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An evaluative comparison of the effectiveness between water-based and ethanol-based Basic Yellow 40 staining as a post 'Super-Glue' fingerprint enhancement technique

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Abstract

Finger marks have often been considered to be one of the most valuable types of evidence that can be found at crime scenes. Cyanoacrylate fuming or "Super-glue" fuming is the most widely used chemical technique for latent finger mark enhancement on non-porous surfaces. There has been extensive research regarding the comparison of various enhancement techniques following cyanoacrylate fuming. However, little research has been conducted regarding the differences between water-based and alcohol-based fluorescent dyes. This study assessed the effectiveness of water-based Basic Yellow 40 (BY40) against the conventionally used ethanol-based Basic Yellow 40 in terms of its ability to enhance finger marks to produce clear friction ridge detail. Both non-porous and semi-porous substrates were used, all of which are frequently submitted to operational forensic laboratories for finger mark enhancement. The results indicate that water based BY40 is a suitable enhancement technique for plastic substrates such as freezer bags and self-seal bags, and appears equivalent to ethanol based BY40 for metal substrates. As a conclusion, water-based fluorescent dyes have the potential to be introduced in order to reduce the health and safety risks associated with ethanol, as well as being more cost-effective.

Keywords: Finger marks; Cyanoacrylate; Basic yellow 40; Fluorescent; Enhancement; Non-porous substrates

Introduction

Ethyl-cyanoacrylate (CNA) fuming, more commonly known as “Superglue” fuming, is one of the most widely used techniques in terms of the development of latent finger marks on non-porous substrates (Bandey 2014). CNA is a colourless, viscous liquid (Lee and Gaensslen 2015) with the molecular formula $C_6H_7NO_2$ (PubChem 2015). The skeletal structural formula is shown by Figure 1.

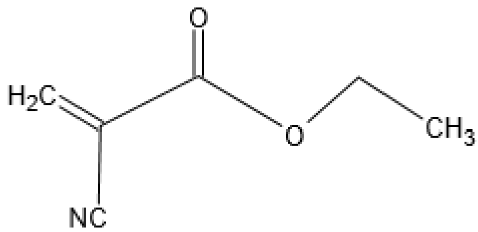

Figure 1: 2D skeletal structural formula of ethyl-cyanoacrylate. Created using ChemSketch software produced by ACDLabs and adapted from PubChem (2015).

Under recommended temperature and relative humidity, CNA will evaporate and undergo polymerisation on the ridges of finger marks thereby forming a white deposit. In the early days of fingerprint development, Superglue fuming was used on its own. However, it was soon discovered that the use of post-staining caused visualisation to be more significant, therefore, CNA fuming is not effective as a technique without the use of post-treatment staining. The fuming process results in the establishment of a fine substrate for dye adherence and it is thought that the molecules within the dye get trapped in the voids between the cyanoacrylate polymer chains, forming the basis of visualisation (Menzel 1999). Over the years, a range of staining techniques have been developed including the fluorescent dye Basic Yellow 40 (BY40) which is the most common and most widely available dye involved in CNA fuming. BY40 can also be referred to as Maxilon Brilliant Flavine (Ramotowski 2012) and it generally replaced the dye Rhodamine 6G (R6G) in the 1980s due to it being a suspected carcinogen although R6G is still used by some organisations (Bleay et al. 2013).

The polymerisation mechanism associated with CNA fuming is not well understood. However, Wargacki, Lewis and Dadmun (2007) devised the theory that the polymerisation of ethyl cyanoacrylate can be proved to be initiated by the major constituents of eccrine sweat, in particular those that are shown in Table 1. It is believed that these constituents vary depending on various factors such as diet, lifestyle and age (Girod, Ramotowski and Wyermann 2012) and therefore may affect the initialisation process which may lead to a reduced number of finger marks developed. By contrast, the presence of aqueous material, primarily water, will initiate the formation of further polymers and, since there is an abundance in eccrine sweat, all latent finger marks have the potential to be developed (Bandey 2014). In addition to this, L. A. Lewis et al. (2001) undertook a study which proved that the composition of prints determined the quality of any developed prints, rather than fuming conditions.

Constituent of Eccrine Sweat	Abundance (%)
Sodium Chloride	43.83
Lactic Acid	29.22
Urea	11.69
Amino Acids	7.79
Others	7.47

Table 1: The major constituents of eccrine sweat secreted from the palms of an individual (Wargacki, Lewis and Dadmun 2007). The 'Others' category includes the solutes monosodium phosphate, glucose and dipotassium phosphate

Ongoing research is presently being directed towards a 'one-step' method of CNA fuming with the aim of reducing the need for post-staining procedures by introducing immediate fluorescent fingerprints following fuming (Lennard 2013) as it is believed that the resultant developed finger mark would be stained as part of the one-step process. However, this process is still relatively new and, as a consequence, it is not known if post-staining will still reveal better quality finger marks and this reduces the validity in terms of reducing costs and time. In a recent Fingerprint Visualisation Manual Update published by the Home Office in February 2016 (Bandey 2016) it is mentioned that such methods could result in substrates that have traditionally been difficult and problematic being less so with this new treatment, although problems may still occur relating to the stability and brightness of the resultant fluorescence of marks. Equipment, for example, may require more regular and substantial cleaning regimes and, as a consequence, this may be a less practical method when compared with a more traditional route.

This project centred on a comparison of ethanol-based and water-based BY40 staining following CNA fuming on a defined range of substrates in which there has been limited research. Currently, water-based BY40 may not necessarily be used operationally within forensic laboratories due to it being perceived to lead to a less intense fluorescence but, with the use of ethanol, comes disadvantages. Ethanol is limited to being used where there is sufficient ventilation and extraction and, as well as being highly flammable (HOPSDB, 2003), is damaging to certain surfaces such as varnishes and those encompassing printed inks (Bleay et al. 2013). On the other hand, ethanol is non-toxic as well as effective across a number of different non-porous substrates. If it can be established that there is no significant difference between ethanol and water-based BY40, then it would be more beneficial to use water due to the many drawbacks of ethanol, primarily health and safety aspects but also cost.

Materials and Methods

Sample Preparation

Surfaces

Both non-porous and semi-porous surfaces were used as substrates in order to assess the enhancement on a range of items often received at police chemical enhancement laboratories. Non-porous materials cannot absorb liquid whereas semi-porous materials allow the absorption of certain liquids and the aqueous material of a finger mark may be absorbed slowly following deposition (Kriel 2011). These substrates will be referred to as exhibits and are outlined together with the quantities used in Table 2. All exhibits were purchased new where possible and wiped in the laboratory using a sterile cloth in order to remove any potential finger marks present that would contaminate the exhibit and lead to undesirable enhancement. The desire to keep the location of the donor-deposited finger marks known was important in order to make enhancement easier by targeting the specific areas.

Porosity	**Exhibit Treated**	**Type and Colour**	**Colour**	**Purchased from**	**Quantities Used**
Non-Porous	Supermarket Plastic Bags	High Density Polyethylene (HDPE)	Orange	Sainsburys	3
	Freezer Bags	Polythene	Pale blue	Wilkos	3
	Small Self-Seal Bags	Polythene	Transparent with white strip across centre	Wilkos	12
	Knives	Stainless steel	Silver	Wilkos	6
	Scissors	Stainless steel blade with plastic handle	Silver and black	Tesco	6
	Plastic Bottles	Polyethylene Terephthalate (PET)	Transparent	Sainsburys	6
Semi-Porous	Heavy Duty Paper - 170gsm (g/m^2)	Glossy	White	Nottingham Trent University	3
	Glossy Magazine Pages	Sainsburys magazine	Various colours	Sainsburys	3

Table 2: Detailed information about exhibits used in this project

Reagents

Both fluorescent dyes were prepared following CAST guidelines (Bandey 2014). To prepare the water-based BY40 dye, a Powder Suspension Stock was made using 40mL of distilled water mixed with 35mL ethylene glycol (Sigma Aldrich, United Kingdom) and Triton X-100 (Sigma Aldrich, United Kingdom), the latter being a detergent. 1mL of this solution was then thoroughly mixed with 500mL of distilled water together with 0.5g of Basic Yellow 40 powder (Ciba-Geigy).

Finger marks

Donors

Throughout the study a total of three donors were used – one male and two females - and all consented to donating their finger marks. All donors left their finger marks on each type of exhibit as opposed to having a designated 'best' donor as this would constitute less of an experimental environment and is therefore representative of real-life forensic submissions.

Deposition Protocol

Prior to deposition, lines were drawn on the exhibits (excluding knives, scissors, bottles and self-seal bags) to produce 4x3 grids to allow a more efficient visualisation. The grids comprised of three rows of four squares, providing a surface for donors to deposit four finger marks on each exhibit containing a grid. This allowed for the exhibit to be cut into two sections in order to process half of each exhibit (two squares per donor, six squares in total) with each dyeing procedure. In order to obtain deposition on the plastic bottles, donors were asked to simulate drinking and for the knives and scissors, the donors were asked to leave various marks on both the blades and handles. The self-seal bags were transparent with a double white strip across one side therefore the donors were asked to deposit two marks on each bag, one on the transparent background and one on the white background. In order to produce good finger marks, the donors were requested to apply a natural amount of pressure and create a rolled impression from base to top of the fingertip, maximising the potential for detail being deposited.

Ageing

CNA fuming can be employed for finger marks that have been left a considerable duration of time between deposition and treatment (Yamashita and French 2010) unless the finger mark has been subject to harsh environmental conditions, such as high temperatures (Cadd et al. 2015). It is believed that 24 hours or more should be left between leaving a finger mark and processing it for chemical enhancement, as any less than this would not be representative of current operational circumstances. From Kent's (2010) recommendations, between 7 and 28 days is useful as a timescale. Based on these recommendations, all of the exhibits were stored in laboratory conditions at room temperature (21 ±0.5°C) for 12 days before being treated, with BY40 being applied within one hour of CNA fuming. The duration between fuming and the application of dye was influenced by the fact that aged prints have a tendency to become more translucent, which therefore causes the visibility of the white deposit to decrease, a statement made by Ramotowski (2012). An increased translucency of the finger mark will also reduce contrast between the mark and background. The final process of visualisation was undertaken within one hour of the exhibits drying following the dyeing process.

Storage conditions were kept constant throughout this study. All the exhibits were kept in shaded areas to ensure sunlight did not affect the aqueous material and volatile compounds of the finger marks as these could also affect degradation (Payne et al. 2014).

Equipment and Processing

The Mason Vectron MVC3000 cabinet (Foster and Freeman) was utilised for this project, which had recently been cleaned and serviced, meeting the manufacturer requirements. The MVC3000 model is a smaller variety of cabinet with a capacity of 620 litres (Foster and Freeman 2014). It has a pre-set 'auto cycle' fuming involving a 1 minute initialisation followed by a 15 minute humidifying cycle, a 15 minute glue cycle and a further initialising stage before a 20 minute full purge. Under these pre-set conditions, approximately 3g of Sureloc CA5 Superglue (Sureloc, United Kingdom) was placed in an aluminium foil dish and secured. This was heated to 120°C with relative humidity reaching 80% (Hahn and Ramotowski 2012). Controls of groomed finger marks left on aluminium foil were used alongside the exhibits to determine the success of fuming and deposition. After each full fuming cycle the control finger marks were developed with success, showing clear detail.

Following CNA fuming, exhibits with 4x3 grids were cut into two pieces and labelled in order to process one side with ethanol-based BY40 and one with water-based BY40. Quantities were doubled for those exhibits that were unable to be divided into grids, in order to allow both treatments to be applied. When enhancing the developed finger marks, the procedures suggested by CAST (Centre of Applied Science and Technology) regarding the application of dyes were followed (Bandey 2014). Exhibits treated with ethanol-based BY40 were left for 20 seconds after the application of the dye and those treated with water-based BY40 were left for 1 minute before washing with tap water to remove excess dye and leaving to dry.

For classification, a Crime-Lite ML supplied by Foster and Freeman was used at a wavelength of 430-470nm with a Schott GG495 filter. This instrument produces light at multiple wavelengths between 400 and 700nm that can be selected depending on the fluorescence of the finger marks, which is determined by the fluorescent dye used, although the excitation spectrum regarding BY40 is broad (Champod 2004). The coloured filter allows a safe viewing of the developed finger marks. The equipment is used with minimal external light present in order to maximise the visibility of ridge detail. It was used by directing the light onto the exhibit and placing the head of the Crime-Lite ML in close proximity to the exhibit which magnified any finger marks present.

Imaging

In order to photograph developed finger marks, the instrument DCS-4 produced by Foster and Freeman was used, which promises to capture fingerprints on various surfaces and backgrounds whilst maximising detail revealed (Foster and Freeman, 2015). A digital single lens reflex camera (Nikon, Japan) with a specialist lens was aligned above an imaging filter and various wavelengths of light were selected in order to determine the optimum wavelength to visualise the most friction ridge detail. No image enhancement methods were used on any photographs in this project in order to allow a fair comparison between the two techniques.

Scoring

An initial examination following CNA fuming was undertaken to assess the number of finger marks visible to the naked eye by viewing the white deposit formed from the treatment process. Due to the location of where each finger mark had been deposited being known, for example within each grid section, white deposits were identified revealing apparent friction ridge detail. A scoring system was not used for the initial examination but a quantity was noted. Following the treatment with BY40, a scoring method (Table 3) based on a Home Office newsletter publication was utilised for the purpose of comparison between methods (HOSDB 2006). Each finger mark developed was assigned a score of 0 to 4 depending on the amount of friction ridge detail visible in that mark as a whole.

Score	Detail Visualised
0	No evidence of a finger mark
1	Some evidence of a finger mark but <1/3 of mark contains friction ridge detail
2	1/3-2/3 of finger mark contains friction ridge detail
3	>2/3 of finger mark contains friction ridge detail
4	Full development – whole finger mark displays clear friction ridge detail

Table 3: Scoring system used to grade the quality of developed finger marks

Results

Initial Examination

As previously mentioned, an initial examination was carried out prior to the dyeing process. This was undertaken in order to assess the amount of finger marks that were visible to the naked eye that could subsequently be used to identify ridge detail following the application of each BY40 dyeing procedure.

The results of the initial examination revealed a total number of 143 marks visible out of a possible 270 marks (Table 4) deposited by a total of three donors.

Exhibit Type	Number of Marks Visible	Total Marks Deposited	Percentage Visible (%)
Supermarket Plastic Bags	22	36	49
Plastic Bottles	18	30	60
Freezer Bags	26	36	58
Knives	31	48	65
Magazine Pages	12	36	33
Heavy Duty Paper	0	36	0
Self-Seal Bags	14	24	58
Scissors	20	24	83
Total	143	270	53

Table 4: Results from the initial examination showing an overall percentage of finger marks visible to the naked eye before the dyeing process

Out of the 143 visible marks, 18 of these were categorised as partial marks in which there was apparent ridge detail to show evidence of a finger mark having been deposited. There were not, however, enough Galton features seen to be able to visualise single friction ridge detail. Galton features, devised by Francis Galton, also referred to as minutiae, include three basic categories of ridge characteristics: dots (Fig. 2a); ridge endings (Fig. 2b) and bifurcations (Fig. 2c) where a ridge divides (Galton 1892).

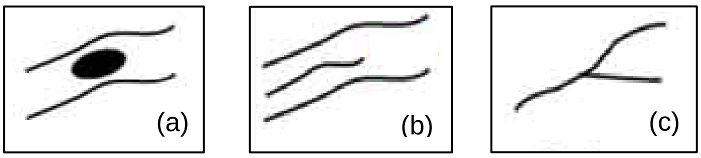

Figure 2: Examples of the three basic categories of ridge characteristics devised by Francis Galton - ridge dot (a), ridge ending (b) and bifurcation (c). Figure adapted from Crime Scene Investigator Network 2016

The overall success rate of the initial examination was calculated to be 53%. This percentage may differ depending on the individual practitioners', their training and their experience, whereby they might utilise available lighting in more or less effective ways. Trends, in terms of donor qualities, were recognised at this stage too. The amount of sweat deposited on items by each individual is dependent on their metabolism, which may inhibit or increase their ability to leave a detailed deposition. For

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example, two of the donors did not appear to deposit clear and detailed marks on a number of occasions causing these deposits to not be visible to the naked eye in the initial examination.

Background colours of exhibits can also affect a person's ability to visualise developed finger marks following CNA fuming. During the study, visibility was found to be very limited where white glossy paper was used as an exhibit substrate, owing to the nature of CNA fuming, which results in white deposits on a white background and therefore provides little or no contrast perceivable to the naked eye without further enhancement.

Ethanol-Based BY40 Development

Half of the finger marks deposited on all exhibits were treated with ethanol-based BY40 following CNA fuming. As a total of 270 depositions were left on the exhibits and the exhibits were split into two for each treatment, there was an initial expectation that 135 marks would be developed using ethanol-based BY40. Although a total of 135 scores were assigned to the finger marks, this did not necessarily mean that all 135 marks were successfully developed due to the grading system (Table 3) incorporating a 0 score whereby no evidence of a finger mark was present.

The modal score from the marks developed using ethanol-based BY40 was 1 (Fig. 3). As can be seen in Table 3, a score of 1 relates to the finger marks showing signs of contact but with less than a third of friction ridge detail visible. Following this development, the exhibit that led to the highest frequency within the higher score category were the plastic bags. The exhibits that led to the most unsuccessful development were metal knives and magazine pages as most of the marks were assigned a score of 0 (Fig. 4).

In terms of noticeable trends, this treatment led to more fluorescence on all exhibits but did not necessarily lead to more identifiable friction ridge detail. For example, on the white strip of the otherwise clear self-seal bags, the fluorescence was too intense to observe features of most marks present at the recommended wavelength of 445nm. A slightly lower wavelength of 410nm was needed to visualise the white strip area of the self-seal bags. Conversely, fluorescence was more effective on the supermarket plastic bags used, leading to more distinctive visible details at the 445nm wavelength, as recommended.

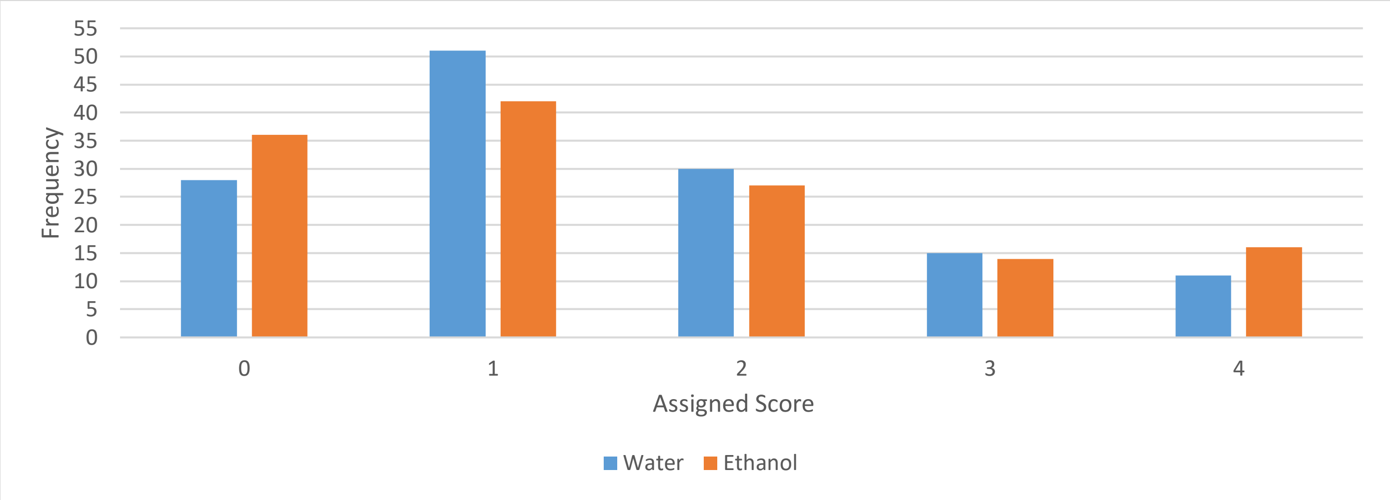

Figure 3: Overall frequency of marks developed that were assigned a score of 0, 1, 2, 3 or 4 using the scoring system previously mentioned (Table 3) following each enhancement technique.

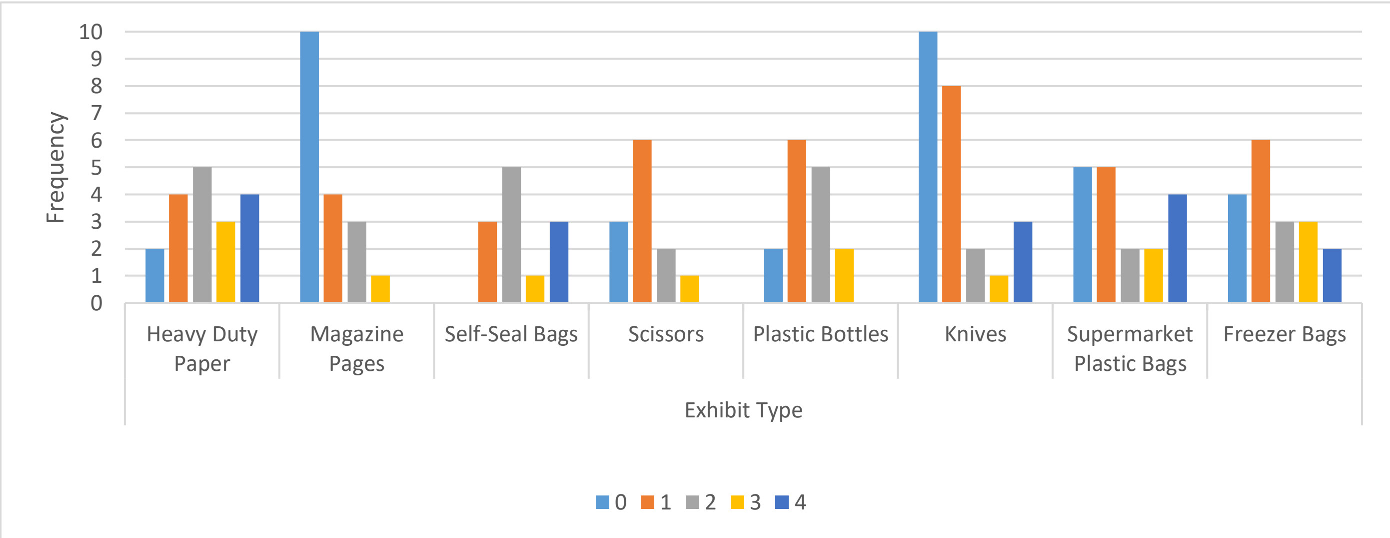

Figure 4: Frequency of scores 0-4 assigned to finger marks developed using ethanol-based Basic Yellow 40 on each exhibit type

Water-Based BY40 Development

As with the results from the treatment with ethanol-based BY40, finger marks developed using water-based BY40 also led to a modal score of 1 (Fig. 3). The total number of marks assigned a score was 135, which was expected, as previously mentioned, due to halving of the 270 depositions between the two BY40 treatments following CNA fuming. This water-based enhancement method was most successful on the self-seal bag exhibits, which led to the highest frequency of a score of 4 being assigned to the marks. Of all of the exhibits used, the most inefficient seen with this treatment were the glossy magazine pages, which resulted in mostly scores of 0 (64%) being assigned (Fig. 5) to finger marks on that exhibit.

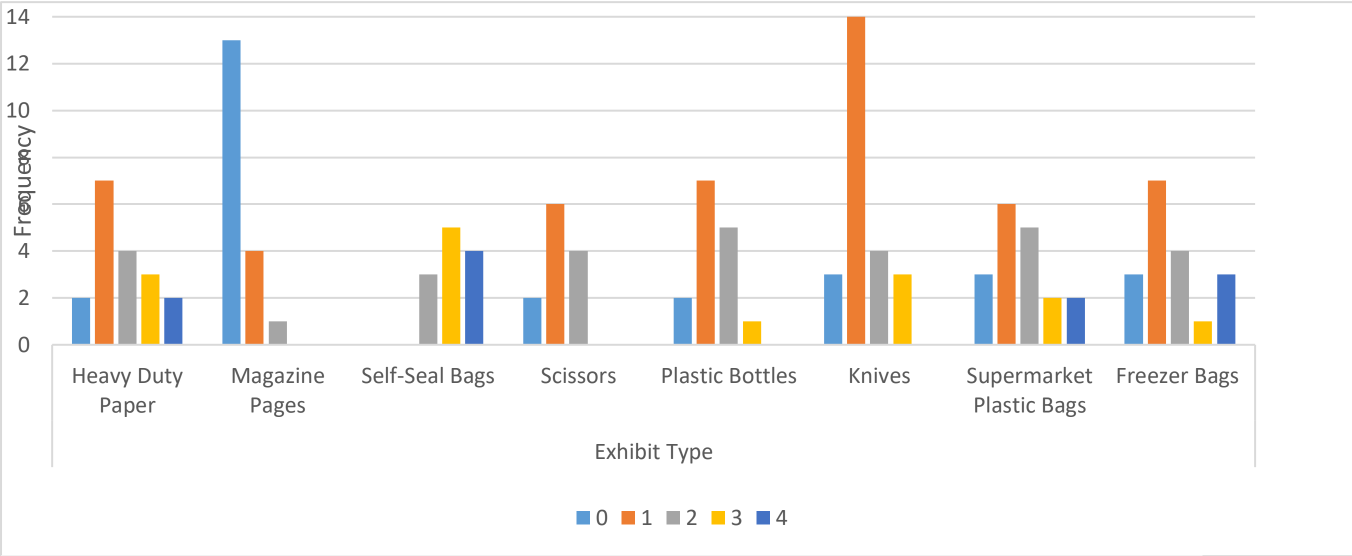

Figure 5: Frequency of scores 0-4 assigned to finger marks developed using water-based Basic Yellow 40 on each exhibit type

As expected, and as previously referred to in section 3.2, fluorescence was not as strong as with ethanol-based BY40. This resulted, for example, in lower scores for some exhibits such as the supermarket plastic bags. On semi-porous exhibits, in particularly paper, the application of this treatment resulted in a speckled appearance. The dye, it seemed, came together in particular areas, which was perhaps a consequence of the dye drying quicker in those areas or from having been somewhat absorbed by that substrate. However, further research in this area is required to fully understand what mechanism occurred with this substrate. This effect appears to have occurred though, due to the solution being sprayed onto the exhibit. In an attempt to overcome the issue, a dipping technique was considered in an effort to maximise potential enhancement and theoretically prevent the dye from concealing the friction ridge detail. CAST on the contrary, state that the actual method of dye application, whether sprayed or dipped, is not a critical factor to the success of the enhancement of finger marks (Bandey 2014). However, in the experiments carried out here, it did appear to affect semi-porous substrates.

Results on Specific Substrates

As outlined in Table 2, the substrates included both non-porous and semi-porous surfaces. Non-porous items included three different types of plastic bag – self-seal, supermarket (carrier) and freezer bags, as well as plastic bottles, knives and plastic-handled scissors. Semi-porous objects included heavy grade paper and magazine pages. There were between 2 to 8 marks were deposited on each single exhibit depending on the size, with totals of between 24 and 48 marks deposited on each exhibit type (Table 4).

Each finger mark was assigned a score to indicate its suitability to be later identified, following the dyeing procedure applied with either with ethanol-based or water-based BY40, using the grading system previously described (Table 3). In order to show an example of the scoring employed, a series of finger marks that were assigned each score can be seen in Fig. 6 below.

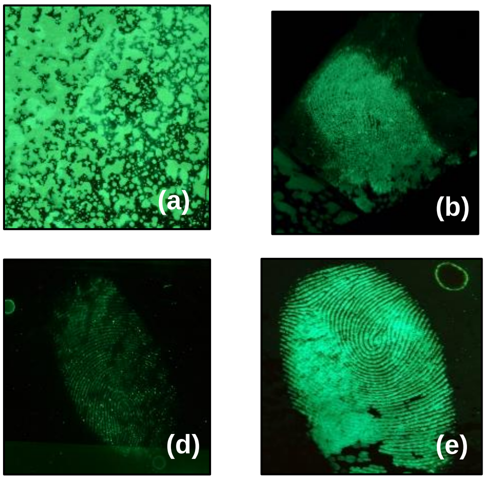

Figure 6: Series of finger marks scored accordingly using Table 3. (a) Development on heavy duty paper - score 0. (b) Development on plastic handle of scissors - score 1. (c) Development on blade of scissors - score 2. (d) Development on self-seal bag – score 3. (e) Development on supermarket plastic bag – score 4

Magazine Pages

With a success rate of 36%, the magazine substrates were least successful of the items processed, with no full latent mark development observed. Indeed, hardly any of the marks deposited and subsequently developed contained any friction ridge detail. Although the surface of the magazine pages used appeared glossy, they may in fact not have been of a high grade in this case as a consequence of the high amount of dye that was absorbed. This would therefore lead to an expectation of unsuccessful development as the fluorescent dye process only works for non-porous or truly semi-porous surfaces. Due to the fact that absorption occurred, the magazine was then considered to have been slightly semi-porous in nature and had a higher porosity (that is to say that it absorbed a larger amount of dye) than other semi-porous materials. As a consequence, this resulted in the highest amount of 0 scores due to no signs of any marks being developed. Another factor that affected the scoring and visualisation of developed finger marks was the complexity of the background of the magazine pages. For example, white backgrounds will obscure the white deposit formed on finger marks developed using CNA fuming and finger marks developed on yellow or bright coloured backgrounds will be difficult to see due to BY40 being yellow in nature.

Heavy Duty Paper

Although paper is often considered to be porous, heavy duty paper with a quality of 170gsm has a shiny, glossy texture and is therefore semi-porous and, as defined in Section 2.1.1, may absorb the aqueous material in a finger mark slowly after deposition. Once the dye had been applied onto the paper exhibits a ‘splodge’ effect was seen, particularly with water-based BY40. In contrast, distribution was more even where ethanol-based BY40 was used. This would, perhaps, suggest that the water-based BY40 is more absorbent than the ethanol based one. As a result of the patchy effect, the finger marks were obscured by the yellow dye, leaving friction ridge detail unclear and leading to a modal score of only 1 for water-based BY40 and 2 for ethanol-based BY40 (Fig. 7).

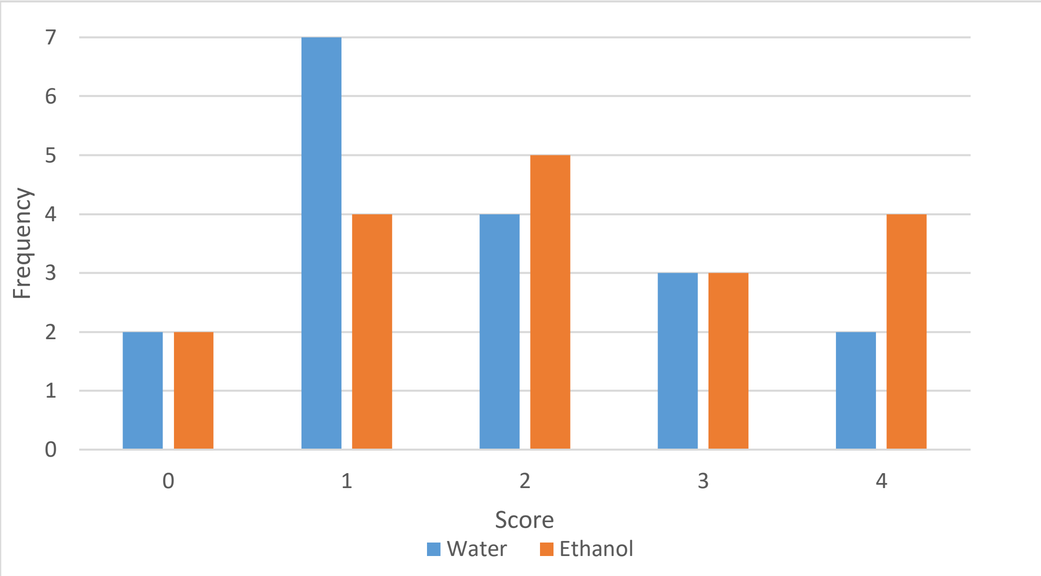

Figure 7: Frequency of scores assigned to finger marks developed on heavy duty paper

This would suggest that the latter is slightly more suitable for friction ridge detail development on semi-porous substrates. The modal score for the water-based BY40 developed marks relates to signs of contact being evidential (see Fig. 8a). Ethanol-based BY40 developed marks (see Fig. 8b) led to a higher modal score, since approximately one third of the ridge detail could be identified in most marks (Fig. 7). The use of fluorescent dye on this type of substrate carries the risk of any finger marks present being washed away, or subjected to unwanted staining of the background because of the dye's apparent high affinity for the substrate in this case.

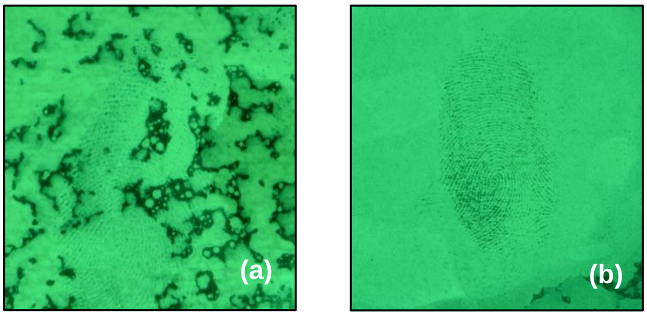

Figure 8: Illustration of finger mark enhancement on heavy duty paper using (a) water-based BY40 and (b) ethanol-based BY40

Plastic Exhibits

Plastic, non-porous exhibits, including the bottles and the three different types of bags (supermarket, freezer and self-seal), treated with water-based BY40 led to a higher modal score in most cases (Fig. 5). There was also a higher frequency of marks assigned a score of 4 on the self-seal bags and the freezer bags. Treatment with the ethanol-based formulation, on the other hand, revealed double the frequency of finger marks developed that were assigned scores of 4 on the plastic bags (Fig. 4) when compared to those subjected to the water-based BY40. Neither treatment seemed effective on plastic bottles, with only 10% of marks developed with both treatments leading to a score of 3 or 4 being assigned. This was, it was believed, due to the shape and grooves which caused the ridge detail to be lost, smudged or deformed. Some features were identified, however, in most cases a score of only 1 was assigned to the finger marks developed as a consequence of them containing little friction ridge detail (Fig. 4, 5). Although ethanol-based BY40 led to more fluorescence (Fig. 9b), there was no significant difference between the amount of ridge detail that could be identified (Fig. 9).

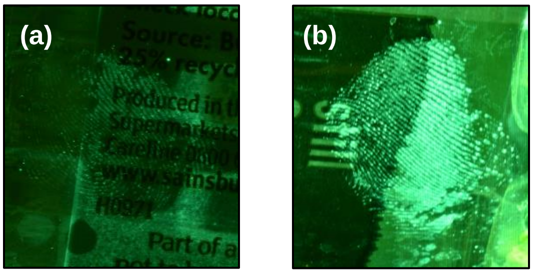

Figure 9: Enhancement of finger marks on plastic bottles using (a) water-based BY40 and (b) ethanol-based BY40

The freezer bags, in general, appeared to have a complex background of multiple colours that noticeably affected the visibility of finger marks, thereby leading to lower scores. Another aspect that may have led to a lower visibility was a misjudgement in the application of dye that may have consequently caused the lower scores. Having repeats of the bag exhibits, (that is to say depositing marks on more than one bag), however, meant that this did not have a significant effect on the scores as a whole as the misjudgement of dye did not occur on all freezer bags. It was also often difficult to photograph all details of the finger marks due to the irregularity of the distribution of the dye (Fig. 10).

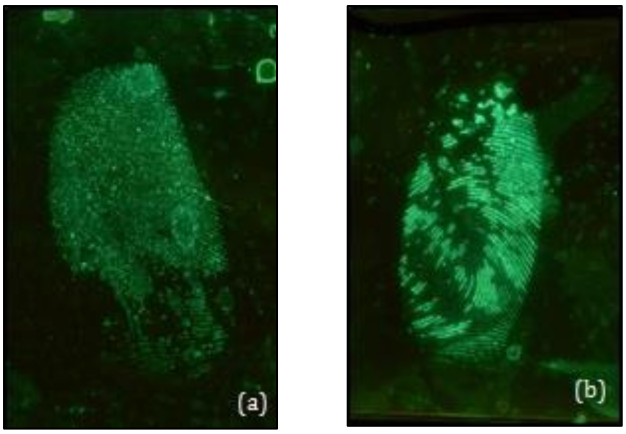

Figure 10: Illustration of the distribution of dye observed on freezer bag finger mark development following (a) water-based BY40 enhancement and (b) ethanol-based BY40 enhancement

When considering both ethanol-based and water-based BY40, the most productive development was on the plastic self-seal bags. As a consequence of there being no 0 scores in the self-seal bag data, there was a 100% success rate in which ridge detail could be identified across all marks.

Higher quality developed finger marks, those with a score of 3 or 4, were on the transparent section of the self-seal bags when compared against those on the white strip for both treatments. Overall, the modal score for water-based BY40 treatment was 3, however for ethanol-based BY40 treatment it was only 2. This, it is believed, was due to the fluorescence of the ethanol-based BY40, which appeared to hinder finger marks located on the white strip of the bag. This seemed to be as a consequence of the light being reflected by the white on the bag, which obscured the ridge detail (Fig.

11b). Finger marks developed with water-based BY40 on the other hand, had a more even intensity of fluorescence across each background (Fig. 11a).

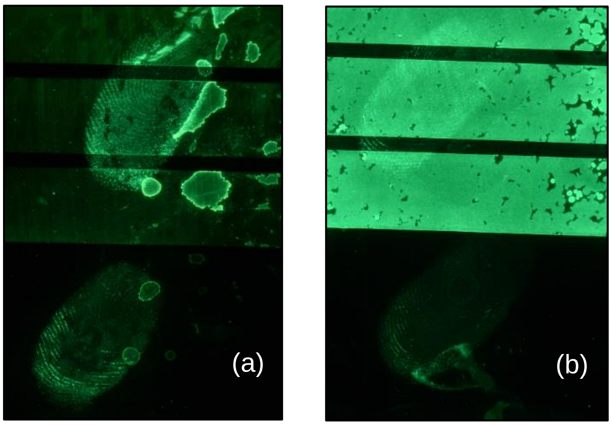

Figure 11: Enhancement of finger marks on plastic self-seal bags using CNA fuming followed by (a) water-based BY40 and (b) ethanol-based BY40

Finger marks deposited on the supermarket plastic bags and treated with the ethanol-based formulation led to better quality results and clearer friction ridge detail as a result of a greater fluorescence being present (Fig. 12). Ethanol developed marks displayed superior contrast (Fig. 12b) on the supermarket plastic bags with more distinct and noticeable details being shown. Marks developed using water-based BY40 did contained identifiable ridge detail despite a lower intensity of fluorescence. Unfortunately, some of the marks had a smudged appearance, which subsequently led to lower scores.

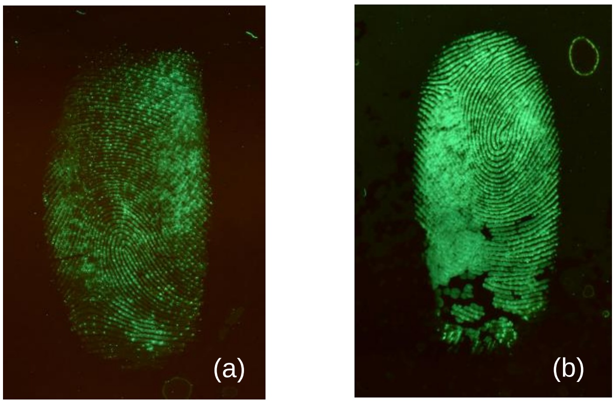

Figure 12: Comparison of fluorescence and ridge detail developed on a supermarket plastic bag using (a) water-based BY40 and (b) ethanol-based BY40

Knives

The modal score for the knife exhibits was 1 for enhancement using water-based BY40 and 0 when using the ethanol-based BY40, although the frequency of the finger marks assigned a score of 0 (10) was not much greater than those assigned a score of 1 (8) as shown in Fig. 3. However, only ethanol-based BY40 development led to scores of 4 as more whole marks were clear with friction ridges present. This is therefore indicative that this treatment produces better quality finger marks as opposed to a higher quantity. As expected, the ethanol-based formulation led to a more intense fluorescence, which was observed when placing images side-by-side for a direct comparison (Fig. 13) as well as when comparing finger marks from different donors (Fig. 14).

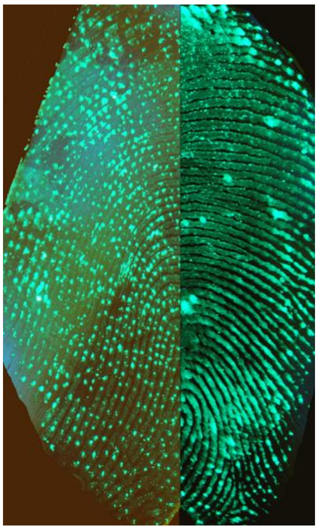

Figure 13: Illustration of fluorescence and ridge detail of a developed finger mark observed on a metal knife. Left side: image taken following water-based BY40 treatment. Right side: Image taken following ethanol BY40 treatment.

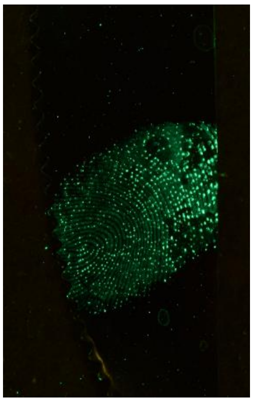

Figure 14: Illustration of difference in fluorescence of water-based BY40 (a) and ethanol-based BY40 (b) on metal knives.

The majority of marks deposited on the knives scoring 0 was due to the speckling effect that was present – a consequence of the glue left behind during CNA fuming. No sign of ridge detail was observed where the marks were expected to be. However, ridge detail was identified from a few marks that also displayed the speckled appearance (Fig. 15) so this was not necessarily always a hindrance.

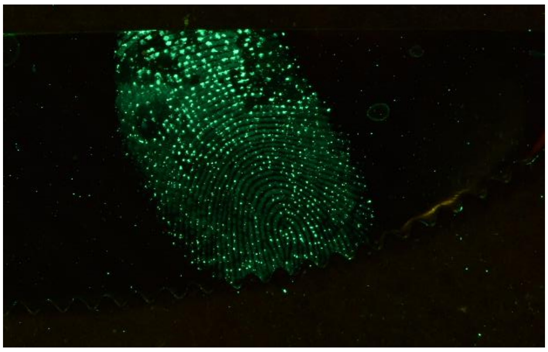

Figure 15: Finger mark developed on a metal knife using ethanol-based BY40 displaying a speckle appearance but still containing ridge detail

Some marks seemed to have been over-developed and had a patchy appearance so it is possible that too much glue had been used for this type of surface. Over-development, however, may have been due to the location of the exhibit within the cabinet, or perhaps a consequence of the type and variances in the substrate used as the glue will have different affinities to different surfaces.

Scissors

Mixed materials items, in this case scissors, produced better results in terms of clarity of friction ridge detail, which were more apparent on the metal blade than on the plastic handle. This was especially noticeable when ethanol-based BY40 development was used. No scores of 4 were assigned to any of the finger marks though. However, a score of 3 was assigned to a mark on the blade that had been treated with ethanol-based BY40 (Fig. 4). There was no change between results on the handle and blade in terms of the frequency of scores allocated following water-based BY40 treatment.

Similar to the fuming with the metal knives, the amount of white deposit left on the scissors gave the impression that too much glue had been used, which may have therefore had an adverse effect on the scoring. Along with the potential of over-development, some marks were too smudged to give a score at the higher end of the scale used. Overall, no significant difference was recognised between marks developed with each fluorescent dye (Fig. 16), only slight variances were noticeable in the amount of smudging and with the clarity of the ridge detail.

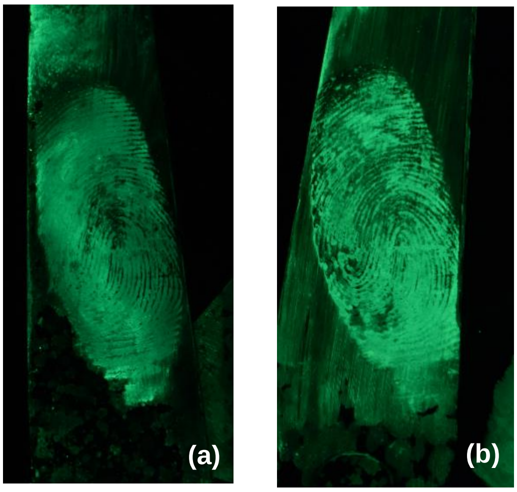

Figure 16: Finger marks developed on metal blade of scissors using (a) water-based BY40 and (b) ethanol-based BY40.

Comparison of Techniques

The characteristics of the sweat of the donors used in the project appears to have had an effect on the scores in some cases. Donor 2, for instance, deposited most marks that were subsequently assigned a score of 0, whilst Donor 3 deposited the most marks assigned a score of 4. Donor 1 provided marks that were allocated a range of scores from 0 to 4. As previously mentioned, the effect on enhancement that the sweat composition and volume has for each donor is critical, but this was seen as the best method to simulate real-life submissions in this case.

In order to compare the two techniques, data was collated including modal scores for each exhibit (Table 5), the frequency of scores 3 and 4 combined for each exhibit (Table 6) and overall frequencies for each technique were used to enable calculation (Fig. 3).

	Frequency of 3 or 4 Score	
Exhibit	**Water**	**Ethanol**
Heavy Duty Paper	5	7
Magazine Pages	0	1
Self-Seal Bags	9	4
Scissors	0	1
Plastic Bottles	1	2
Knives	3	4
Supermarket Plastic Bags	4	6
Freezer Bags	4	5
Total	26	30

Table 5: Modal scores that were assigned to each surface type for each enhancement technique

Exhibit	**Modal Score**	
	Water	**Ethanol**
Heavy Duty Paper	1	2
Magazine Pages	0	0
Self-Seal Bags	3	2
Scissors	1	1
Plastic Bottles	1	1
Knives	1	0
Supermarket Plastic Bags	1	1, 2
Freezer Bags	1	1

Table 6: Combination of frequency of marks assigned a score of 3 or 4 for each enhancement technique on different substrates

Discussion

In order to give an indication of which enhancement technique is most effective for each type of substrate, the combined frequencies of 3 and 4 scores were taken into account (Table 6) This would reveal the most effective at developing those marks whereby over two thirds of the mark contained friction ridge detail. Overall, ethanol-based BY40 developed 30 marks that were assigned a score of 3 or 4 compared with 26 for water-based BY40. For semi-porous substrates as well as the non-porous substrates (excluding self-seal bags), ethanol-based BY40 was more effective at producing the higher scores. It should be noted that the time between the deposition and treatment of the finger marks may have been a large influence of the development of low scoring marks on semi-porous surfaces, due to this type of surface being able to slowly absorb aqueous material. The only exhibit to produce a higher frequency with water-based BY40 than with ethanol-based BY40 was the self-seal bags, potentially due to them containing differing backgrounds of transparent plastic with a white opaque strip.

Alternatively, the overall frequencies of finger marks developed can be observed (Fig. 3) in order to determine the most effective technique. Water-based BY40 produced a higher frequency of marks with scores of 1, 2 and 3 whereas ethanol-based BY40 developed more marks assigned a score of 0 and 4. This would therefore suggest that water is most effective as an all-round technique and more reliable in order to develop a third or more of a finger mark's friction ridge detail.

Modal scores generated from each substrate developed with each technique were also considered (Table 5). These were identical for some exhibits (magazines, scissors, bottles and freezer bags), so this method of comparison may not be as effective as those mentioned at the beginning of this section. Ethanol-based BY40, on the other hand, developed marks that had a higher modal score for paper and plastic bags, which supports the outcomes of the other calculations (overall frequencies and frequency of finger marks assigned a score of 3 or 4). The fact that water produced better quality marks when applied to the self-seal bags was also proven with the other calculations.

Concerning semi-porous substrates, the results in this research show that CNA fuming followed by a fluorescent dye may not be the most effective technique at developing good quality finger marks. In an article by Prete et al. (2013), research was undertaken to determine the effectiveness of Lumicyano – a new, one-step method of CNA fuming that eliminates the need for fluorescent dyes. It appears that the results were marginally better than those presented here, with fuming developing finger marks with a bright fluorescence and good background contrast. This may be due to the absence of the risk that the dye will stain the background, which often obscures finger marks. The use of one-step luminescent CNA fuming should therefore be considered as an alternative for treatment of semi-porous surfaces.

Apart from the statistical evidence, by solely visualising the enhanced finger marks, ethanol-based BY40 developed marks were significantly easier to observe due to the higher fluorescence and, as a result, this reduced background effects. This also led to quicker imaging as a lower shutter speed was required thereby decreasing the exposure time.

An overall summary of the developments was compiled (Table 7) and the exhibits were split into the following sections with performance relating to the quality of friction ridge detail development: performance better with ethanol-based BY40; performance better with water-based BY40; a slight difference noticed between the two techniques, and an insignificant development observed with both techniques relating to only a few or no finger marks being assigned a score of 3 or 4.

Banner, E. (2018) An evaluative comparison of the effectiveness between water-based and ethanol-based Basic Yellow 40 staining as a post 'Super-Glue' fingerprint enhancement technique. *The Journal of Undergraduate Research at NTU*. Volume 1, Issue 1, P.99 – 222..

Performance Better with Ethanol-Based BY40	
Supermarket Plastic Bags	Heavy Duty Paper
Plastic Bottles	
Performance Better with Water-Based BY40	
Self-Seal Bags	Freezer Bags
Slight Difference in Performance of Water-Based and Ethanol-Based BY40	
Scissors	Knives
Insignificant Performance of Water-Based and Ethanol-Based BY40	
Magazine Pages	

Table 7: Summary of results from finger mark developments on different substrates comparing performance of each fluorescent dye.

It was noted that there was not a significant difference between each treatment with both being shown to be effective on the different types of substrate. Interpretation, however, relies solely on the expertise of the fingerprint experts studying each finger mark and scores would be expected to differ slightly. Also, within this project, there was no account taken for the variations between donors in terms of the composition of their finger marks nor were changes over time or any fluorescent contaminants taken into account (Cubuk 2002). Significant variations can occur involving various aspects of the development process, such as during print deposition, and it is therefore difficult for exact comparisons to be made.

Furthermore, as referred to previously, using different wavelengths, rather than those recommended by CAST (Bandey 2014), can lead to finger marks still being visible on complex backgrounds as can be demonstrated by the findings of this research project. It may be that the use of a different wavelength for each different treatment with the various fluorescent dyes available could be a solution in order to maximise the friction ridge detail visualised. This factor, however, was not explored but the recommendation may direct future research in order to determine whether or not the intensity of light or the wavelength of light would be an issue with these enhancement techniques.

Conclusion

Using water-based BY40 has provided a comparable finger mark enhancement success rate to the more commonly used ethanol-based dye. Although the fluorescence and contrast may not be as intense, the friction ridge detail was still identifiable on most substrates used in this project. This led to an equivalent quality, or better with regards to two of the exhibit types, when compared to ethanol-based BY40 developed marks. It is possible for this water-based formulation to be introduced gradually and to be utilised on some substrates as well as at crime scenes (HOPSDB 2003). It could therefore be recommended that forensic laboratories may consequently choose to use water-based BY40 in order to reduce health and safety risks as well as being more cost-effective. The success of the treatments in this project relied heavily on the background as well as the shape of the exhibit – complex backgrounds and shapes generally led to finger marks being assigned lower scores. Although variation in donor types is representative of real-life situations, it is occasionally not ideal for small-scale studies. On a larger scale, the constituents of each donor's sweat could be identified, as well as diet and lifestyle taken into account, in order to determine if any elements are present that may inhibit development or if there is a certain composition that is the most effective.

This study involved treatment on a small-scale involving a small substrate range across a short period of time in which the cabinet used for the fuming process was not operational for the entire period. It is understandable that this may not be as representative of forensic laboratory conditions as necessary, but notable trends have been revealed that can direct future research. It is interesting to note that none of these trends showed that water-based BY40 leads to lower identifiable friction ridge detail.

A more extensive study should be conducted involving a wider range of surfaces. Basic Red 14 (BR14), another water-based fluorescent dye, could be investigated alongside the two BY40 dyes as BR14 has been shown to be a more effective dye formulation than BY40 (Stewart, Deacon and Farrugia 2016). Also, it has been suggested that the quantity of finger marks detected would increase post BR14 staining using a recently developed visualisation technique (Bleay et al. 2013).

Future research could also be directed towards blind testing whereby the location of the finger mark is unknown to the examiner. This would highlight the effectiveness of each dye on the entirety of an exhibit, as opposed to a section of that exhibit, as well as minimising the risks of the examiner being subject to observer bias (Houck 2016).

The times between application of the dye and the washing process to remove any excess dye could also be investigated. Currently, the times are 20 seconds and one minute respectively for ethanol-based BY40 and water-based BY40. An alteration of these may lead to different observations in the quality of finger mark development.

Furthermore, preliminary tests could be considered prior to visualisation to assess the optimum wavelengths that should be used as this may also affect results. CAST provides a guideline of which wavelengths to use (Bandey 2014). However, this is universal and not specific to operational forensic laboratories and the equipment used in each. It is unknown as to whether different wavelengths or light sources may lead to brighter fluorescence or an increase in the visibility of developed finger marks.

Overall, there are various options of areas in which future research can be directed, led by the endless amount of emerging trends.

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