty. Ltd., Australia), with a Polilight PL550XL*. Different combinations of excitation and emission filters were trialled and the optimal visualisation conditions are listed in (Table 3) In order to conduct all the required comparisons images were digitally stitched together using Adobe Photoshop 2020 to compare each developed mark. This led to a total of 4500 images.

Table 2: Comparison guide for powders used in this study

Comparison	**Visualisation conditions**					
	White light vs White light	**White light vs Visible**	**White light vs NIR**	**Visible vs Visible**	**Visible vs NIR**	**NIR vs NIR**
Black vs GREENcharge™	✓	✓				
Black vs FpNATURAL 1®	✓		✓			
Black vs UP	✓	✓	✓			
GREENcharge™ vs FpNATURAL 1®	✓				✓	
GREENcharge™ vs UP	✓			✓	✓	
UP vs FpNATURAL 1®	✓				✓	✓

Table 3: Visualisation parameters used in this study for all powders

Powder	Visualisation conditions		
	White light	**Visible Luminescence** *450nm excitation* *555nm bandpass filter*	**NIR region** *450nm excitation* *715nm longpass filter*
Black	✓	n/a	n/a
GREENcharge™	✓	✓	n/a
FpNATURAL 1®	✓	n/a	✓
Universal Powder	✓	✓	✓

Fingermark Analysis

Images were then compared and given a quality score by three independent assessors based on an adapted version of the University of Canberra scale (Table 4) [19]. The independent assessors were fingermark researchers, not fingerprint experts. Score were then collated and median values were determined for each comparison using Microsoft Excel and graphs were generated. Results were then presented as a percentage value of the total number of comparisons conducted.

Table 4: Adapted University of Canberra scale used in this study [19]

Score	Qualitative Equivalent
2	Significant increase in enhancement with Technique A when compared with Technique B
1	Slight increase in enhancement with Technique A when compared with Technique B
0	No difference in enhancement with Technique A when compared with Technique B
-1	Slight decrease in enhancement with Technique A when compared with Technique B
-2	Significant decrease in enhancement with Technique A when compared with Technique B
No Detection	Neither technique developed any mark

Results and Discussion

General Overview

From this study, each comparison was first conducted under white light followed by the optimal luminescent conditions. While the luminescent powders are designed to be imaged in luminescent mode, if they are to be used at a crime scene, the hope is that they are visible under white light to make it easier to recognise when a mark has been developed and where to best image the mark. In most cases all powders were able to provide some visualisation of marks under white light, however the luminescent powders tended to provide lower contrast and poor quality when viewed under white light. This was evident when looking at the number of no detection score for the three luminescent powders under white light, which ranged from 10-65%. This number decreased to 4-10% across all comparisons once the powders were viewed under luminescent conditions. Five donors were used in this study, as previous studies have indicated donors have a significant impact on the effectiveness of a fingermark development technique, however this tends to indicate more about the donor ability to deposit fingermarks than it does about the technique efficiency [20]. Similarly, while different age of marks and depletions were collected, all powder comparisons followed similar trends of increasing number of no detection marks as the age of the mark and depletion number increased. Based on this for clearer comparison between the powders, the results presented have all donors, depletions and ages combined.

Black Powder Comparisons

When comparing black powder to the luminescent powders, the best results for black powder were observed when both techniques were viewed under white light, however when compared under the techniques optimal conditions the differences between the powders becomes less apparent. As seen in Figure 1, when compared under white light the black powder provided much better development when compared to all other powders. There are some instances where the luminescent powders provided some advantages which likely came from samples with a high degree of background powdering from the black powder. When black powder was compared to the luminescent powders at their optimal luminescent conditions, there is a noticeable decrease in the number of 1 and 2 scores and an increase in the 0 and - 1 scores. For example FpNATURAL 1® (FP) when examined under white light 10% of specimens had a score of 0, however when compared in the NIR, the number of 0 scores increases to 48%. When Universal Powder (UP) was compared to black powder in the visible region, black powder provided better enhancement for 44% of the marks, however when the same marks were viewed in the NIR, this decreased to 12%. This demonstrates an advantage of Universal Powder as it can improve the quality of the marks recovered depending on the visualisation condition. Of all the luminescent powders tested, GREENcharge™ (GC) gave slightly better development overall with 41% of samples providing greater enhancement when compared to black powder. UP and FP gave 33% and 27% respectively greater enhancement when viewed in the NIR, while UP in the visible region only gave 8% improvement. Based on these results, when compared at their optimal visualisation conditions, the luminescent powders provide similar performance to black powders. This would imply that there is limited advantages to using luminescent powders since black powder is shown to be very effective. On the surface this result is not unexpected, only one of the substrates chosen (aluminium soft drink cans) would be challenging to visualise using black powder due to its coloured and patterned background. Individual substrate results are explored in later sections to understand these differences.

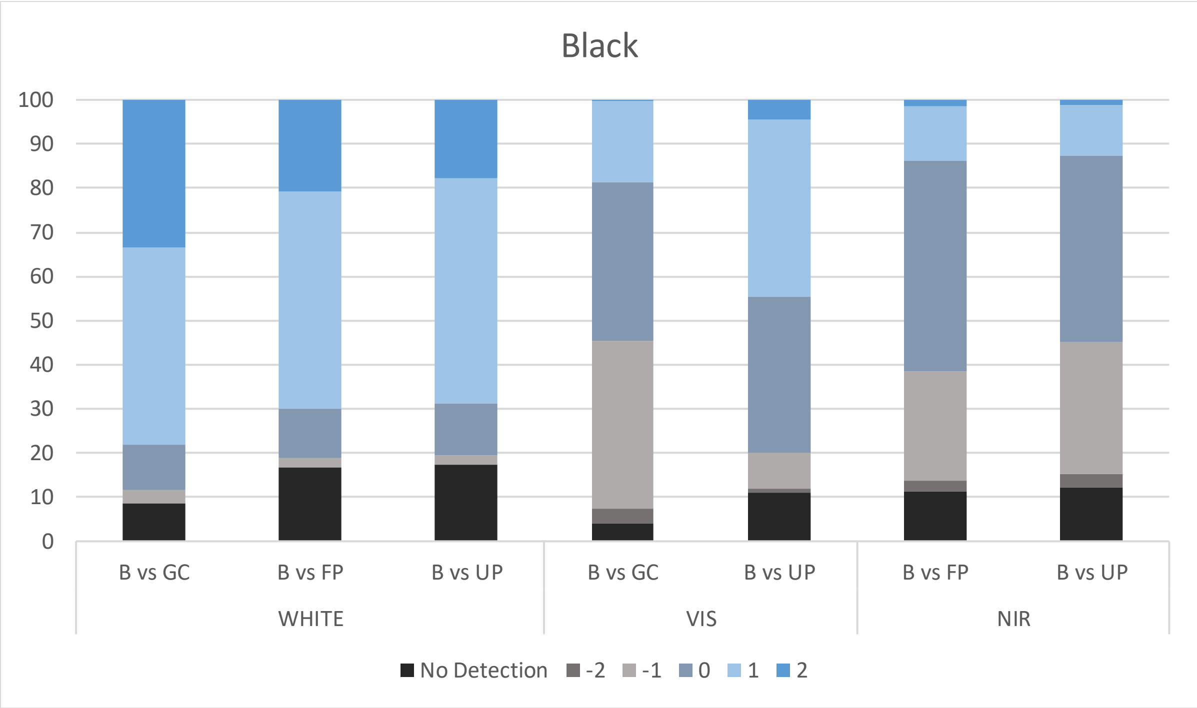

Figure 1: Comparison of black powder (B) to GREENcharge™ (GC), fpNATURAL 1® (FP) and Universal Powder (UP) under all visualisation conditions. Positive scores indicate that black powder performed better, negative scores indicate that the luminescent powders performed better.

Luminescent Powders

When the luminescent powders were compared to each other (Figure 2), the largest number of no detections come from when they are viewed under white light. This result is not surprising since these powders were optimised for luminescent visualisation. This does identify a potential issue that marks may be missed or looked over if they are not easily visible under white light, particularly with the NIR powders where the luminescence would only be visible with specialised cameras/imaging equipment. Similar to the comparisons with black powder, once compared under the appropriate luminescent conditions, the number of no detection scores decreased, and the number of 0 scores increased. When compared under the luminescent conditions, UP and GC performed very similarly, with 44% of developed marks showing no difference, 22% of samples indicated that GC had slight improvement over UP, while 25% of samples indicated that UP has slight improvement over GC. Since both techniques are visualised at the same wavelengths, the differences in performance may be substrate dependant. When GC is compared to FP, ~50% of samples indicated that GC performed better than FP, with only 8% samples showing that FP performed better than GC. This indicates that while FP can reduce interferences from the substrate, on common surfaces the performance of that powder is limited. When GC was compared to UP in the NIR, the performance of UP did decrease relative to when it was imaged in the visible region. This could indicate that not as much contrast was produced in the NIR, when compared to the same mark visualised in the visible region.

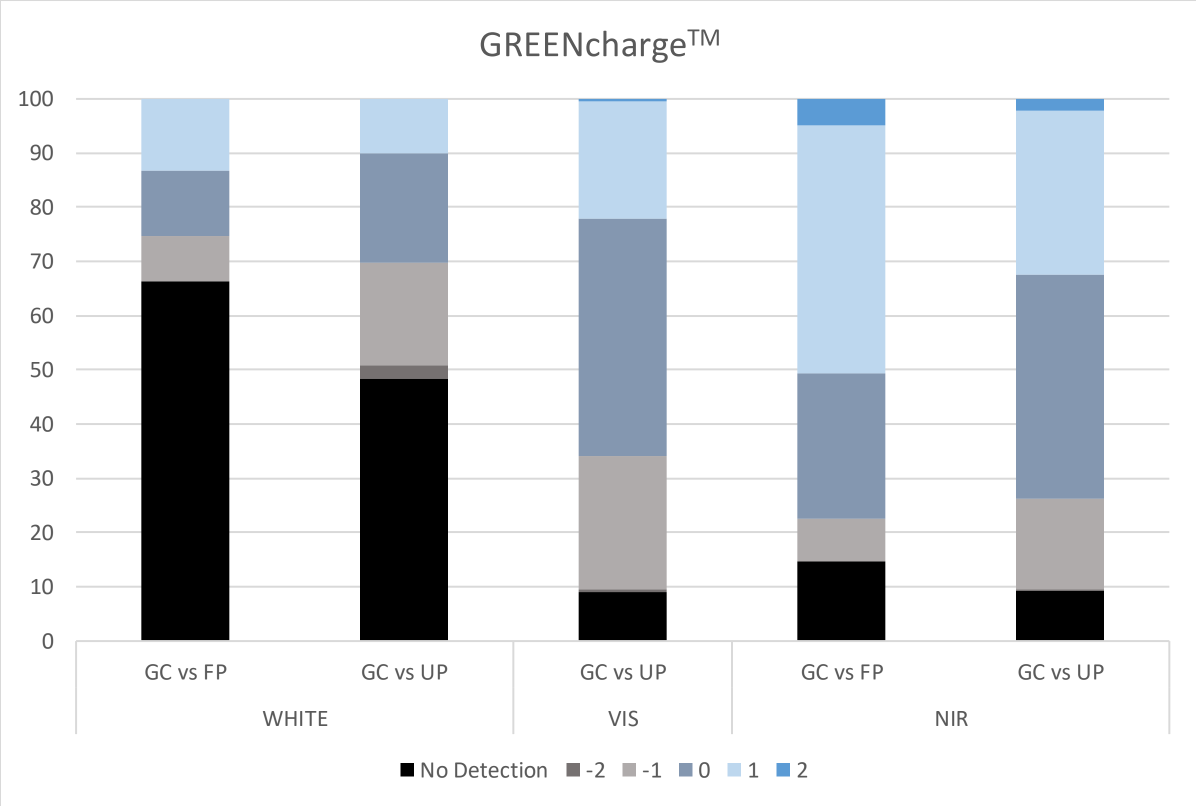

Figure 2: Comparison of GREENcharge™ (GC) with fpNATURAL 1® (FP) and Universal Powder (UP) under all visualisation conditions. Positive scores indicate that GREENcharge™ performed better, negative scores indicate that the NIR powders performed better

NIR Powders

When the two NIR powders were compared to each other (Figure 3), there is a clear indication that Universal Powder performed better than FP under most visualisation conditions. While there was some improvement with FP when shifted into the NIR, the performance of Universal Powder was still stronger than FP. Overall when examined under the visible and NIR region Universal Powder gave better development in 59% and 46% of the samples tested. This is a strong indication that Universal Powder is the preferred NIR fingerprint powder from this study. When looking at the developed marks, FP did not tend to adhere well to weak or aged marks which resulted in more background powdering and poor contrast when compared to UP. There were several instances where FP did give strong luminescence and clear ridge detail, however these cases were quite rare.

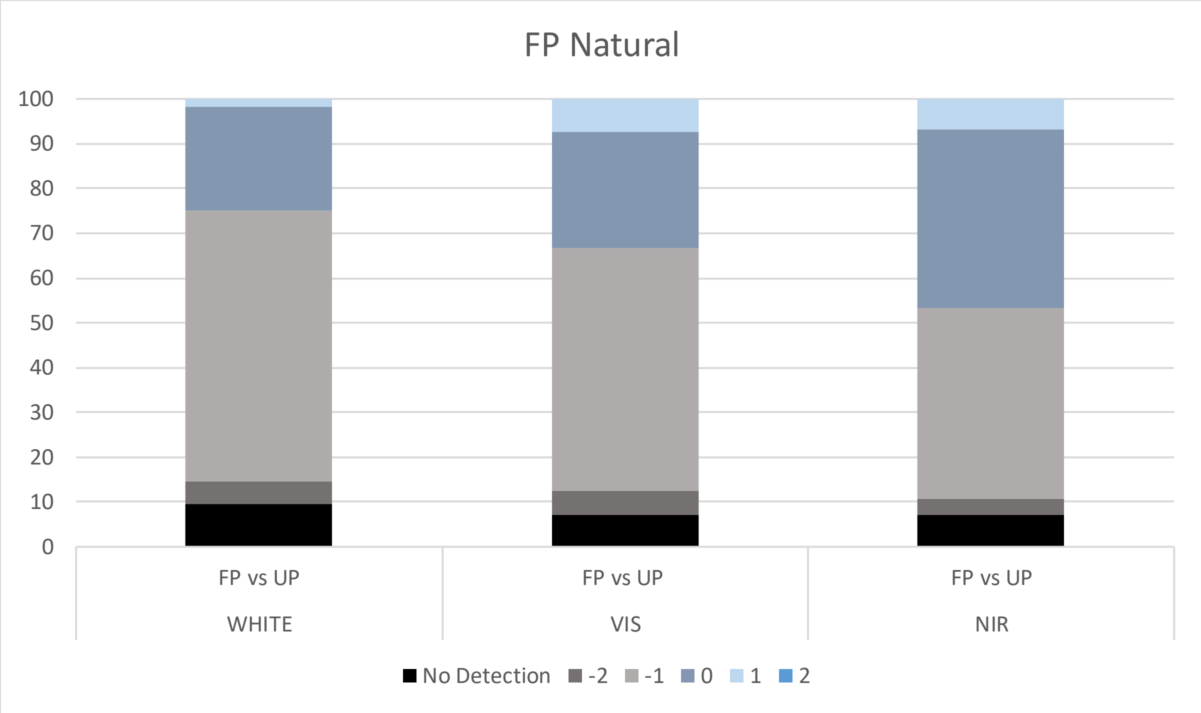

Figure 3: Comparison of fpNATURAL 1® (FP) and Universal Powder (UP) under all visualisation conditions. Positive scores indicate that fpNATURAL 1® performed better, negative scores indicate that the Universal Powder performed better

Surface Comparison

In order to determine if there was any influences from the substrates that may provide some additional information into the performance of each powder, each surface was separated out from each other and only the optimal visualisation condition comparisons were included for analysis (Table 5**Error! Reference source not found.**). This is to reflect the best case comparison for each powder combination.

Table 5: Optimal visualisation conditions for comparison based on surface type

Powder	Optimal visualisation conditions
Black	White light
GREENcharge™	Ex 450 nm, em 555 nm bandpass filter
fpNATURAL 1®	Ex 450 nm, em 715 nm longpass filter
Universal Powder	

Aluminium Cans

Aluminium cans were chosen as a substrate as these provide a strongly patterned/coloured background which has previously been shown to be an effective surface to showcase the advantage of visualising in the NIR. Interestingly this did not appear to be the case in this study (Figure 4, Figure 5). Both black powder and GC were shown to be quite effective on this surface with very little impact on fingermark quality. This can be seen in the results for black powder vs GREENcharge™, which had zero instances of no detection which indicates that a visible mark could be imaged for all specimens tested. When the NIR powders were compared to black powder, there was found to be an advantage with each powder giving better development in ~34% of samples. When the luminescent powders were compared on this surface, there was an increase in the number of no detections (4-12%) and there was an observable difference between each powders performance. FP gave better development in 10% and 7% of samples when compared to GC and UP respectively. This result is interesting since an advantage of NIR imaging is that is allows for the suppression of the background. However in this instance the powder had difficulties adhering to the mark on this surface which may have impacted the ability of the powder to be visualised.

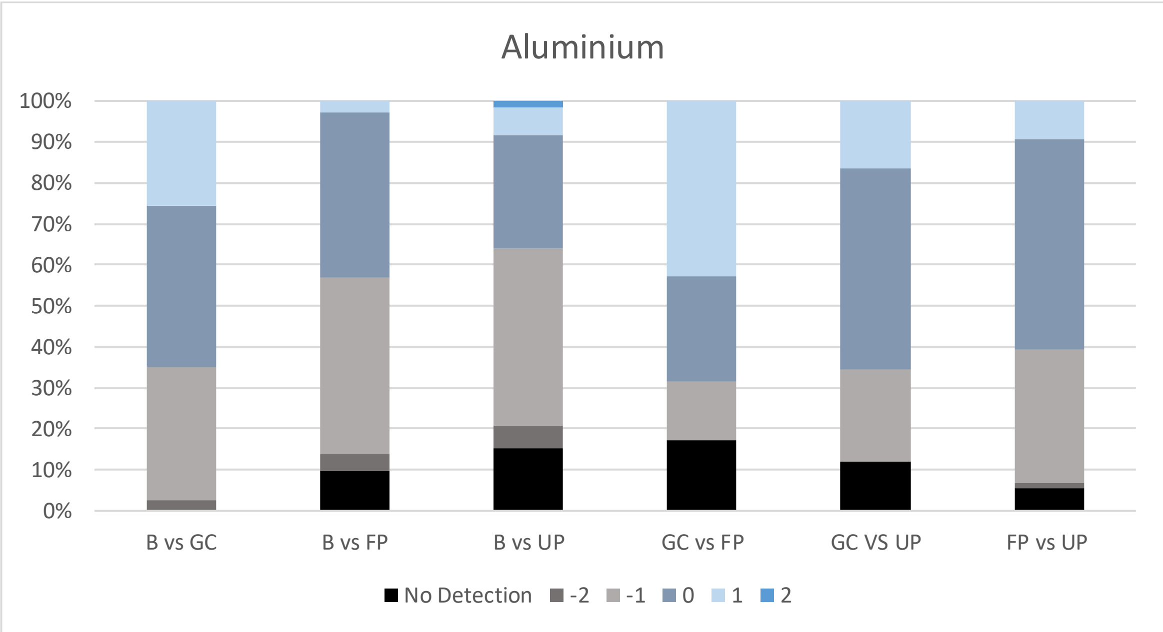

Figure 4: Comparison of all powder black (B), GREENchargeTM (GC), fpNATURAL 1® (FP) and Universal Powder (UP) on aluminium cans. A positive score indicates that the left technique performed better, a negative score indicates that the right technique performed better

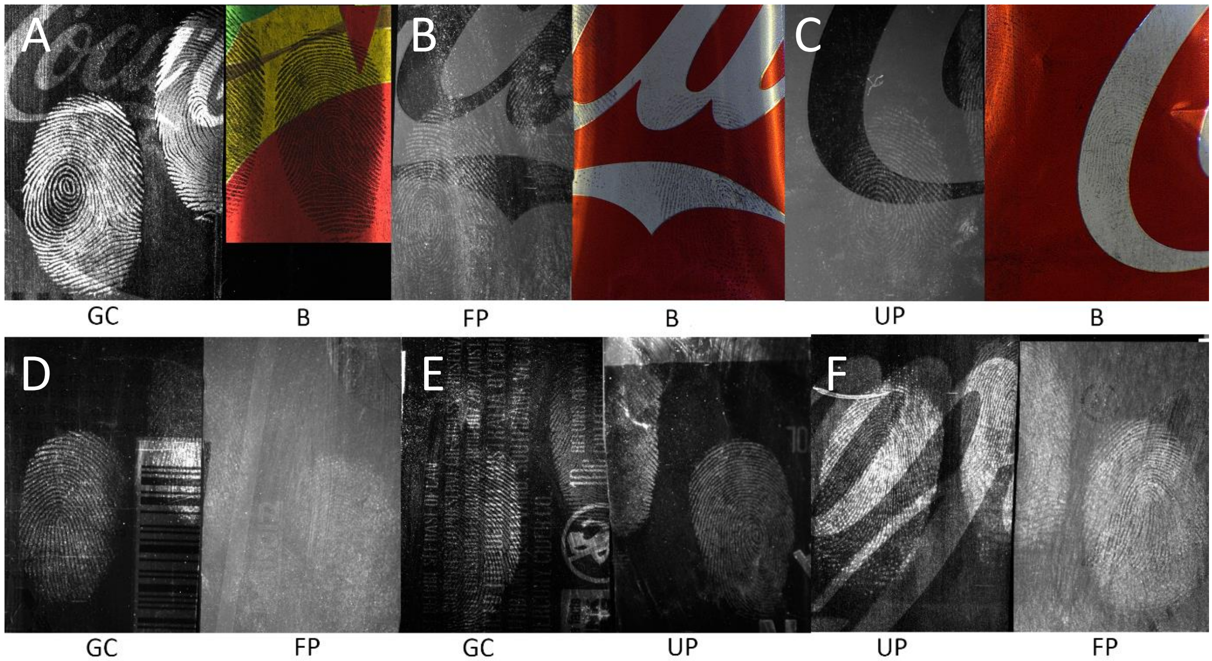

Figure 5: Representative comparison images for fingermarks developed on aluminium cans for: A: GreenCharge^{TM} (GC) vs Black Powder (B), B: fpNATURAL 1® (FP) vs Black powder (B), C: Universal powder (UP) vs Black powder, D Green Charge (GC) vs fpNATURAL 1®, E: GreenCharge^{TM} (GC) vs Universal Powder (UP), F: Universal Powder (UP) vs fpNATURAL 1®

Ceramic Tiles

Ceramic tiles were chosen as it represents a fairly common substrate that can be powdered at crime scenes. All powders were able to develop fingermarks fairly well with very few marks being given a ‘no detection’ score (Figure 6). This indicates that all powders are appropriate for this surface type. In terms of the preferred method, black, GC and UP performed very similarly with comparable amount of positive and negative scores across the comparisons. When compared to black powder, FP gave similar performance, however when compared to GC, there is a clear difference between the powders on this surface, with GC giving better development in ~44% of specimens tested. Based on these results, it would indicate that the NIR powders do not provide any significant advantage over current methods, if a NIR powder was required, then Universal Powder would be the preferred NIR powder method (Figure 7).

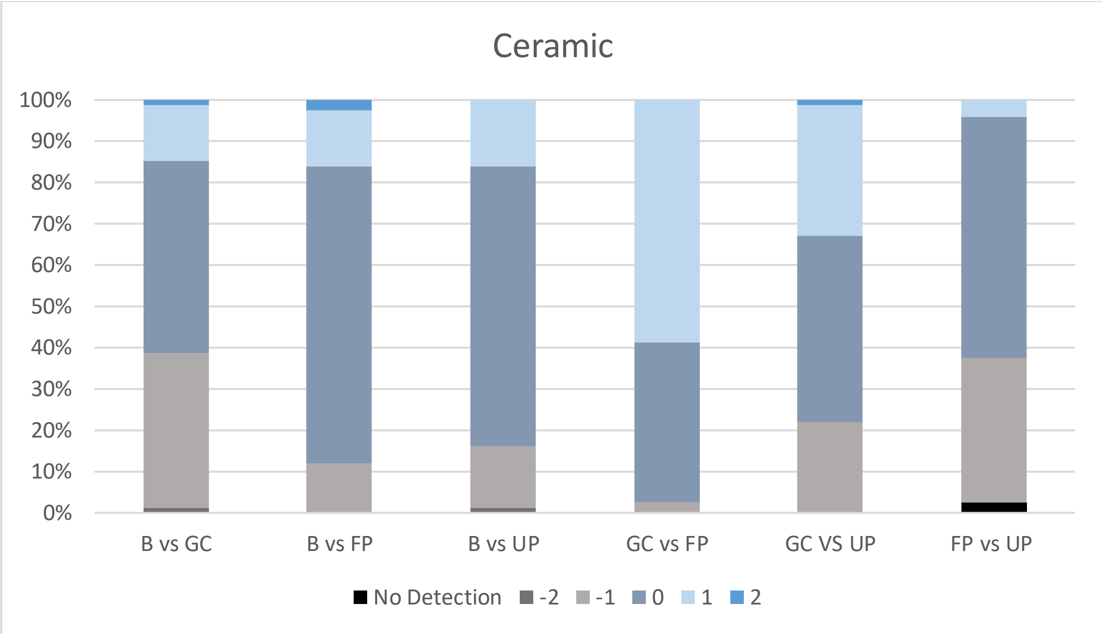

Figure 6: Comparison of all powder black (B), GREENcharge^{TM} (GC), fpNATURAL 1® (FP) and Universal Powder (UP) on ceramic cans. A positive score indicates that the left technique performed better, a negative score indicates that the right technique performed better

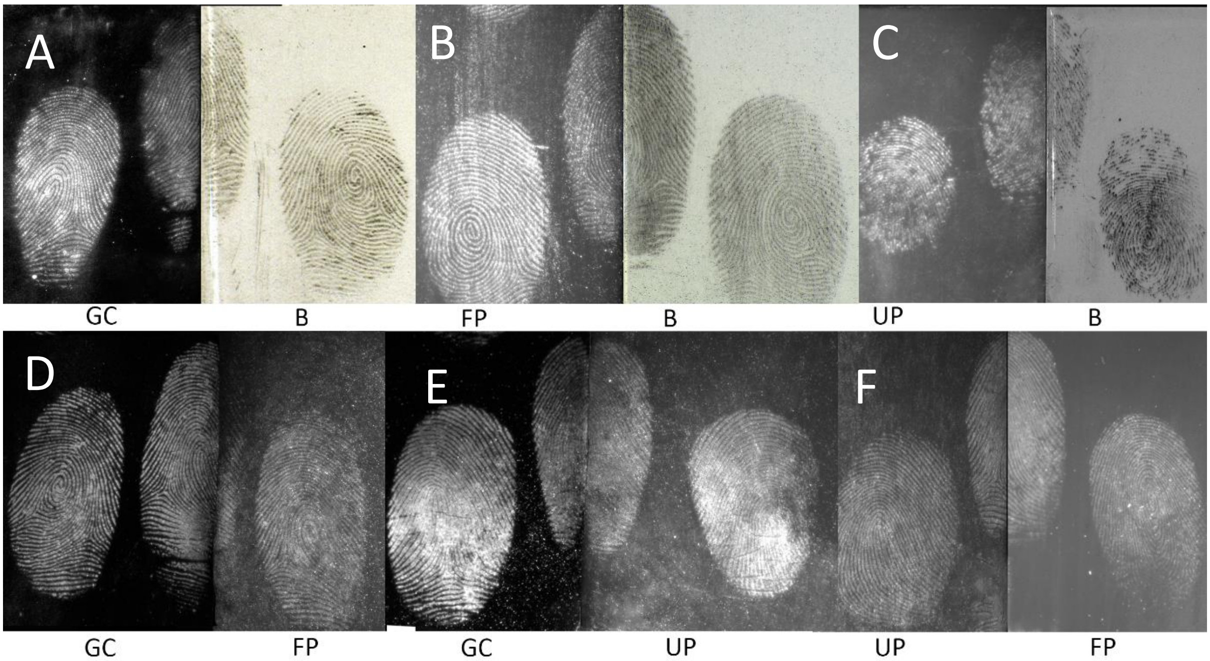

Figure 7: Representative comparison images for fingermarks developed on ceramic tiles for: A: GreenCharge^{TM} (GC) vs Black Powder (B), B: fpNATURAL 1® (FP) vs Black powder (B), C: Universal powder (UP) vs Black powder, D Green Charge (GC) vs fpNATURAL 1®, E: GreenCharge^{TM} (GC) vs Universal Powder (UP), F: Universal Powder (UP) vs fpNATURAL 1®

Glass

Fingermarks on glass gave the highest number overall of no detection scores (Figure 8), which when examined further, tended to be from the aged marks (7-14 days). As with ceramic, GC had very strong performance when compared to all techniques. Black powder tended to provide very little advantage over the luminescent powders, this may have to do with the amount of background powdering which was more apparent for black powder. Unlike other common surfaces, the luminescent and NIR powders actually outperformed the traditional black powder (Figure 9). This indicates that even on surfaces where background interferences are not present, there is an advantage to imaging under luminescent conditions to enhance contrast. GC tended to be the best performing luminescent powders, with 26% and 22% of specimens having a positive score when compared to FP and UP respectively. When comparing the NIR powders to each other, UP did provide better enhancement for 47% of developed marks. Further indicating that UP is the preferred NIR powder from this study.

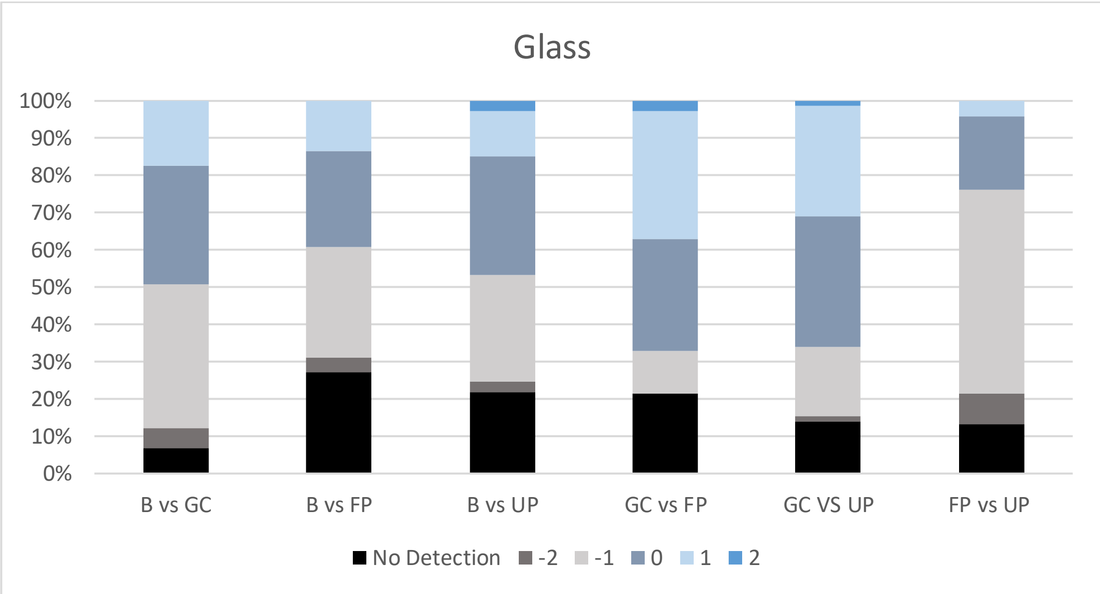

Figure 8: Comparison of all powder black (B), GREENcharge^{TM} (GC), fpNATURAL 1® (FP) and Universal Powder (UP) on glass. A positive score indicates that the left technique performed better, a negative score indicates that the right technique performed better

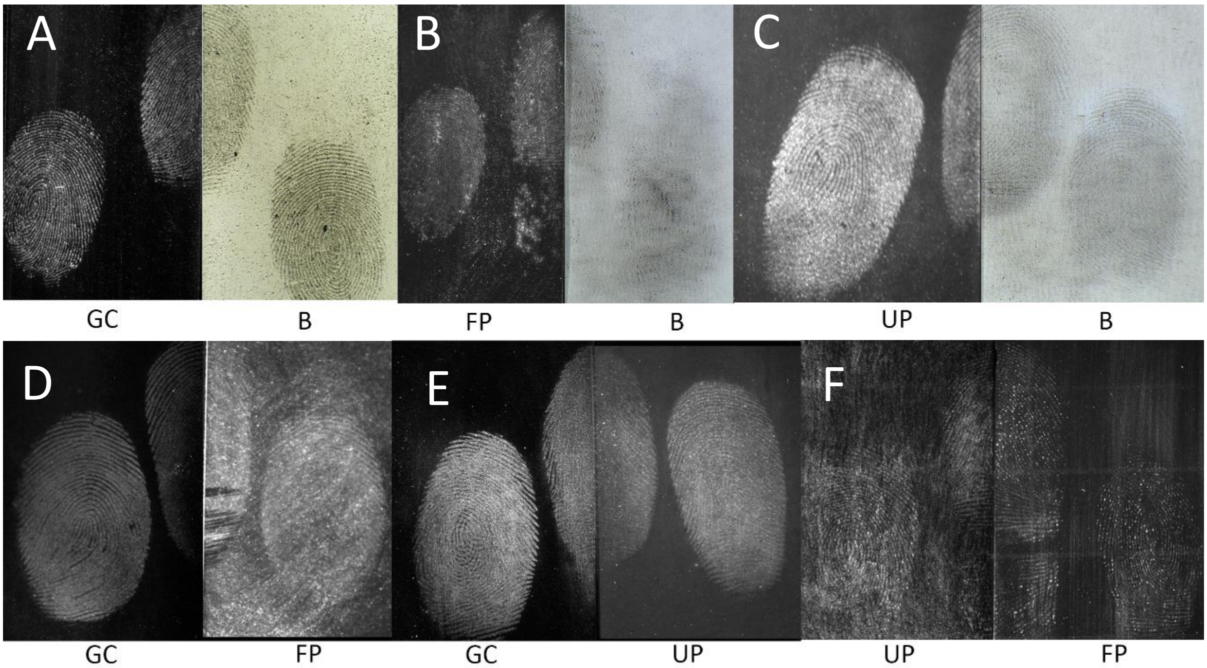

Figure 9 Representative comparison images for fingermarks developed on glass for: A: GreenCharge™ (GC) vs Black Powder (B), B: fpNATURAL 1® (FP) vs Black powder (B), C: Universal powder (UP) vs Black powder, D Green Charge (GC) vs fpNATURAL 1®, E: GreenCharge™ (GC) vs Universal Powder (UP), F: Universal Powder (UP) vs fpNATURAL 1®

Polyethylene Bags

Plastic, while not commonly powdered in case work, was tested in this study to determine the effectiveness of these powders on a commonly encountered substrate (Figure 10). GC gave the best performance out of all the powders tested giving better development across all the comparisons. FP was the poorest performing powder with very few instances of providing better development when compared to other methods. This is clearly illustrated in the comparison between GC and FP with only 9% of specimens indicating that FP performed better. This is further illustrated in the comparison between the NIR powders, where FP only gave better development 7% of the specimens tested. Similar to ceramic, there is little value in using a NIR powder for this type of surface, since the conventional method, in this case GC provides superior development to the other methods tested in this study (Figure 11).

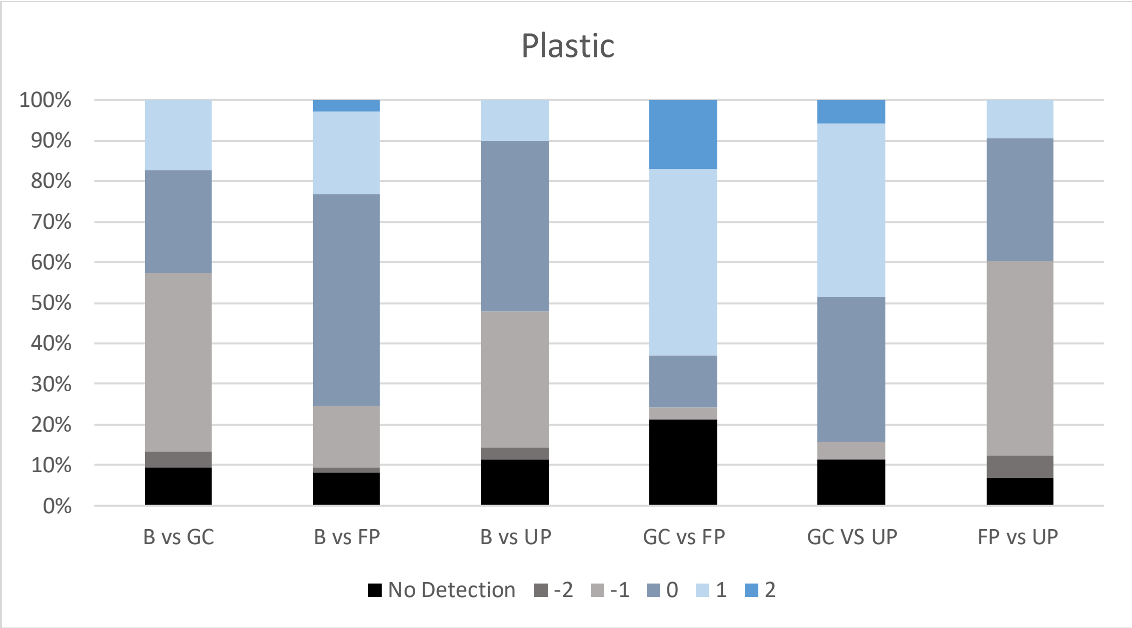

Figure 10: Comparison of all powder black (B), GREENcharge™ (GC), fpNATURAL 1® (FP) and Universal Powder (UP) on polyethylene bags. A positive score indicates that the left technique performed better, a negative score indicates that the right technique performed better

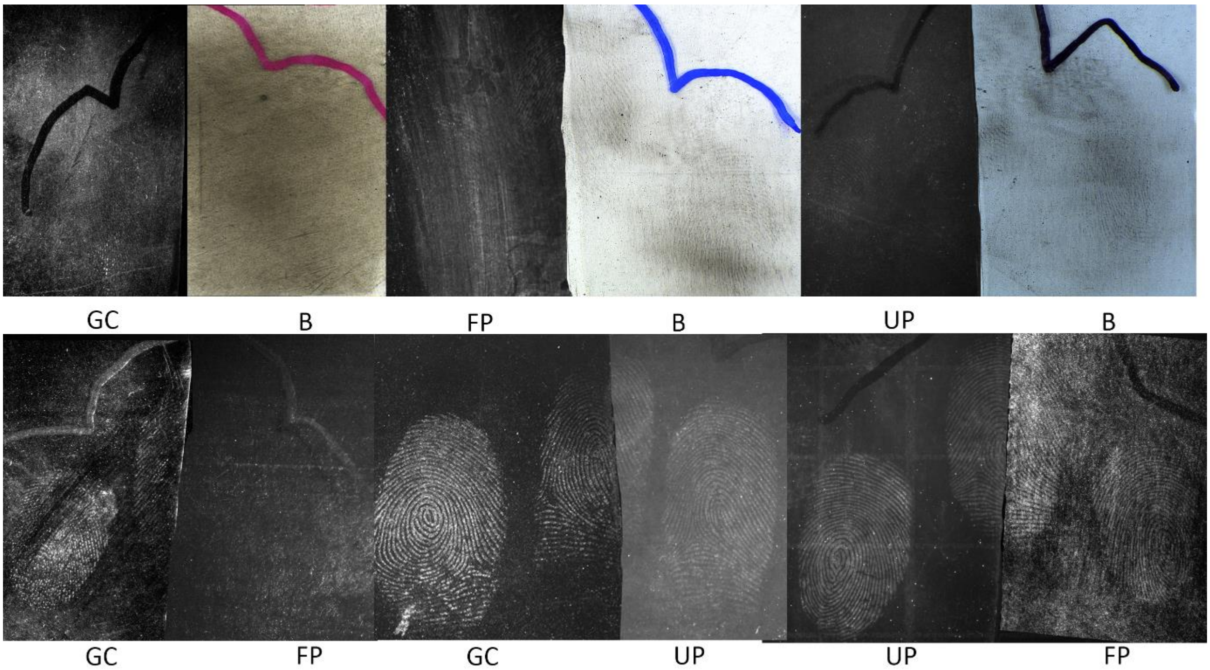

Figure 11: Representative comparison images for fingermarks developed on plastic for: A: GreenCharge™ (GC) vs Black Powder (B), B: fpNATURAL 1® (FP) vs Black powder (B), C: Universal powder (UP) vs Black powder, D Green Charge (GC) vs fpNATURAL 1®, E: GreenCharge™ (GC) vs Universal Powder (UP), F: Universal Powder (UP) vs fpNATURAL 1®

General discussion

The recent development of NIR powders have focussed on specific surface types, such as polymer banknotes [13, 15, 16], outside of these specific surfaces there has been limited research into their performance on more common surfaces. This study has highlighted a few advantages and limitations of the NIR powders, that while they may not replace the conventional methods, they can provide a suitable alternative in certain circumstances. An interesting note from this study was that despite the aluminium cans having a highly patterned background, the background did not always interfere with the visualisation in the visible region. This was seen in the results for GREENcharge™ on aluminium, where it outperformed fpNATURAL 1® in over 30% of samples tested. This tended to be a common trend with fpNATURAL 1®, that while the imaging in the NIR did give a strong background suppression and high contrast, the issue was more with the ability of the powder to adhere to the fingermark. It was noted by the users that it was very difficult to see if fpNATURAL 1® was adhering to the mark when they were powdering, which meant that they occasionally over powdered or gave higher degrees of background development. This indicates a limitation with any powder that is not clearly visible under white light, if the user cannot see the mark when they are developing it, it can make it difficult to judge if more powder is needed. This was also an issue for GREENcharge™ and Universal Powder, however the darker colour of those powders makes it easier to visualise under white light so the users could more effectively judge when to stop powdering.

Based on previous studies [13, 16], fpNATURAL 2® appears to provide better contrast and development when compared to fpNATURAL 1®. Unfortunately due to the costs associated with purchasing the NIR sources in order to use fpNATURAL 2® it was not able to be compared in this study. While this may limit the conclusions that can be drawn on the effectiveness of available NIR powders, finding powders that are compatible with current illumination methods are more likely to be incorporated into the current workflow. A study comparing the different powders using conventional light sources may provide suitable alternatives without compromising the quality of fpNATURAL 2® enhancement.

Another aspect of this project was to examine the performance of Universal Powder and assess its ability to develop marks. Based on the results presented here, it indicates potential for further research. It performed similarly to the commercial powders on most surfaces and was found to be the preferred NIR powder over fpNATURAL 1®. The performance of this powder is largely impacted by the incorporation of GREENcharge™ into the STaR 11 powder, which not only makes it a magnetic powder, but also broadens the visualisation conditions to include most of the visible spectrum and into the NIR region. This provides the user with a choice in which visualisation condition to capture the fingermark image. This was illustrated in Figures 1 to 3 where the performance of Universal Powder did change depending on the visualisation conditions. Further work should be conducted on this powder to assess its ability to develop mark on polymer banknotes and compare to both fpNATURAL 1® and fpNATURAL 2® on this surface type.

Conclusions

This study aimed to compare the effectiveness of a range of powders and assess their ability to develop marks on a range of common and challenging surfaces. In particular this study wanted to examine the performance of two NIR powders, fpNATURAL 1® and Universal Powder, and determine the advantages of these powders could be applied to other surface types. Overall it was shown that both black and GREENcharge™ powders remain the most effective methods for powdering on the surfaces tested in this study. Despite the aluminium cans having high levels of background patterning, suitable contrast was still able to be obtained in the visible region or under white light. Universal Powder did have similar performance to the conventional powders on the tested substrates, however did not provide a significant improvement, whereas fpNATURAL 1® gave poor performance on most of the surfaces tested. Based on this study, NIR powders should only be applied to surfaces where it is known that traditional methods will not work.

References

1. Sodhi, G.S. and J. Kaur, *Powder method for detecting latent fingerprints: a review.* Forensic science international, 2001. **120**(3): p. 172-176.
2. Maynard, P., J. Jenkins, C. Edey, G. Payne, C. Lennard, A. McDonagh, and C. Roux, *Near infrared imaging for the improved detection of fingermarks on difficult surfaces.* Australian Journal of Forensic Sciences, 2009. **41**(1): p. 43-62.
3. Bleay, S. and T. Kent, *The use of infra-red filters to remove background patterns in fingerprint imaging.* Fingerprint Whorld, 2005. **31**(122): p. 225-238.
4. Chadwick, S., P. Maynard, P. Kirkbride, C. Lennard, X. Spindler, and C. Roux, *Use of Styryl 11 and STaR 11 for the Luminescence Enhancement of Cyanoacrylate-Developed Fingermarks in the Visible and Near-Infrared Regions.* Journal of Forensic Sciences, 2011. **56**(6): p. 1505-1513.
5. Bartkowiak, A., A. Siejca, K. Borkowski, S. Lis, and T. Grzyb, *Up-converting LuF3 and NaLuF4 fluorides doped with Yb3+/Er3+ or Yb3+/Tm3+ ions for latent fingermarks detection.* Journal of Alloys and Compounds, 2019. **784**: p. 641-652.
6. Kanodarwala, F.K., S. Moret, X. Spindler, C. Lennard, and C. Roux, *Novel upconverting nanoparticles for fingermark detection.* Optical Materials, 2021. **111**: p. 110568.
7. Kumar, A., S. Tiwari, A. Singh, and K. Kumar, *Synthesis of Gd 2 O 3: Ho 3+/Yb 3+ upconversion nanoparticles for latent fingermark detection on difficult surfaces.* Applied Physics B, 2016. **122**(7): p. 1-10.
8. Ma, R., E. Bullock, P. Maynard, B. Reedy, R. Shimmon, C. Lennard, C. Roux, and A. McDonagh, *Fingermark detection on non-porous and semi-porous surfaces using NaYF4: Er, Yb up-converter particles.* Forensic Science International, 2011. **207**(1-3): p. 145-149.
9. Ma, R., R. Shimmon, A. McDonagh, P. Maynard, C. Lennard, and C. Roux, *Fingermark detection on non-porous and semi-porous surfaces using YVO4: Er, Yb luminescent upconverting particles.* Forensic Science International, 2012. **217**(1-3): p. e23-e26.
10. Wang, M., M. Li, M. Yang, X. Zhang, A. Yu, Y. Zhu, P. Qiu, and C. Mao, *NIR-induced highly sensitive detection of latent fingermarks by NaYF 4: Yb, Er upconversion nanoparticles in a dry powder state.* Nano research, 2015. **8**(6): p. 1800-1810.
11. Wang, M., Y. Zhu, and C. Mao, *Synthesis of NIR-responsive NaYF4: Yb, Er upconversion fluorescent nanoparticles using an optimized solvothermal method and their applications in enhanced development of latent fingerprints on various smooth substrates.* Langmuir, 2015. **31**(25): p. 7084-7090.
12. Chadwick, S., P. Maynard, P. Kirkbride, C. Lennard, A. McDonagh, X. Spindler, and C. Roux, *Styryl dye coated metal oxide powders for the detection of latent fingermarks on non-porous surfaces.* Forensic Science International, 2012. **219**(1-3): p. 208-214.
13. Downham, R.P., E.R. Brewer, R.S. King, A.M. Luscombe, and V.G. Sears, *Fingermark visualisation on uncirculated£ 5 (Bank of England) polymer notes: Initial process comparison studies.* Forensic Science International, 2017. **275**: p. 30-43.
14. Errington, B., G. Lawson, S.W. Lewis, and G.D. Smith, *Micronised Egyptian blue pigment: A novel near-infrared luminescent fingerprint dusting powder.* Dyes and Pigments, 2016. **132**: p. 310-315.
15. King, R.S., P.M. Hallett, and D. Foster, *Seeing into the infrared: A novel IR fluorescent fingerprint powder.* Forensic Science International, 2015. **249**: p. e21-e26.

16. King, R.S., P.M. Hallett, and D. Foster, *NIR− NIR fluorescence: A new genre of fingermark visualisation techniques.* Forensic Science International, 2016. **262**: p. e28-e33.
17. Modica, M., G. Aprea, A. Chiuri, F. Zampa, and G. Lago, *NIR luminescence for the inspection of thermal paper: a novel tool for fingermarks detection.* Forensic Science International, 2014. **244**: p. 50-56.
18. Shahbazi, S., J.V. Goodpaster, G.D. Smith, T. Becker, and S.W. Lewis, *Preparation, characterization, and application of a lipophilic coated exfoliated Egyptian blue for near-infrared luminescent latent fingermark detection.* Forensic Chemistry, 2020. **18**: p. 100208.
19. McLaren, C., C. Lennard, and M. Stoilovic, *Methylamine pretreatment of dry latent fingermarks on polyethylene for enhanced detection by cyanoacrylate fuming.* Journal of Forensic Identification, 2010. **60**(2): p. 199.
20. Chadwick, S., S. Moret, N. Jayashanka, C. Lennard, X. Spindler, and C. Roux, *Investigation of some of the factors influencing fingermark detection.* Forensic Science International, 2018. **289**: p. 381-389.