AN INVESTIGATION INTO THE SELECTIVE DEPOSITION OF IRON OXIDE WET POWDER SUSPENSION

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A thesis submitted in partial fulfilment of the requirement of Staffordshire University for the degree of Doctor of Philosophy

In collaboration with Defence Science and Technology Laboratory, formerly the Centre for Applied Science and Technology

June 2018

Acknowledgements

I would like to express my upmost gratitude and thanks to my principle supervisor Dr Sarah Fieldhouse. Your continual guidance, expertise and professional advice were invaluable to me and, without which I could not have successfully completed my Ph.D. I cannot thank Sarah enough for the emotional support, unwavering patience, motivation and friendship she gave to me throughout my research, even whilst on maternity leave.

I would also like to thank my supervisors, Associate Professor Andy Platt and Dr Steve Bleay. I am extremely grateful to Associate Professor Andy Platt for his constructive feedback, support and, most importantly for having the confidence in me to complete my Ph.D. Many thanks to Dr Steve Bleay for his advice and expertise that aided me in starting my research and ensuring it would be impactful.

I would like to thank Mr. Rory Downham and Mr. Vaughn Sears for giving their time and resources to my research, as well as sharing their immense and invaluable knowledge and experience. The assistance and support given by the laboratory technicians, in particular Mrs. Jayne Francis and Mr. Paul Bailey was greatly appreciated; I could not have completed the practical research without your help. Thank you to Professor David Clark-Carter for his advice on the statistical analysis carried out in my research. Many thanks also to the participants who took time out from their busy schedules to deposit their fingermarks; this research simply wouldn't have existed without you.

I would like to thank my fellow PhD researchers for making the highs and lows of completing a Ph.D feel normal; their friendship has helped me to stay sane, to succeed and to never give up.

I would like to thank my colleagues (and friends) in the department of Criminal Justice and Forensic Science at Staffordshire University; their constant support and enthusiasm kept me going. Special thanks to Dr Lauren Metcalfe and Mrs. Deborah Sproston-Bewley; their advice and words of encouragement helped to keep me motivated and positive when undertaking my first year of full-time lecturing, whilst writing my thesis.

Thanks must also be given to Mr. Hilton Middleton and Professor Andrew Jackson for encouraging and convincing me to undertake a Ph.D following the graduation from my undergraduate degree.

I would like to give a huge thank you to my family; especially to my Mum, Dad, Nigel, Gabriella, Grandma, Grandpa, Jessica and my in-law family for encouraging and enabling me to fulfill my ambition. I cannot express how truly grateful and thankful I am to them for giving me their continual support, words of encouragement and patience needed to help me complete my Ph.D. Thank you all for helping me in whatever way you could and, for never losing confidence in me despite the length of time it took.

Finally, a very special thank you to my husband, Richard for being my rock throughout the duration of my Ph.D. Thank you for lifting me up when I needed it and, for giving me space when I needed it. Thank you for being so understanding and patient during the many hours I spent away from you and Riley to write my thesis. My success would not be possible without your support, encouragement and love; for this I am eternally grateful.

Abstract

Latent fingermarks are residue impressions left on surfaces touched by the fingertip which contains unique friction ridge detail. Latent fingermarks are invisible to the naked eye and usually require development to make them visible. Wet powder suspensions (WPS) are a paint-like fingermark development technique that are recommended in the Fingermark Visualisation Manual, UK guidelines. Problematically, relatively little is known on what factors influence the quality of development of latent fingermarks, when visualised with WPS's. The aim of this study was to fill this gap in knowledge.

There were six main objectives to the research project; to establish which type of sweat (eccrine, sebaceous or natural) developed most successfully with iron oxide WPS, to observe inter person consistency in participant development, to observe intra person consistency in participant development, to explore if one or more individual constituents commonly found in fingermark residue may be the cause of interaction, to establish if the age of fingermark affected the quality of development and, to investigate if substrate type influenced the quality of development. The objectives were achieved by applying a combination of phase 1 and phase 2 studies, which are often used when researching a new or relatively unknown fingermark development technique.

The results from each objective would generate new knowledge towards a fundamental understanding of what causes the selective deposition of iron oxide WPS and, some of the variables that may influence the quality and consistency of development. This fundamental understanding is vital to be able to recommend the use of WPS to its optimum potential and, to improve the technique beyond its current capabilities.

The overall results of this project showed that iron oxide WPS may have an affinity to eccrine residue but when held in place by water insoluble material from other residues or contaminants. There was considerable variation in the quality of development of participant fingermarks (inter and intra personally), suggesting that composition, quantity and distribution of residue impacted the quality of development. The individual constituents tested had varying results depending on the method. It appeared that, when able to persist during the

development process, all constituents developed but with varying qualities. Visual analysis indicated that the quality of development improved with the age of the fingermarks however, statistical analysis indicated that there was no statistically significant difference. Furthermore, it was established that substrate type appeared to have some influence on the quality of development of both participant fingermarks and individual constituents.

Contents

Chapter 1. Introduction

1.1. Fingermarks

Fingermarks are the residue impressions left on surfaces when contact is made with the patterned portion of the fingertip, known as friction ridge skin (1.1.1). The composition of a fingermark is often a mixture of eccrine residue secreted directly from the pores on the fingertips, residues collected from other areas of the body and, contaminants from other items touched such as food and cosmetics (1.1.2). The impressions form a unique set of patterns which can be used for identification purposes (1.1.3). The depositions are often invisible to the naked eye and require some form of 'development'.

1.1.1. Friction ridge skin

Friction ridge skin is the raised, patterned part of the epidermis found on the fingers and palms of the hands. Friction ridge skin serves many functions such as protection, sensation, grip and heat regulation through the excretion of sweat through glands (Ramotowski, 2001). Friction ridges found on the distal part of the finger (the fingertip) form patterns which, as far as research shows, are unique to everyone (Berry and Stoney, 2001, Maltoni *et al.*, 2003 and, Stoney, 2001). It is the uniqueness of the patterned friction ridges which mean fingermarks can be used in identifying individuals.

Friction ridge skin is formed into the unique patterns during gestation and generally do not change throughout an individual's life. According to Champod (2004) volar pads appear on the finger tips during weeks 7 to 8 of the gestation period, forming a soft mass of tissue which become covered by the epidermis as the hands begin to grow. At around weeks 11 to 20 of the gestation period friction ridge skin starts to form over the volar pads, creating the patterned, texture ridges (Champod, 2004). It is thought that the ridge patterns start to form at the centre of the fingertip, on the highest point of the volar pad. The speed of friction skin growth, height of volar pad and general bone morphology are known to be contributing factors

which influence the unique ridge patterns and characteristics (Babler, 1991 and, Penrose and O'Hara, 1973 as cited in Champod, 2004). As a result of variation in these factors, the fingermarks formed by friction ridge detail varies from one person to another, as well as between fingers on the same individual.

Despite the uniqueness of friction ridge patterns found on the fingertip, they can be catergorised into three main types of class characteristics; loops, whorls and arches (Berry and Stoney, 2001; Champod, 2004; Cowger, 1993). Fixed points such as cores and deltas can be located to help identify the pattern type. A core is situated near the central point of a fingermark; deltas have three branches similar in shape to a triangle, with two branches opening out towards the core. Figure 1 illustrates an example of a core and delta from one fingermark. Except where noted all images have been taken from the NPIA's UK National Fingerprint training manual.

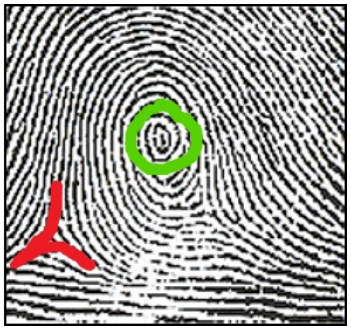


Figure 1. An example of a core and delta fixed points. The green circle indicates the core; the red schematically demonstrates the location and shape of the delta.

Loops are the most common pattern type of class characteristic. This pattern type will display at least one ridge entering from one side of the finger which will recurve and exiting from the same side. Loops typically display fixed points of one delta and one core. A whorl pattern type must contain one continuous or several short sections of friction ridges that complete a 360° formation, with one core and at least two deltas. Arches are reported to the be the least common pattern type, displaying at least one ridge that enters the finger from one side and

exits the finger on the opposite side. Arches have no fixed points such as cores or deltas. Figure 2 shows an example of a plain loop, whorl and arch.

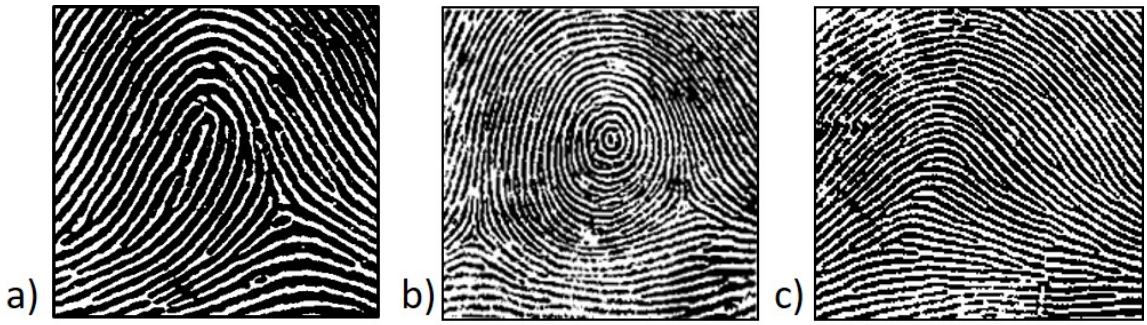


Figure 2. An example of a) a plain loop, b) a plain whorl, c) a plain arch.

The complex patterns formed on the friction ridge skin are made up of minutiae details known as individual characteristics. The most basic minutiae details are ridge endings, simply where a ridge ends and, bifurcations where one ridge splits into two (Champod, 2004; Cowger, 1993). Figure 3 illustrates six types of individual characteristics (minutiae detail) that can be found in friction ridge skin patterns. The individual characteristics are the most defining features of a fingermark.

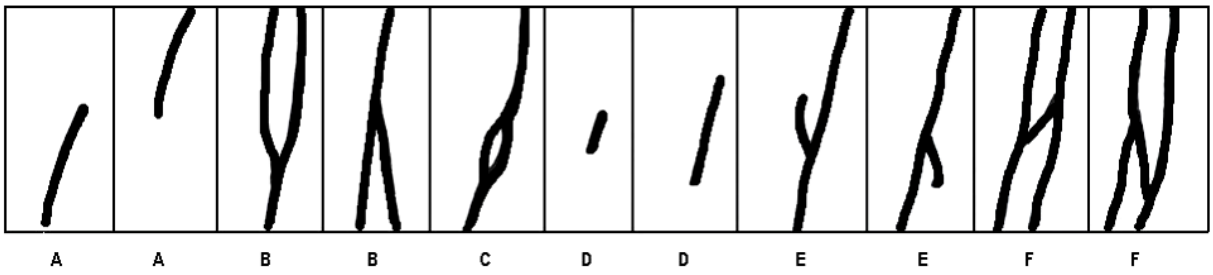


Figure 3. A schematic of individual characteristics found in friction ridge skin. A) ridge endings, B) bifurcations, C) lake, D) independent ridges, E) spurs, F) crossovers.

The unique location and combinations of class and individual characteristics in friction ridge skin aid in the identification of individuals from their fingermarks. These characteristics are permanent from birth and will remain unchanged unless the epidermis is physically damaged

or altered (Cowger, 1993; Kucken and Newell, 2004). Damage and alterations to friction ridge skin can occur as a result of many factors; for example, occupation, injury, skin conditions, medical treatments (Al-Ahwal, 2012; Azadeh *et al.,* 2013) and age. The epidermis must be damaged deeper than 2mm to result in permanent scarring, thus altering the original pattern of friction ridges (Cowger, 1993; Champod, 2004).

As well as having a unique pattern formation, friction ridges contain pores which secrete sweat from eccrine glands. Understanding the composition of fingermark residue aids in the creation and progression of fingermark development techniques.

1.1.2. Fingermark residue

The human body contains three types of glands that produce sweat which is secreted through pores on the epidermis. Eccrine glands are found all over the body, largely on the palms and soles (Girod, Ramotowski and Weyermann, 2012; Ramotowski, 2001; Cowger, 1993). Sebaceous glands are mostly found on the face, scalp, chest and back (Girod, Ramotowski and Weyermann, 2012; Ramotowski, 2001; Cowger, 1993). Apocrine glands are found in the armpit and genital regions (Girod, Ramotowski and Weyermann, 2012; Ramotowski, 2001). Due to the unlikelihood of apocrine secretions being found in fingermark residue, only eccrine and sebaceous secretions are detailed further in this study.

Eccrine residue is excreted directly from the pores found on the distal part of the finger and makes up a significant portion of the composition of fingermark residue (Croxton *et al.,* 2010; Girod, Ramotowski and Weyermann, 2012; Kent, 2016). Although the hands secrete residue from eccrine glands, fingermarks found at crime scenes are likely to comprise of a combination of eccrine secretions, sebaceous secretions picked up from the face and scalp, and contaminants from anything else touched by the hands; particularly food and cosmetics (Ramotowski, 2001; Girod, Ramotowski and Weyermann, 2012; Kent, 2016). The secretions from both eccrine and sebaceous glands, and any contaminants form a matrix of residue that is left in the form of a fingermark on surfaces that come in to contact with the fingertips; these are classed as natural fingermarks (Sears *et al.,* 2012; Ramotowski, 2001).

1.1.1.1. Eccrine secretions

Eccrine secretions excrete directly on to the skin from open pores on the epidermis. The research that has been conducted on the composition of eccrine sweat generally indicates that it is comprised of up to 99% water upon initial excretion, combined with a mixture of organic and inorganic water soluble constituents (Girod, Ramotowski and Weyermann, 2012; Ramotowski, 2001; Fritz *et al.,* 2013). Table 1 lists some of the most abundant organic and inorganic constituents found in eccrine residue, according to Ramotowski, 2001, Girod, Ramotowski and Weyermann, 2012, Fritz, *et al.,* 2013 and, Cadd *et al.,* 2015.

Table 1. Some of the most abundant organic and inorganic constituents found in eccrine residue as reported in literature. The quantities have been taken from Cadd *et al.* (2015).

Organic	**Inorganic**
Proteins 200 mg/L	Chloride 3.5 g/L
Lactate 3.15 mg/L	Sodium 3.3 g/L
Amino Acids 1.45 mg/L	Potassium 0.2 g/L
Urea 0.75 mg/L	Fluoride 69 µg/L
Glucose 3.5 mg/L	Iron 3.5 g/L

Although research is lacking in this area, literature suggests that the constituents detailed in table 1 are frequently observed in natural fingermark depositions; however, the quantities of these constituents have been reported to vary intra personally and, inter personally as a result of age, sex, diet and race (Girod, Ramotowski and Weyermann, 2012; Cadd *et al.,* 2015). The significance of the causes for inter person variation remains questionable, largely due to lack of research and, the size of studies (number of participants or repeats deployed).

Significant research exists on the affect the age of donor has on the composition of fingermark residue. Studies have found that the composition of fingermark residue changes vastly throughout a lifetime, particularly with the absence and production of sebum and lipids (Ramotowski, 2001; Mong *et al.,* 2004; Buchanan, Asano and Bohanon, 1997, cited in Cadd *et al.,* 2015 and Girod, Ramotowski and Weyermann, 2012; Antoine *et al.,* 2010; Hemmila, McGill

and Ritter, 2008). De Puit *et al.* (2013), found that sex may affect the composition of fingermark residue, especially the concentration of amino acids. However, this study was conducted using a small sample size (n=20) so further investigations would be needed to draw more robust conclusions. Similarly to De Puit *et al.* (2013), Buchanan, Asano and Bohanon (1997) (cited in Girod, Ramotowski and Weyermann, 2012) found there to be a difference in the levels of urea detected in fingermark residue between male and female participants. A review by Cadd *et al.,* (2015) states that there is limited research on the effects of race on fingermark composition of eccrine residue however, differences have been found in constituents largely associated with sebaceous secretions.

Between 20 and 22 amino acids have been reported be found in eccrine sweat in varying levels (Cadd *et al.,* 2015; Ramotowski, 2001). Serine was the first amino acid identified in eccrine reside by Embden and Tachau in 1910 (cited by Ramotowski, 2001). Since then, research conducted on active and inactive participants has found that the most abundant amino acids present in eccrine residue are serine, glycine and alanine (Girod, Ramotowski and Weyermann, 2012; Ramotowski, 2001). Table 2 has been taken from Girod, Ramotowski and Weyermann, 2012 and demonstrates the four most abundant amino acids found in eccrine residue as a serine ratio.

Table 2. The most abundant amino acids present in eccrine residue.

Amino Acid	**Serine Ratio %**
Serine	100
Glycine	54-67
Ornithine	32-45
Alanine	22-35

Variations have also been studied in the quantities of amino acids present in fingermark residue. Croxton *et al.* (2010) found that amino acids were present in all participant samples analysed yet, with inter person varying quantities. Many development techniques such as, Cyanoacrylate Fuming, Ninhydrin and, 1,8-Diazafluoren-9-One (DFO) are reported to interact with the amino acids found within fingermark residue (Lewis, 2013; Almog, 2013; Ramotowski,

2013). Therefore, a thorough understanding of those amino acids most frequently and abundantly found in eccrine residue is vital.

This necessity extends to the composition of eccrine residue as well as the amino acids within eccrine residue. Knowledge that differences in eccrine residue composition occur inter personally is vital to fingermark development research. It is imperative that a range of development techniques are available and, that the range available may target different constituents within fingermark residue. This would ensure the maximum potential of the successful, full recovery of fingermarks regardless of the chemical composition.

1.1.1.2. Sebaceous secretions

Sebaceous glands are largely associated with hair follicles; sebum is dispersed into the hair follicle canal before being excreted on to the skin (Ramotowski, 2001). Sebum is the secretion produced by sebaceous glands; it has high fatty acid properties, making it less water soluble and giving it an oilier appearance than the water soluble eccrine secretions. *Table 3* has been taken from Downing and Strauss (1974 (cited by Ramotowski, 2001)) and demonstrates an approximate composition of sebum.

Table 3. The approximate composition of sebum.

Constituent	**Sebum (wt%)**
Glyceride/free fatty acids	57.5
Wax esters	26.0
Squalene	12.0
Cholesterol esters	3.0
Cholesterol	1.5

Similarly to the inter person differences discovered in eccrine residue, it has also been reported that there are differences sebaceous residue. Croxton *et al.* (2010) found that there was a difference in the quantity of fatty acids and squalene between participants, as well a difference

in amino acids. Ramotowski (2001) reported a difference in the concentration of sterols and sterol esters between male and female participants. However, Asano (2002) and Cutherbertson (1969) (cited in Girod, Ramotowski and Weyermann, 2012) found no differences in the lipid compounds between male and female participants.

1.1.1.3. The effect fingermark residue composition has on the selection of a development technique and research

Knowledge of the composition of fingermark residue is a key element of fingermark development. Some development techniques target different constituents found in fingermark residue and therefore, the composition of the fingermark will directly influence the quality of development (Sears *et al.,* 2012; Croxton *et al.,* 2010). For example, cyanoacrylate fuming has been reported to interact with anions and amino acids found in eccrine residue (Lewis, 2013; Ramotowski, 2013) and, ninhydrin has also been reported to interact with amino acids (Almog, 2001).

Fingermark residue behaves differently on different surfaces, therefore an understanding of this aids the selection of which development technique to select (Croxton *et al.,* 2010, Bobev, 1995). For example, when fingermarks are deposited on to porous surfaces such as paper, constituents like amino acids gradually soak in to the paper leaving the fatty acids remaining on top of the surface and any volatile constituents to evaporate. This means that development techniques that specifically target amino acids, can develop fingermarks on paper for many years after the original mark was deposited (Mink *et al.,* 2013). Whereas on non-porous surfaces, fingermark residue cannot penetrate the surface of the substrate and so the residue remains on top; making the fingermark less likely to remain over long periods of time (Bobev, 1995).

1.1.3. The relevance of fingermarks to crime scene investigation

As far as research shows, no two individuals have the same fingerprint detail (Berry and Stoney, 2001, Maltoni *et al.*, 2003 and, Stoney, 2001). Fingerprints are classified as such, when the individual to whom they belong is known. Fingerprints are usually recorded or used for identification, comparison or exclusion purposes. Fingermarks are unidentified marks deposited on to any surface touched by the patterned, friction ridge skin covering the distal portion of the finger.

Fingermarks found at a scene of crime can be categorised as latent, patent or plastic (Cowger, 1993). Latent fingermarks are deposits of the residue from the fingertip, when the friction ridge skin comes in to contact with a surface. Latent fingermarks are invisible to the human eye and require some form of development to make them visible, for the marks to be recovered and used for identification purposes. Latent fingermarks are the most common type of fingermark recovered from a crime scene. Patent fingermarks are already visible to the human eye; they are the deposit of a coloured substance such as blood or ink from the fingertip to a surface. Patent fingermarks do not usually require any development before being recovered although, additional lighting or enhancement may be required to provide better contrast before analysis can be carried out (Au *et al.,* 2011). Plastic fingermarks are 3 dimensional marks that are deposited on malleable surfaces such as wax or wet paint. Although plastic fingermarks are categorised as visible marks, they are usually enhanced with oblique lighting or a development technique to improve visualisation (Cowger, 1993).

The unique and identifying nature of the patterned friction ridge skin, means that positively identified fingermarks from the scene of a crime, or on items of evidence relating to a crime are an impactful form of evidence as they can connect an individual to the crime. The potential impact that positively identified fingermarks can have on an investigation means it is essential that there are appropriate methods available for visualising and recovering fingermarks from any given circumstance.

1.2. Wet powder suspensions.

Wet powder suspensions (WPS's) are recommended in the UK for developing latent fingermarks on non-porous and semi-porous surfaces (Centre for Applied Science and Technology, 2014). WPS's have been reported to develop latent fingermarks on problematic surfaces such as the sticky side of adhesive tapes (Martin, 1999; Sneddon, 1999; Yeo, 2000) and, under challenging circumstances such as items which are or have been wetted, food items (Ferguson *et al,* 2013), contaminated with grease or blood (Au *et al.,* 2011), or items that have been damaged by heat (Dominick, Daeid, and Bleay, 2011; Bradshaw *et al,* 2008; Gardner, Cordingley and Francis, 2016).

Au *et al.* (2011) explored the use of carbon and titanium dioxide based wet powder suspensions as an enhancement technique for bloodied fingermarks. Au *et al.* (2011) found that titanium dioxide WPS improved the quality of fingermark enhancement as single technique or, following an acid dye treatment. The fingermarks treated with titanium dioxide WPS proved to be of a better quality than the fingermarks which were enhanced with acid dye alone.

Dominick, Daeid, and Bleay (2011), Bradshaw *et al.* (2008) and, Gardner, Cordingley and Francis, (2016) reported that WPS's, particularly iron oxide WPS, was able to develop fingermarks recovered from fire scenes but, with varying qualities of development particularly in comparison to other development techniques. Dominick, Daeid, and Bleay (2011) reported that iron oxide WPS was not the most successful development technique used in their study, however, it still showed a positive ability to develop the fingermarks.

It is thought that WPS's work well on wetted surfaces due to its paint like properties. The aqueous nature of the development technique reduces surface tension and, unlike a dry powder will not adhere to the moisture content on a surface. The ability for WPS's to be able to develop fingermarks from wet environments would suggest that it is selective enough in the characteristic(s) it has an affinity to, to selectively deposit on components that the water does not affect or degrade. Goldstone, Francis and Gardner (2015) investigated the development of fingermarks which had been exposed to sea-spray. During the study,

fingermarks were deposited on glass and exposed to sea salt spray for 1 week and 1 month. The results for both time periods showed that iron oxide WPS and titanium dioxide WPS gave significantly better development than the other 9 development techniques applied.

The Fingermark Visualisation Manual (Centre for Applied Science and Technology, 2014) suggests that WPS's are the most effective sequential process for non-porous surfaces following powdering (where the application of powder is appropriate) and, as an alternative to superglue fuming. In some instances, for example, when faced with items of evidence that are wet, the application of dry powders would be inappropriate so WPS's may be used as the initial treatment rather than sequentially. The Fingermark Visualisation Manual (Centre for Applied Science and Technology, 2014) lists WPS's as a category A process, which means they are classed as a standard procedure for regular operational use. The Fingermark Visualisation Manual (Centre for Applied Science and Technology, 2014) highly recommends the use of WPS's, yet a basic and fundamental understanding of the way in which the development technique interacts with and develops a fingermark is still unknown.

1.2.1. History

During the 1990's, Tokyo's Metropolitan Police started to research fingermark development techniques for use on the sticky side of adhesive tapes. They created a formula that used a black powder (specification unknown) as the colouring/developing agent (Burns, 1994). An American police officer who was working in Tokyo when this developer was created, took the formula to the Lightning Powder Company who then produced Sticky-Side Powder. Sticky-Side Powder is a commercially available wet powder suspension that consists of a pre-mixed black powder (exact composition unknown) that is combined with a surfactant of equal parts Kodak Photo-Flo 200 and distilled water.

Following the creation of Sticky-Side Powder, the Police Scientific Development Branch (PSDB), now the Defence Science and Technology Laboratory (DSTL), also formerly, the Home Office Scientific Development Branch (HOSDB) and, the Centre for Applied Science and Technology (CAST), started research on Sticky-Side Powder (Yeo, 2000), in order to create alternative WPS

systems. PSDB looked at precipitated, magnetic, and iron oxide powders as a black option and, titanium dioxide as a white option; both mixed with Kodak Photo-Flo 200 and distilled water as the surfactant. Both new formulations were compared to the original Sticky-Side powder, with the iron oxide black WPS, displaying improved quality.

The iron oxide formulation was compared to basic violet 3 and cyanoacrylate fuming, followed by basic yellow 40, on the sticky side of adhesive tapes (Alderwick, 2002). The results again showed that the iron oxide WPS gave better contrast on the developed fingermarks than both of the other techniques.

Until around 2004, WPS were only used to develop fingermarks on the sticky side of adhesive tapes. At this time, Auld (2004) started looking at using WPS to develop fingermarks on vehicles, in particular those that had been wetted at some point and, Sanchez (2004) with Strathclyde Police, investigated the use of WPS on items recovered from arson scenes. Both found WPS to be a successful development technique in these scenarios.

The outcomes of these two studies resulted in operational and laboratory trials being carried out using WPS on other non-porous surfaces. In the laboratory trials, the Home Office Scientific Development Branch (HOSDB) (formerly PSDB and, CAST; now, DSTL) studied WPS on various substrates and, how it would fit in a sequential development process (Lawrie, 2007). Although, iron oxide WPS gave good results over a variety of non-porous and semi-porous surfaces, results indicated that the commercially available carbon based formulation superseded HOSDB's iron oxide WPS on the sticky side of adhesive tapes.

Operationally, the WPS were applied at scenes after powdering, or in the laboratory as a replacement technique to superglue fuming. The WPS was used on items recovered from the outside of vehicles or drugs packaging, that were likely to have been wetted at some point or contaminated. The results showed that application WPS increased the recovery rate.

1.2.2. Available wet powder suspension systems.

Wet powder suspensions have a solid phase and an aqueous phase. The solid phase is a powder of particulates, for example iron oxide or carbon, and the aqueous phase is a surfactant, detergent solution (Home Office, 2013). When the two phases are combined, they form a paint-like consistency; this is brushed on to an area of interest and washed off using running water. The paint-like consistency of the developer means that it is well-suited to developing latent fingermarks found on substrates that are or have been wetted (Home Office, 2013), contaminated substrates (drugs packaging, evidence from fire scenes), as well as the sticky side of adhesive tapes (Home Office, 2013). In addition to these challenging scenarios, WPS's can be used on most non-porous and some semi-porous surfaces, regardless of whether they are or have been wetted.

There are three Wet Powder Suspension (WPS) systems recommended in the Fingermark Visualisation Manual (2014); carbon based, iron oxide based and, titanium dioxide based. Carbon and iron oxide based WPS's are both black in colour for application on light coloured substrates, and titanium dioxide based WPS is white in colour for use on darker substrates.

Research showed that carbon based WPS was the most effective on the sticky side of tapes with results exceeding those where iron oxide WPS was used (Home Office, 2013). Yet, on substrates other than the sticky side of tapes, carbon based WPS can give high background staining. As a result, the Fingermark Visualisation Manual (2014) recommends that carbon WPS is used for developing fingermarks on the sticky side of tapes and iron oxide WPS should be used on all other non-porous and semi-porous surfaces, whether they have been wetted or not. Iron oxide based WPS tends to give less background staining (although this can be surface depend) and is said to be more sensitive than the carbon based alternative (Home Office, 2013).

Both carbon and titanium dioxide based WPS's are commercially available as pre-made working solutions, with an unlimited shelf life (BVDA; Wet Wop). Whereas, iron oxide based WPS is not commercially available pre-made so, a working solution must be made as it is needed, both operationally and in the laboratory. Studies have been conducted on the shelf

life of iron oxide WPS with results indicating that a change in surfactant can aid in the shelf life of the technique. It was found that if Triton X-100-ethylene glycol was used instead of Kodak Photo-flo, the shelf life could extend to two years (Downham *et al*., 2017a).

Due to carbon WPS being available pre-mixed, it may be viewed as a more convenient suspension for operational use at a crime scene, rather than iron oxide WPS which must be made in to a working solution before being available for application. Being required to make a working solution either at a crime scene or before attending a scene is not practicable so, although iron oxide WPS has a wide application use, it may not be a technique that is considered over other, more readily available alternatives. However, when items of evidence are presented for development and analysis in a laboratory, iron oxide WPS may be more likely to be used in the recommended manner as the constraints faced at a crime scene are no longer involved.

In addition to the impracticality of having to make a working solution of iron oxide WPS prior to use, the application of WPS's can also cause issues during operational crime scene use. The application and rinsing process can be very messy and difficult to contain in a localised area. For optimum results, this development technique lends itself better to laboratory processing where possible.

There are currently no alternative application methods for WPS systems recommended in the Fingermark Visualisation Manual (Centre for Applied Science and Technology, 2014).

1.2.3. Recent background research on iron oxide wet powder suspension.

The Home Office (2013) details the recommended formation for iron oxide WPS as, 20g of precipitated magnetic iron oxide powder, mixed with 20 mL of a 1:1 surfactant solution of Kodak Photo-Flo and distilled water. This formulation is known as the 2006 formulation, recommended by CAST (Downham *et al.* (2017a). Jones, Downham and Sears (2009) studied latent fingermarks developed with the 2006, Kodak Photo-Flo formulation (Home Office, 2013) of iron oxide WPS, on a range on non-porous substrates. The study found that the iron oxide

particles that had remained on the fingermark after rinsing, thus developing the fingermark, formed clusters of cubic crystals. The crystals were observed in a variety of sizes, ranging from a couple of hundred nanometres to to 1 micrometre. The study also found that the topography of substrates had a slight impact on the way the iron oxide particles deposited on the substrate and the way the particles adhered to the fingermark residue. The knowledge from this study helped to inform CAST of the standard of iron oxide powder that should be considered for an optimum formulation of iron oxide WPS.

Atherton (2013) found that the effectiveness of iron oxide WPS development varied between participants, as did the chemical compositions of the participant fingermark residue. Therefore, the study highlighted that there may be a correlation between the two variables; the quality of development and the amount, presence and/or absence of chemicals in fingermark residue. This study was the first to compare the chemical composition of fingermarks to the quality of development when using iron oxide WPS; therefore, adding vital knowledge to the minimal understanding of how iron oxide WPS works.

The most recent studies on iron oxide WPS prior to this were by carried out by CAST, to establish if the most appropriate formulations and surfactant concentrations for iron oxide WPS were being advised in the Fingermark Visualisation Manual (2014) (Downham *et al.* 2017a and 2017b). Downham *et al.* (2017a) reported that the 2009 iron oxide WPS formulation utilising Triton X-100 and ethylene glycol as the surfactant, gave a development quality that was comparable to the 2006 iron oxide WPS formulation which used Kodak Photo-Flo as the surfactant. The research suggested that there was no decline in the quality of development between the two formulations, indicating that Triton X-100 could be used as an alternative surfactant to Kodak Photo-Flo (Downham *et al.* 2017a). This was of importance due to the decline in manual photography development. Kodak Photo-Flo is primarily used for the manual development of photographs; as this has been deemed to be in decline, it was feared that Kodak Photo-Flo may not always be accessible thus, giving a vital need for an alternative.

Downham *et al.* (2017a) also investigated the shelf-life of the 2009, Triton X-100 working solution formulation. The study found that the working solution was able to develop

fingermarks with a consistent quality and with no decline until after 100 days of the solution first being made. This was an important contribution to knowledge as, working solutions make the use of development techniques more widely appealing and convenient to crime scene and forensic examiners.

After establishing the 2009, Triton X-100 formulation was comparable to the 2006 formulation, Downham *et al.* (2017b) investigated the effects of Triton X-100 in more detail. The study indicated that the originally recommended concentration of Triton X-100 could be reduced to 10 times the critical micelle level, with no detrimental affect to the quality of fingermark development. The study also found that a both the Triton X-100 and, ethylene glycol concentrations could be reduced without affecting the quality of fingermark development. However, Downham *et al.* (2017b) reported that CAST were confident enough in the results from this study to recommend formulation changes in the Fingermark Visualisation Manual (2014) at that time.

1.2.4. Mechanism of iron oxide wet powder suspension.

The mechanism behind the interaction taking place when a latent fingermark is developed by any wet powder suspension system is currently unknown. This is a significant gap in the knowledge of this field and prevents a full understanding of the technique in order to be able to recommend the application of the technique or to improve the technique beyond its current capabilities.

1.3. Fingerprint research.

Scientific research project designs are often created with the aim that as many variables as possible will be monitored or controlled and where possible, ensuring that the simulation is representative of a real scenario, to be able to investigate the effects of those variables (Sears *et al.,* 2012). A controlled variable is a factor(s) of the experiment that is kept constant throughout the experiment in order to monitor the effects occurring when another factor is changed. The consideration of variables is vital to fingermark research as there are a large number of factors that are known to influence the quality of a fingermark prior to, on and post deposition and, the development techniques available.

Currently, there is no recognised standard for fingerprint research however, there are some published, widely used guidelines (IFRG, 2014; Sears *et al.,* 2012; Kent, 2010; Jones *et al.,* 2001). There are many variables that should be considered when creating the method for fingermark development technique research study. So, the main aim and objectives of the research should be considered when planning the method, to ensure the objectives will be met.

1.3.1. Participant selection.

As mentioned in 1.1.2 fingermark residue can vary intra and inter personally; due to the variation encountered in fingermark residue, a representative sample of the population should be considered when designing the research experiment and collecting participant fingermarks.

It is widely accepted in fingermark research that participant fingermark residue composition cannot be controlled. Some research method guidelines suggest selecting light, medium and heavy or, poor, average and good quality donors to ensure a range of fingermark residue composition (Sears *et al.,* 2012; IFRG, 2014). The theory of this method is to be able to test the sensitivity of a development technique for a range of fingermark compositions. However, if the research stating inter and intra person variation is accurate, it could be proposed that assigning a participant as (for example) light, medium or heavy, may not be consistent for every

repeat or enhancement technique and thus, perhaps futile. Suggestions have also been made on using artificial residues to control the composition however, this has also been deemed problematic as the composition of commercially available artificial residue is largely unknown and, is not entirely replicable of natural fingermarks (Girod, Ramotowski and Weyermann, 2012, Sears *et al*, 2012). Where participants are not selected for their quality of deposition, it is recommended that, where possible a range of ages, sexes and races should be considered, with other factors such as medication, specific diets and frequent habits (such as smoking) should be noted (Sears *et al.,* 2012; IFRG, 2014; Jones *et al.,* 2001; Kent, 2010).

Fingermarks are not only inconsistent as a result of residue composition, they can also be inconsistent as a result of a number of other variables such as the force and angle of deposition. If too much force is applied on deposition, the friction ridges can become distorted and may merge with one another, eliminating the detail necessary for identification. Equally, if too little force is applied, insufficient amounts of residue may be transferred to the surface, resulting in poor quality development. Due to the inconsistent nature of fingermark depositions, if it is deemed necessary to the study, consistency and reproducibility should be considered and controlled as much as possible. Many methods have been reported in literature for the control of deposition such as, depositing the fingermarks on top of a top pan balance, ensuring a specific 'weight' is achieved per deposition (Jasuja *et al.*, 2009). Although this method may appear to successfully control the force applied when depositing fingermarks (ensuring consistency), the method is still susceptible to variation. For example, if a participant does not achieve the desired weight (force) upon initial deposition, that finger would essentially be 'wasted' for further depositions, as less residue would be present subsequent to previously coming into contact with a surface. This could be considered a timely method if participants are unable to achieve the desired force on every attempt. After reviewing current methods, Fieldhouse (2011) created a device known as a 'fingerprint sampler' to control the force and angle of deposition of a fingermark. The device allows the participant to hold their finger stationary, at a pre-set angle whilst the surface is controlled and brought up to the finger by the device. The force at which the surface touches the finger is preset and so can be consistent for all participants; the length of time the surface touches the finger is reliant on

the researcher's control. Positively, this method produced consistent results intra personally and appeared to eliminate the potential for participant skill affecting deposition, as is the case with a top pan balance. However, both of the controlled methods do not account for the natural variability that would be encountered operationally.

1.3.2. Type of residue

It is important to have a fundamental understanding of new development techniques and, techniques where relatively little is known about the interactions taking place to develop a fingermark. It can be beneficial to investigate which properties of a fingermark the technique may have an affinity to, particularly the type of residue and/or individual constituents. Groomed fingermarks, natural fingermarks and when relevant, constituent test spots are often used to investigate the interaction between fingermark residue and a development technique

Groomed fingermarks are marks that have been loaded with one specific type of residue. The most commonly used groomed fingermarks are eccrine and sebaceous rich marks. Developing eccrine residue and sebaceous residue separately and, observing the intensity of development will give an indication of which constituents a development technique may have an affinity to. For example, ninhydrin and Diazafluoren-9-one (DFO) are known to interact with amino acids found in eccrine residue and, lipid stains such as Oil Red O are known to interact with lipids found in sebaceous residue (IFRG, 2014, Sears *et al*, 2012). It is necessary to understand what (within fingermark residue) a fingermark development technique may be interacting with to recommend the use of that technique to its optimum potential and, to further improve the technique beyond its existing capabilities.

Usually, any type of groomed fingermark is initially prepared by participants washing their hands to remove contaminants, followed by loading the friction ridge skin with a specific type of sweat. Groomed eccrine fingermarks are often produced by allowing the hands to sweat naturally from the eccrine glands whilst avoiding contamination from, other types of residue, foods, dirt and cosmetics (Sear *et al*, 2012, De La Hunty *et al.*, 2015b). To avoid contaminants when generating eccrine rich fingermarks, participants are often required to wear powderless

gloves. Groomed sebaceous fingermarks are often generated by participants rubbing their fingertips over areas of the skin which are known to be abundant in sebaceous glands; for example, the back of the neck, top of the back and, providing cosmetics are not present, the forehead and nose (Jones *et al,* 2001, Kent, 2010, Sears *et al,* 2012).

Although groomed fingermarks are effective in establishing which group of constituents a development technique may have an affinity to, the method must be exercised with caution ensuring appropriate analysis and conclusions are drawn from the results. Groomed fingermarks should only be used to indicate which chemicals the development technique has an affinity to, and not to test or analyse the quality of the developed fingermarks or, the quality of the performance of the technique. To test or analyse quality, natural fingermarks should be used.

The International Fingerprint Research Group (IFRG, 2014) state that researchers may initially choose to use groomed fingermarks to ensure a positive result however, this is not accurate and should be avoided. The loading of fingermarks with a specific sweat can lead to poor results or false positives/negatives due to the heavy nature of the marks. The IFRG (2014) noted that physical developer (PD) can be unsuccessful at developing new, heavily loaded sebaceous fingermarks indicating that it is perhaps a less sensitive technique. Yet, PD has been reported to be very sensitive on aged fingermarks. Similarly, heavily loaded eccrine fingermarks can yield poor results with amino acid interacting techniques such as DFO (IFRG, 2014).

Croxton *et al* (2010) found that loading fingermarks with sebaceous residue had a significant effect on the composition of the fatty acid and some amino acids, compared to the composition in natural fingermarks. The study suggested that groomed fingermarks could negatively affect the results of a study and so, natural fingermarks should be preferentially used (Croxton *et al*, 2010).

As a result of the impact groomed fingermarks can have on the results of a study, it has been suggested that sole use of natural fingermarks should be preferentially used and, sole use of

groomed fingermarks should be avoided. Where groomed fingermarks are used, they should be used in conjunction with natural fingermarks (IFRG, 2014; Croxton *et al*, 2010).

Natural fingermarks are the most representative of operational fingermarks (IFRG, 2014). Natural fingermarks are not controlled or loaded prior to deposition; it would be anticipated that natural fingermarks contain a combination of eccrine residue, sebaceous secretions and contaminants (1.1). Usually when participants are asked to deposit natural fingermarks, they will have been instructed to go about their daily activities for 30-60 minutes after last washing their hands before depositing the marks (Sears *et al*, 2012). This is to allow the hands time to sweat naturally and to pick up any contaminants. Natural fingermarks are highly recommended when designing methods for fingermark research so that the interaction between the complex matrix of a fingermark and development technique can be observed. Groomed fingermarks and test spots are beneficial to observe a development technique with specific elements of a fingermark. However, operational fingermarks have a complex structure and mixture of residue that is difficult to replicate in any other way than using natural fingermarks. Unlike groomed fingermarks and test spots, using natural fingermarks means that the quality and sensitivity of a development technique can be observed; this is particularly useful for validation studies (IFRG, 2014).

As the quantity or composition of groomed and natural fingermarks cannot be controlled, to further phase 1 studies, test spots of individual constituents found within fingermark residue could be utilised (Sears *et al.,* 2012; Wargacki, Lewis and Dadmun, 2007; De la Hunty *et al*., 2015a). Test spots are a controlled method of being able to investigate what may cause the selective deposition (interaction) of a development technique. Whilst the information gleaned from such a study may be beneficial, it must be noted that individual constituents may behave differently when isolated way from the complex matrix and combination of a fingermark. Therefore, the method should be used in conjunction with the analysis of whole, natural fingermarks.

De La Hunty *et al* (2015a) used test spots of constituents that are known to originate from sebaceous glands to understand if Physical Developer (PD) has an affinity to lipids. The test

spots indicated that PD did not have a particular affinity to the constituents tested. The additional use of groomed sebaceous fingermarks in the study indicated that PD may have an affinity for eccrine constituents but when held in place on a surface by sebaceous constituents. De La Hunty *et al* (2015a) continued the investigation into the deposition of PD but focusing on eccrine constituents. The further study did not continue with the use of test spots, instead using groomed eccrine rich fingermarks. It could be suggested that, to make the two studies comparable, test spots of eccrine constituents could also have been tested. Isolating constituents means that the volume and, the concentration of the constituents can be controlled, creating a reproducible method. Whereas, using groomed fingermarks means you get the complicated matrix of a fingermark however, quantity and composition of residue is uncontrollable. Additionally, Wargacki, Lewis and Dadmun (2007) used test spots of alanine and sodium lactate to investigate the chemistry of development with cyanoacrylate fuming. Whilst conclusions were drawn from the study on the reactions occurring; the researchers should consider if the reactions may change when the constituents examined form part of a natural fingermark.

1.3.3. Substrate selection

Substrate type is one of the most vital pieces of information to aid in the selection of a fingermark development technique. Development techniques are usually selected on whether the substrate being treated is porous, non-porous or semi porous. As Cadd *et al.* (2015) summarises, porous substrates allow aqueous components to absorb beneath its surface and into its structure, such as paper, newspaper and, cardboard. Non-porous items do not allow the migration of aqueous components underneath its surface such as, plastics, glass and, treated metals. Semi-porous items generally permit much slower absorption of aqueous components than porous item; items such as some adhesive tapes, polymer bank notes and, painted wood are classed as semi-porous surfaces.

Development techniques are selected by the substrate type as different techniques work most effectively on a particular category of substrate. For example, WPS's would be inappropriate

for use on porous items due to its aqueous nature and, ninhydrin would be ineffective on non-porous substrates (Centre for Applied Science and Technology, 2014). Therefore, when conducting research on a new or relatively unknown development technique, substrates for the project should be representative of those which may be encountered at crime scene scenarios and would be treated with the development technique in question (Sears *et al.* 2012; IFRG, 2014; Kent, 2010).

Due to the importance of substrate types on the selection of development technique, internationally used guidelines, The Fingermark Visualisation Manual (Centre for Applied Science and Technology, 2014) suggest recommended sequential processes for items of evidence based on the substrate type. There are two main sequential processes, designed with the intention of developing as many fingermarks as possible from a single item of evidence. The sequential processes are designed for either non-porous or porous surfaces.

1.3.4. Aging of fingermarks.

It has been noted in guidelines for fingermark research methods that the age of a fingermark can have an impact of the quality of development. Literature suggests that a fingermarks composition changes fairly rapidly from the initial deposition over time (Kent, 2016: Cadd *et al.*, 2015; Sears *et al.*, 2012). As most crime scenes or items of evidence are not usually processed within 24 hours of a fingermark being deposited, it is necessary for the existence of development techniques that are able to develop fingermarks that are older than this (Kent, 2010; IFRG, 2014; Sears *et al.,* 2012).

When looking at non-porous surfaces in particular, literature suggests that over time, the water content will evaporate, leaving the less water soluble material to persist on the substrate (Kent, 2016; Cadd *et al.*, 2015). This knowledge is vital to the formation and improvement of fingermark development techniques, as it gives an indication of the constituents that a technique may need to have an affinity for to be able to develop aged fingermarks.

When conducting research on a new or relatively unknown development technique, it may be necessary to understand how sensitive a technique to aged fingermarks. Literature suggests that it is reasonable to assess aged fingermarks from 24 hours up to 4 weeks to replicate operational work (Kent, 2010; IFRG, 2014; Sears *et al.,* 2012). Problematically, the age of a fingermark is often unknown to it could be reasonable to think that in some instances (especially when revisiting cold cases), fingermarks may be much older than 4 weeks. This suggests the necessity to test established development techniques with fingermarks significantly older than 4 weeks.

1.3.5. Validating a new development technique.

Four stages of research are widely recommended for the investigation in to a new development technique to establish a fundamental understanding of the way the technique interacts with latent fingermarks and the quality of development that may be expected in a given scenario (Sears *et al*., 2012; IFRG, 2014; Kent, 2010).

The first stage of research is often called a phase 1 study. Literature suggests that this stage of research is usually the closest to a pilot or preliminary study. During this stage of study, the technique may be tested to see if it interacts with participant fingermarks, the quality of development that can be expected and, the sensitivity of the technique (Sears *et al*., 2012; IFRG, 2014; Kent, 2010). During this stage of research, the quality of development with different types of residue on a single substrate may be investigated, depletion series, test spots of individual constituents may be used and, a selection of ageing time periods may be considered.

This is then usually followed by a phase 2 study; a more exploratory investigation of a development technique. This part of a study is to investigate the robustness of a development technique by establishing the parameters of that technique (Sears *et al*., 2012; IFRG, 2014; Kent, 2010). This stage of research generally investigates the quality and cause of development utilising more participants (fingermark compositions), multiple substrates and, more (or

different) ageing periods. Where possible, the variables considered, should be representative of those which may be found in operational work.

Phase 3 studies are validation or pseudo-operational trials. Phase 3 studies are carried out to test the development technique on samples representative of case work; the aim is to establish if the results obtained in phase 1 and 2 are reflected on operationally representative samples (Sears *et al*., 2012; IFRG, 2014). IFRG (2014) suggest that pseudo-operational trials should include many participants, to cover a variety of donor types and range of fingermark compositions, with the substrates used being representative of commonly encountered, current operational work. Sears *et al*. (2012) suggests that surfaces representative of current case work should be collected, with an unknown history of who has handled the items and, without depositing specific fingermarks. Sears *et al*. (2012) state that this method is more representative of the type of items and fingermark compositions that may be encountered in operational work.

Finally, phase 4 studies are applied. Literature states that phase 4 studies are full operational, live casework trials where the new development technique is introduced alongside current techniques (Sears *et al*., 2012; IFRG, 2014). The aim is to establish if the new development technique is a beneficial addition or replacement to current development methods.

The outcome of these stages of research form a basic and fundamental understanding of a development technique. Without which, a technique may not be used efficiently, effectively or in the most appropriate manner.

1.4. Fingermark quality assessment.

In general, fingermark research produces descriptive, visual, qualitative data (Vanderwee *et al.,* 2011); however quantitative data is required in order to carry out some form of statistical analysis. Two popular methods of turning fingermark qualitative data in to quantitative data is to either by grading the developed fingermarks or, creating a grey scale of contrast between the developed mark and the background substrate (Sears *et al.,* 2012; IFRG, 2014; Fieldhouse and Gwinnett, 2016; Humphreys, 2007; Matuszewski and Szafalowicz, 2013; Vanderwee *et al.,* 2011). Grading fingermarks involves assigning a value to each individual mark which can then be statistically analysed. Alternatively, a software package can be used to create a grey scale of contrast between the substrate and developed fingermark; resulting in numerical data that can be statistically analysed.

Grading developed fingermarks converts a visual image in to a numerical value in order to be able to explore any patterns, correlations or differences between the fingermarks using statistical analysis. The method of grading fingermarks is very subjective, as it is based on a person's opinion as to how good a mark is perceived to be. For example, a fingerprint identification expert may grade a fingermark differently to an academic researcher. For this reason, when carrying out research, it must be considered whether it benefits the study to have only one (or more) individual grade the marks. Using one individual to grade all fingermarks in one study is beneficial as it eliminates inter person variation in opinion and ensures that all marks will be graded consistently to that individual's ability. However, quality control must be considered to ensure the accuracy, consistency and reproducibility in an individual's grading consistency.

To assign a grade to a fingermark the quality of the developed mark is considered, with different grading systems addressing and analysing the quality of different criterion. Most grading systems will consider the quality and continuity of ridge detail present, with some grading systems considering other criteria such as, the contrast between the developed fingermark and back ground substrate.

One of the most widely used grading systems has been developed by Centre for Applied Science and Technology (Sears *et al.,* 2012), formerly HOSDB. This system grades developed fingermarks on a scale of zero to four. Table 4 details the criteria used by CAST for each grade. This grading system was created using the qualities that a fingerprint expert would look for when trying to make an identification; focusing mainly on the quality of ridge detail. Sears *et al.* (2012), mention that the grading system in Table 4 is suggested as the primary grading system used however, secondary features (other than ridge detail) may sometimes need to be analysed for a more detailed outcome. Secondary features may include, contrast between ridge and background or ridge continuity.

Table 4. The grading system published by CAST, frequently used in fingermark research (Sears *et al.,* 2012)

Fingermark Grade	**Criteria**
0	No evidence of mark
1	Weak development; evidence of contact but no ridge detail
2	Limited development; about 1/3 of ridge details are present but probably cannot be used for identification purposes
3	Strong development; between 1/3 and 2/3 of ridge details; identifiable fingermark
4	Very strong development; full ridge details; identifiable fingermark

Although the CAST grading system is well used, it only analyses one feature of a fingermark and therefore it is not always the most relevant method to use. Depending on the reason a fingermark is being graded and what the intended outcome of the research is, a grading system that addresses more features of a developed fingermark will be more appropriate.

Fieldhouse and Gwinnett's (2016) grading system addresses four separate features of a developed fingermark. Each of the four features/criterion are independent of each other and

are individually graded out of five. The four separate grades are combined to give an overall score out of twenty. The grading system assumes that the higher the combined score, the better the quality of developed fingermark. Figure 4 illustrates the criteria and, 4 step process used to grade fingermarks using the Fieldhouse and Gwinnett (2016) system.

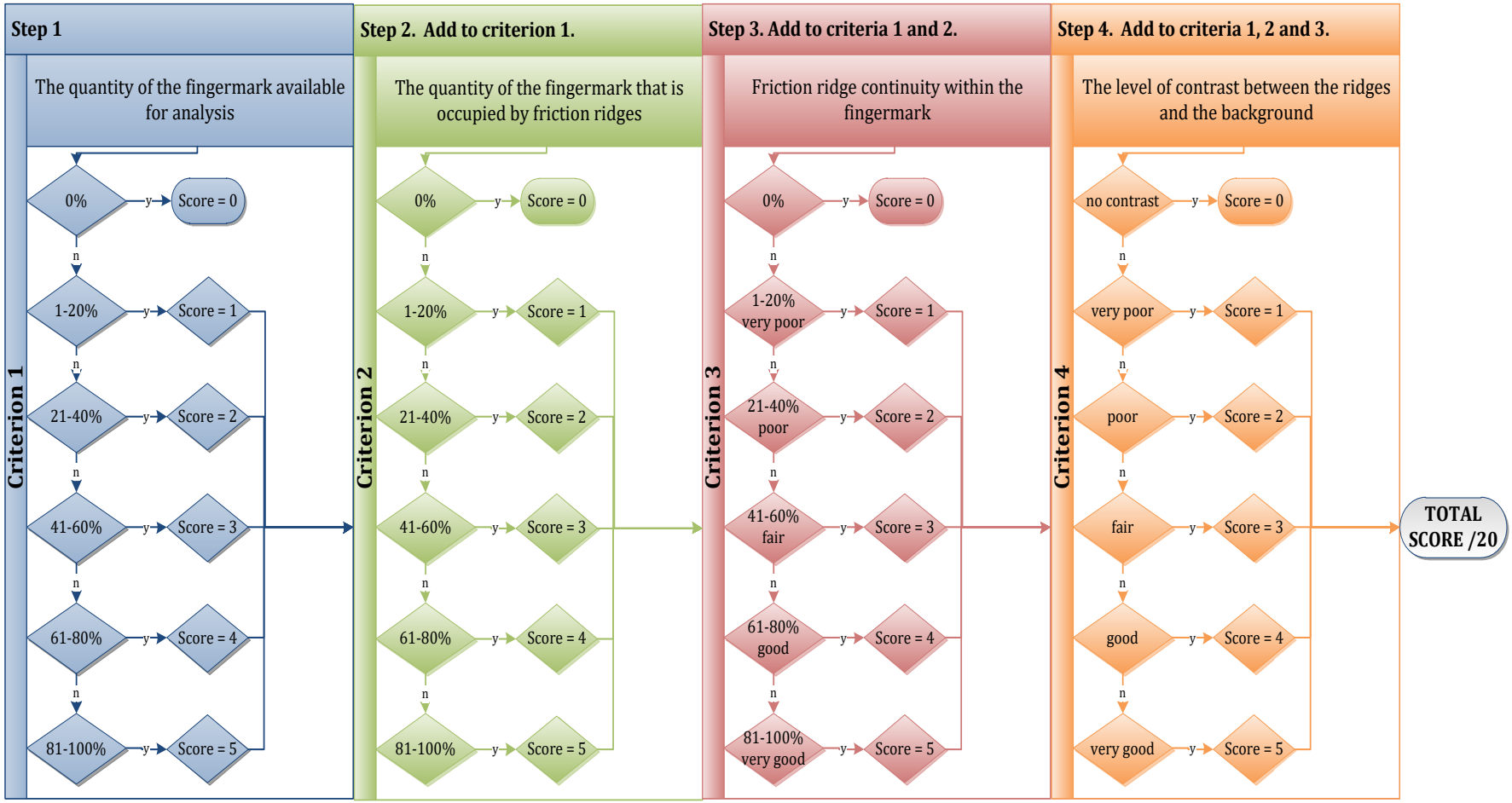


Figure 4. Fieldhouse and Gwinnett (2016), grading system used to give a numerical value to the developed fingermarks.

1.5. Aim and objectives of the research.

1.5.1. Aim

The aim of this research project was to investigate factors that may influence the development of latent fingermarks, when visualised with iron oxide wet powder suspension.

1.5.2. Objectives

The objectives of this research were;

1) To determine which type of sweat (eccrine, sebaceous or natural) develops most successfully with iron oxide WPS;
2) To study the consistency in quality of developed fingermarks between participants, when developed with iron oxide WPS;
3) To study the consistency in quality of developed fingermarks within each participant, when developed with iron oxide WPS;
4) To investigate if substrate type influences the quality of fingermark development, when developed with iron oxide WPS;
5) To determine if the age of latent fingermarks affects the quality of fingermark development, when developed with iron oxide WPS;
6) To explore the development quality between iron oxide wet powder suspension and individual constituents found in eccrine residue.

1.5.3. Original contribution to knowledge.

Wet powder suspension systems have been used to successfully develop latent fingermarks since the 1990's. The factors which influence the quality of development and, those which causes the powder particles to selective deposit on the fingermark residue, resulting in the development of a fingermark is still unknown.

This research will contribute to the existing knowledge on wet powder suspensions systems by, creating a rudimentary and fundamental understanding of the factors which influence quality of interaction between iron oxide wet powder suspension and latent fingermarks. This research will produce a fundamental understanding by extensively investigating the way in which the development technique develops latent fingermarks as a complex matrix of components as well as, the way in which it develops individual constituents found in eccrine residue when separated from the matrix of a fingermark. Extensive research on the rudimentary nature of iron oxide wet powder suspension development has not been carried to this degree prior to this study.

This contribution to knowledge will impact on the current use and understanding of iron oxide wet powder suspension, with the potential for changes to be made at a crime scene or in the laboratory as a result. If the nature of the interaction between the development technique and latent fingermarks is known, the formula could be modified to improve development, it could be adapted for an improved crime scene application and, best practice as an independent development technique and within a sequential process could be advised, so that the development technique can be used to its optimum (Sears *et al.,* 2012; IFRG, 2014).

Chapter 2. Methods

2.1. Overview of participant fingermarks deposited on glass microscope slides, developed using iron oxide wet powder suspension; phase 1 study

Ten volunteer participants, each deposited a total of 135 latent fingermarks on to glass microscope slides (2.1.2) using a fingerprint sampler (2.1.2). The participant demographics are detailed in *Table* 5. Each participant deposited 10 consecutive latent fingermarks consisting of three different types of residue; natural residue, groomed sebaceous and, groomed eccrine (2.1.1). The depletions of different residue types were repeated three times on one occasion to allow each set to age for different time periods; fresh (within 1 hour of deposition), after 24 hours and 1 week (2.1.3). These sets were repeated on five separate occasions to account for intra person variation.

When aged for the relevant period, all latent fingermarks were developed using a freshly made, working solution of iron oxide wet powder suspension (2.1.4). After development, the fingermarks were left to air dry in a laboratory, before being graded and analysed (2.1.5 and 2.4).

Table 5. Participant demographics.

Participant	Sex	Age	Occupation	Smoker/non-smoker
01	Male	26	Electrician	Non-smoker
02	Female	26	Research student	
03	Female	24	Office worker	
04	Male	28	Website designer	
05	Female	52	Post Office clerk	
06	Male	49	Commercial cleaner	
07	Male	39	Research student	
08	Female	38	Research student	
09	Female	23	Research student	
10	Male	22	Research student	

2.1.1. Residue preparation for participant fingermarks on glass microscope slides

Participants deposited 27 (of their 135) fingermarks on one occasion, consisting of natural residue, sebaceous rich residue and, eccrine rich residue respectively. The residues were prepared on the participants' fingers as detailed below:

Natural residue; participants were asked to go about their daily routine without washing their hands for at least 30 minutes prior to depositing latent fingermarks. The participants were asked to avoid heavy contact with cosmetics or greasy/acidic foods.

Sebaceous residue; participants were asked to wash their hands with soap (Pristine Antibacterial Foam Soap) and water and dry them on clean paper towels. They then rubbed their fingertips on their face and/or back of their neck and behind the ears to collect sebaceous secretions; no instruction was given as to how many times to rub these areas. The participants were asked if they had any cosmetics present on their face; if there were cosmetics present, that participant was asked to exclusively rub the back of their neck and behind their ears. Latent fingermarks were deposited immediately after grooming the fingers with the sebaceous residue.

Eccrine residue; participants washed their hands in the same way as detailed in the collection of sebaceous residue, then wore powderless gloves for approximately 30 minutes. As the gloves were removed, the participants rubbed their hands together and immediately deposited the latent fingermarks.

2.1.2. Deposition of fingermarks on glass microscope slides

A fingerprint sampler (Fieldhouse, 2015) was used to control the force and angle of fingermark deposition on each glass slide. A fingerprint sampler was set up and used in accordance with the manufacturer's operating instructions (SciChem International), using 4N force. Figure 54 shows the fingerprint sampler used.

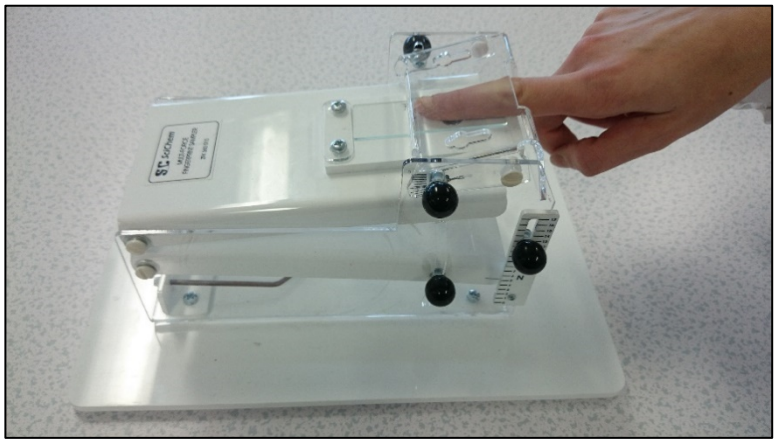


Figure 5. Fingerprint sampler used to control fingermark deposition.

Participants were asked to gently rub their fingertips together to help to distribute the residue evenly. Depletions of ten consecutive fingermarks were deposited using a fingerprint sampler. The fingermarks were deposited onto individual glass microscope slides (Fisherbrand™, 75 mm x 25 mm x 1.0-1.2 mm), retaining the 1st, 5th and 10th mark in the depletion series for analysis. The depletions were repeated with three separate fingers, resulting in three sets of 1st, 5th and 10th fingermarks for that residue condition.

The above procedure was repeated for all three residue conditions; starting with the deposition of natural residue, then sebaceous residue and finally, eccrine residue.

2.1.3. Aging time periods for participant fingermarks on glass microscope slides

Three sets of each residue condition (natural, eccrine and sebaceous) were taken, one set was developed within 1 hour after deposition, one set after 24 hours and the remaining set developed after 1 week.

The sets of fingermarks that were aged prior to development were stored in plastic, glass slide boxes in a cupboard under ambient laboratory conditions.

The collection of three sets of each residue condition consisting of 27 fingermarks, was repeated on five separate days (occasions); totalling in 135 fingermarks per participant.

Fingermarks were developed using iron oxide wet powder suspension in accordance with the details given in section 2.1.4.

2.1.4. Iron Oxide Wet Powder Suspension formulation and application

All deposited samples were developed using iron oxide based wet powder suspension; using the same formula and application for each study.

20 g of magnetic based, Fe_3O_4 iron oxide (Fisher Scientific) was mixed with 20 mL of a 1:1 solution of Kodak Photo-flo 200 (Crime Scene Investigation Equipment LTD) and deionised water to make the working suspension (UK Home Office, 2013). The working suspension was mixed until all the powder was blended in to a smooth paint like consistency. A fresh working solution was made and used each day that fingermarks were developed.

The working solution wet powder suspension was brushed on to each sample in turn using a soft squirrel haired brush. The wet powder suspension was left on the substrate for ~15 seconds before being washed off with deionised water.

Each substrate was left to air dry before the results were recorded and analysed.

Figure 6 shows the working solution of iron oxide wet powder suspension, the application of WPS, and the rinsing method.

Figure 6. Iron oxide wet powder suspension system.

2.1.5. Grading system applied to all developed fingermarks

Once dry, all developed fingermarks were viewed by eye in open laboratory conditions with artificial and natural lighting and, graded to provide a measure of their quality. The system created by Fieldhouse and Gwinnett (2016) was used to grade the developed fingermarks (1.4, Figure 4). Each fingermark was graded on four criteria; each criterion was scored out of five, giving a possible maximum total score of twenty per fingermark.

2.1.5.1. Examples of grading criteria for fingermarks developed on glass microscope slides

Figure 7 gives examples of fingermarks developed on glass using iron oxide WPS for each available grade under each of the criteria using the system detail in 2.1.5.

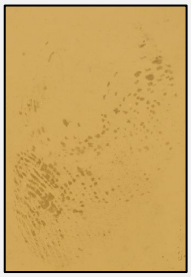
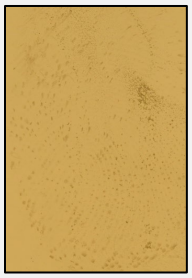
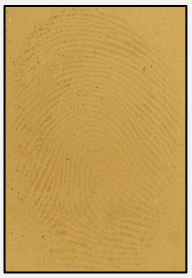
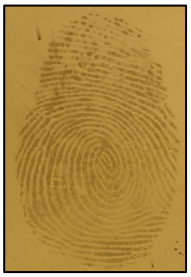
	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Criterion 1; The quantity of area of a fingermark that is available for analysis.					
Criterion 2; The quantity of fingermark that is occupied by ridge detail.					
Criterion 3; Friction ridge continuity.					
Criterion 4; Contrast between the ridges and background.					

Figure 7. Examples of fingermarks developed on glass for each grade and criterion.

2.2. Overview of eccrine constituent test spots and spiked fingermarks on multiple substrates; phase 2 study

Six of the most abundant constituents found in eccrine residue were selected for study and dissolved in deionised water. For the first part of this study, ten 20 µL spots of each of the dissolved constituents were pipetted on to 7 non-porous substrates (2.2.4). The spots were air dried in laboratory conditions for 5 days before either being developed with iron oxide WPS or, being coated with a fixing agent (2.2.5) then developed using iron oxide WPS.

For the second part of this study, a 20 µL droplet of each of the constituents was then pipetted on to a participant's finger (individually). The droplet was rubbed between two fingers until air dry and, deposited on to the same 7 substrates using the distal portion of the finger (2.2.6). The spiked fingermarks were also left to air dry in laboratory conditions for 5 days (2.2.4) before being developed using iron oxide WPS.

All of the above marks were left to air dry before being graded and statistically analysed (2.2.7 and 2.4).

2.2.1. Substrates types used for eccrine constituent test spots and spiked fingermarks

White acrylonitrile butadiene styrene (ABS), 3 mm thick, white, polyethylene (PE) sheets, 4 mm thick, and grey, polyvinyl chloride (PVC) sheets, 3 mm thick were purchased from RS Components LTD.

Polyethylene (PE) carrier bags were supplied by Tesco.

White, unplasticised polyvinyl chloride (uPVC) fascia board, 9 mm thick, was obtained from Wickes; product code 162635.

Grey, painted metal taken from a genuine car bonnet; type of metal, paint, lacquer and age unknown.

Sheets of window glass, 4 mm thick were supplied by RK Windows and Glass LTD.

2.2.2. Preparation of substrates used for the test spots and spiked fingermarks

All substrates (except PE bags) were washed with warm soapy water using a non-abrasive cloth, and then rinsed with deionised water. Each substrate was then rinsed with ethanol and deionised water and left uncovered on a drying rack to air dry in ambient laboratory conditions (Sears et al., 2011).

Each PE carrier bag was opened out so that the inside was face up ready to be used as the deposition surface. The carrier bag was secured to a 30 cm x 24 cm piece of cardboard using adhesive tape.

2.2.3. Eccrine constituent solutions used for test spots and spiked fingermarks

Ten mL solutions of 0.5 M of glucose, urea, sodium fluoride, sodium chloride, alanine and serine were individually prepared in deionised water.

Alanine, serine and urea were obtained from Sigma-Aldrich; sodium chloride from Fisher Scientific. Sodium fluoride was obtained from Chimica and, glucose from Lancaster Synthesis (now part of Alfa Aesar, part of Thermo Fisher Scientific).

2.2.4. Eccrine constituent test spots deposition, without a fixing agent.

Ten 20 µL drops of each solution, plus control samples of deionised water were deposited onto each substrate. The substrates were air dried for five days uncovered on a bench top, away from direct sunlight, in ambient laboratory conditions. Iron oxide wet powder suspension was used to develop the dried test spots

2.2.5. Eccrine constituent test spots deposition, with the application of 3M Spray Mount™ as a fixing agent.

Test spots were produced according to the method outlined in section 2.2.4. A layer of 3M Spray Mount™ was sprayed onto the test spots, with the aerosol can being held at an approximate height of 30 cm. It was not possible to control or monitor the exact amount and/or thickness of adhesive, and therefore the operator applied the adhesive until all test spots had been covered. The fixing agent was air dried for 1 hour in the laboratory, the test spots, including a control sample of 3M Spray Mount™ were then developed with iron oxide wet powder suspension.

2.2.6. Eccrine constituents deposited as spiked fingermarks

A 20 µL drop of one of the constituent solutions were pipetted to a participant's fingertip (with their residue in a natural state). The 20 µL drop was rubbed between two fingertips until it was thoroughly distributed and had air dried. A depletion series of 5 consecutively deposited fingermarks were placed onto one of the substrates using the two fingers that had been rubbed together (giving two repeats of 5 depletions per substrate). This was repeated with the same constituent solution, using a different pair of fingers for each substrate, until each of the 7 substrates had two repeats deposited. The participant then washed their hands, went about their daily routine for approximately 30 minutes before returning to repeat the above methodology with the next constituent. This was repeated until all constituents had been deposited on all substrates. For each substrate, control samples of deionised water and natural fingermarks were deposited prior to the deposition of the spiked constituent fingermarks. The spiked fingermarks were left to air dry for 5 days as detailed in 2.2.4 before being developed using iron oxide wet powder suspension.

2.2.7. Overview of grading systems applied to developed test spots and spiked fingermarks

The test spots were graded using a system created for the purpose of this study (2.2.7.1), to produce quantitative data for statistical analysis (2.4). The spiked fingermarks were evaluated using ImageJ (The Laboratory for Optical and Computational Instrumentation, 2016) to analyse the contrast between the developed fingermark and the background (2.2.7.2). The data produced from ImageJ was statistically analysed (2.4).

2.2.7.1. Grading of developed test spots

Test spots were graded on two criteria; completeness of the developed spot and contrast between the background and developed spot to give a quantitative value for analysis purposes. Each of the two criteria were graded from 0 – 4. The two grades were added to give an overall score out of 8; the average score from the ten test spots for each constituent on each substrate was used for the statistical analysis. Figure 8 and Figure 9 detail the criteria used to grade the test spots, with illustrated examples of each grade.

Completeness

0	**No development.**
1	Limited signs of development.
2	Development of the outer edge, no development to the inner test spot.
3	Development of the outer edge, some development of the inner test spot.
4	Complete development of both, the outer edge and the inner test spot.

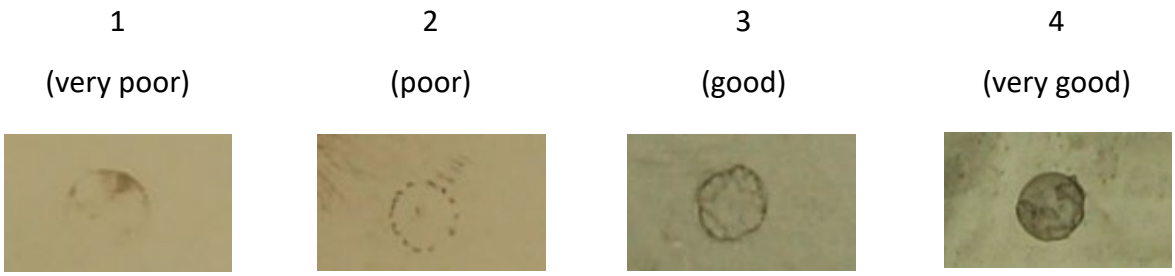


Figure 8. Grading criteria for the completeness of developed test spots.

Contrast

0	**No development.**
1	Very poor contrast between the background and developed test spot.
2	Poor contrast between the background and developed test spot.
3	Good contrast between the background and developed test spot.
4	Very good contrast between the background and developed test spot.

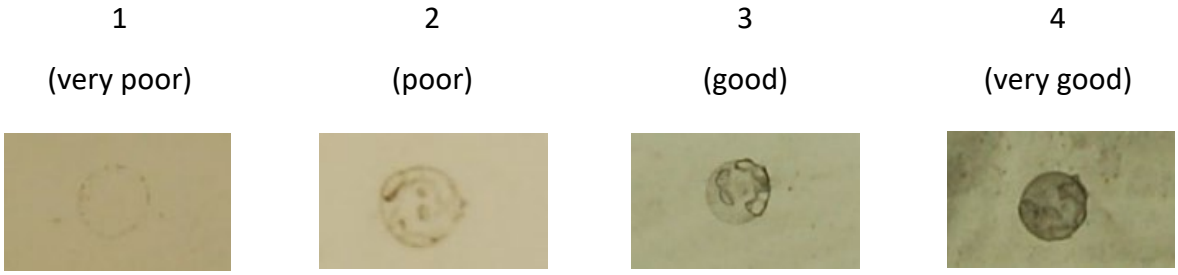


Figure 9. Grading criteria for the contrast of developed test spots.

2.2.7.2. Recording and analysis of developed spiked fingermarks

The dry developed fingermarks were photographed individually using a Nikon D3200 digital single lens reflex (DSLR) camera with an AF-S Micro NIKKOR 40mm 1:2.8G lens. The DSLR camera was set up using a DCS 121 with cross polarised ring lighting. The DSLR camera was used in manual mode with the shutter speed set at 1/4000, aperture set at F.7.1, and ISO at 200 for all light coloured substrates (including glass); and shutter speed set at 1/4000, aperture set at F.4, and ISO at 200 for the darker surfaces (PVC and painted metal).

The images were then analysed using ImageJ (The Laboratory for Optical and Computational Instrumentation, 2016). Each image was converted to an 8-bit, greyscale image; the area of image containing the fingermark was selected, and the pixel greyscale threshold was manually adjusted. Figure 10 demonstrates the adjustments made to the pixel greyscale threshold histogram, and the subsequent fingermark image. The blue, left threshold line was moved to the start of the left peak, finding the darkest pixel indicated on the histogram. While, the green, right threshold line was moved past the first right peak, until the background containing the lightest pixels of the image, were eliminated. The area of histogram in between the adjusted thresholds were the greyscale pixel values present over the friction ridges. The image was visually examined to ensure that the whole fingermark was selected. The value of the darkest pixel was subtracted from the value of the lightest pixel to give an overall greyscale contrast value for that mark. The larger the contrast value, the wider the range of pixels present meaning that there was a larger difference between the background and darkest pixel present on the developed fingermark.

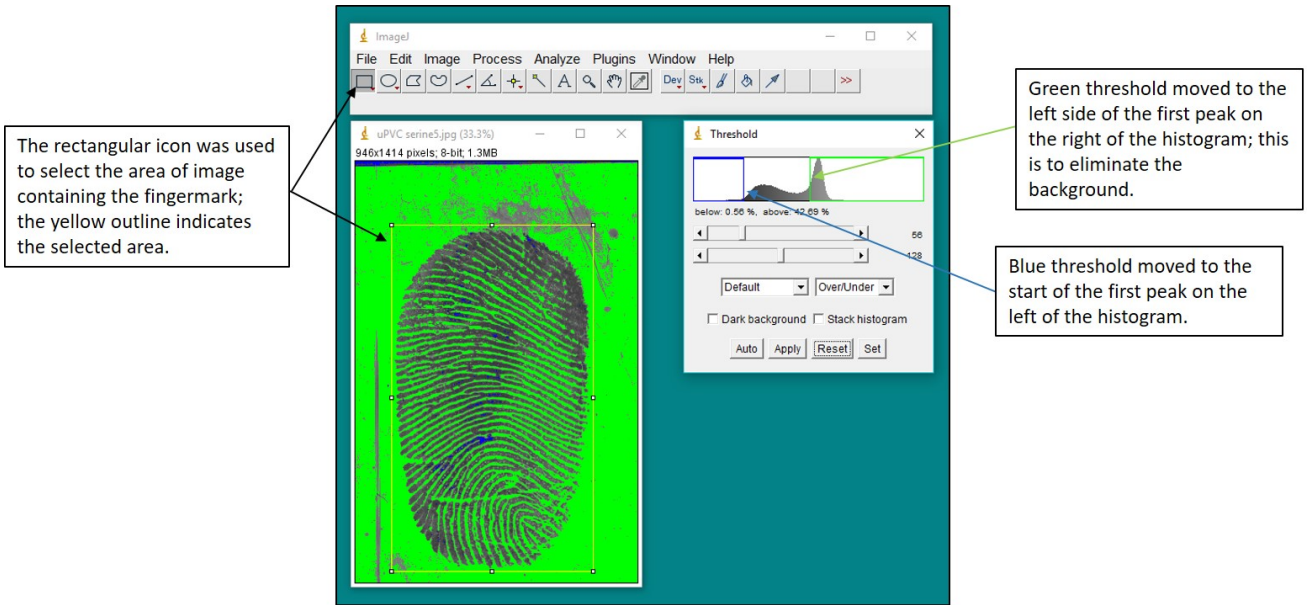


Figure 10. Method using ImageJ to get a contrast value for the spiked fingermarks.

2.3. Overview of participant fingermarks deposited on multiple substrates, developed using iron oxide wet powder suspension

The ten participants used in section 2.1 each deposited a further 189 natural latent fingermarks on to seven different non-porous substrates (2.3.1). Each participant deposited three sets of ten consecutive latent fingermarks, retaining the 1st, 5th and 10th depletions, on each of the seven surfaces; totaling 63 fingermarks per participant on one occasion (2.3.3). The three sets were aged for one of the following time periods; 24 hours, 2 weeks or 4 weeks (2.3.4). Each participant deposited these three sets of natural latent fingermarks on all 7 surfaces, on three separate occasions (2.3.3).

When aged for the relevant time period, all latent fingermarks were developed using freshly prepared iron oxide wet powder suspension. After development, the fingermarks were left to air dry in a laboratory (2.3.4), before being graded and analysed (2.3.5 and 2.4).

2.3.1. Substrate types and substrate preparation for the participant fingermarks on multiple substrates

The substrates used for the participant fingermarks on multiple substrates were the same as those detailed in 2.2.1.

All substrates, apart from PE carrier bag, were cleaned as detailed in section 2.2.2. A grid was drawn on to each dry substrate giving each individual participant an area of 3x4 cm to deposit each fingermark.

2.3.2. Residue preparation for the participant fingermarks on multiple substrates

All fingermarks deposited were of a natural residue condition. Participants were asked to go about their daily routine, without washing their hands for at least 30 minutes prior to depositing the latent fingermarks, avoiding excess contact with cosmetics or greasy/acidic food.

Each participant deposited a total of twenty-one depletions on one occasion; therefore, after all ten fingers had been used once, participants were asked to continue with their daily routine for another 30 minutes before returning to deposit ten more depletions. This was repeated once more for the one remaining depletion.

2.3.3. Deposition of fingermarks without a fingerprint sampler, for the participant fingermarks on multiple substrates

Participants were asked to deposit consecutive depletions as described in 2.1.2, on each of the substrates detailed in 2.2.1 however, without the use of a fingerprint sampler. The 1st, 5th and 10th depletions were recorded for analysis.

The participants deposited fingermarks without the use of any pressure or angle control (such as a fingermark sampler). The researcher demonstrated to the participants how to touch the surfaces using only the distal portion of the finger containing friction ridges, with a pressure that was, neither too heavy to distort the friction ridge retail, nor too light as to not leave behind sufficient residue. This meant that the pressure for each fingermark deposition was controlled by each participant.

Participants deposited fingermarks on three separate sets of the seven different substrates; totaling in 63 fingermarks per participant on one occasion. This process was repeated on three occasions (different days); totaling in 189 fingermarks per participant.

2.3.4. Aging time periods for the participant fingermarks on multiple substrates

The three sets of substrates were left to age uncovered, away from direct sunlight, in ambient laboratory conditions.

One set of fingermarks on each of the seven substrates were developed 24 hours after deposition. Another set were developed 2 weeks after deposition, and the third set were developed after 4 weeks.

All of the above were developed using iron oxide wet powder suspension.

2.3.5. Grading system applied to the developed fingermarks from the participant fingermarks on multiple substrates study

The developed fingermarks were graded using Fieldhouse and Gwinnett (2016) grading system. Figure 11 demonstrates the quality of fingermarks developed using iron oxide WPS on white coloured substrates for each available grade and criteria and, Figure 12 demonstrates the same on grey coloured substrates (PVC and painted steel).

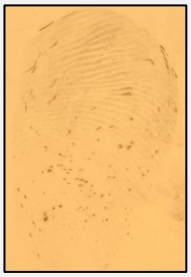
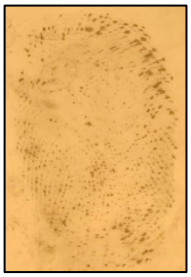
	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Criterion 1; The quantity of area of a fingermark that is available for analysis.					
Criterion 2; The quantity of fingermark that is occupied by ridge detail.					
Criterion 3; Friction ridge continuity.					
Criterion 4; Contrast between the ridges and background.					

Figure 11. Examples of fingermarks developed on white coloured substrates, for each grade and criterion.

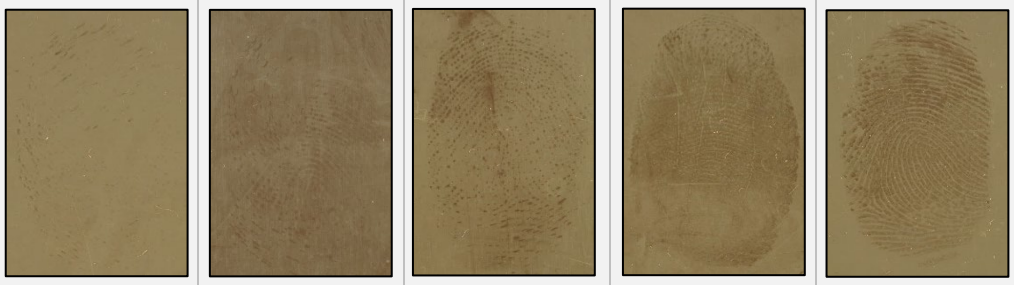
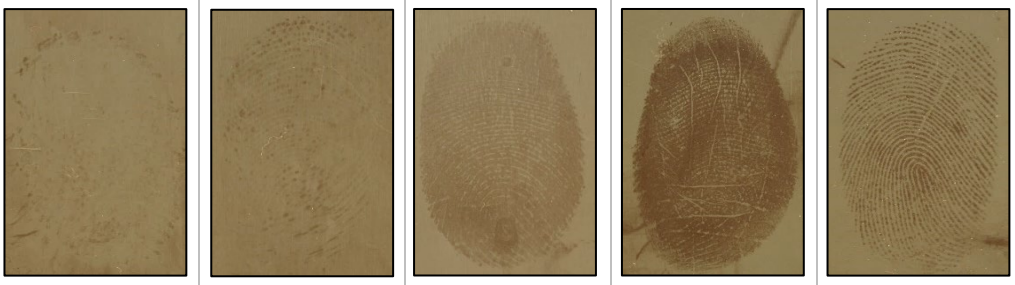
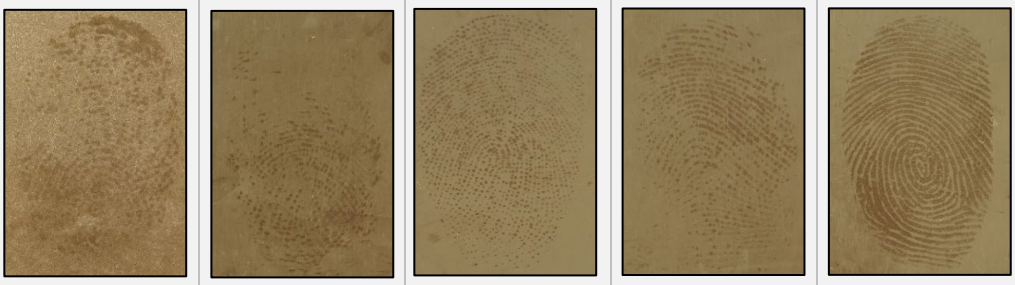
	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Criterion 1; The quantity of area of a fingermark that is available for analysis.					
Criterion 2; The quantity of fingermark that is occupied by ridge detail.					
Criterion 3; Friction ridge continuity.					
Criterion 4; Contrast between the ridges and background.					

Figure 12. Examples of fingermarks developed on grey coloured substrates, for each grade and criterion.

2.4. Statistical analysis of graded participant fingermarks

SPSS v22.00 – v24.00 (SPSS Inc.) were used to implement various tests to analyse if there were any statistically significant differences in the grades between variables. Table 6 shows the variables that were investigated along with the tests that were applied to each set of data. Where statistically significant differences were found as a result of the initial test, pairwise comparison post hoc tests were applied, to specifically identify where the differences were present. A Bonferroni correction was applied to adjust the alpha level for each test accordingly (Field, 2018). The effect sizes generated from the significance test outputs were compared to Pearson's r classification of effect size (Field, 2018). Pearson's r was calculated by applying the equation, $r = Z/\sqrt{N}$. The output from the calculation was then classified as a small, medium or large effect size by comparing to Pearson's thresholds; small = 0.1, medium = 0.3 and large = 0.5. All tests were carried out using the Monte Carlo method for probability, not the asymptotic significance.

Assumptions of the test.

Variable	Test for distribution	Distribution of data	Number of groups	Repeated/ Independent design	Test	Post hoc test	Number of pairwise comparisons
Participant	Shapiro Wilk	Non-parametric	>2	Repeated	Friedman	Wilcoxon Signed Rank	45
Substrate							21
Time							3
Constituent (test spots)							15
Constituent (spiked fingermark)							28
Sex			2	Independent	Mann-Whitney U	N/A	N/A
Sweat type			>2		Kruskal Wallis	Mann-Whitney U	3

Table 6. Statistical analysis applied to the data from this project.

A Shapiro Wilk test for distribution indicated normal distribution for constituent spiked fingermarks when comparing serine across all substrates and, when the spiked fingermarks were compared on glass, PE sheet and PE bag (separately). As there were more than 2 groups with a repeated measures design in each instance, a one-way repeated measures ANOVA was applied. If there was a significant difference the partial eta squared value for effect size was recorded and, pairwise post hoc tests were applied.

For the pilot study, a multiple regression test was carried out to analyse the effect of the independent variables (time since deposition, depletion number and condition of sweat; 'natural', 'sebaceous' and 'eccrine') on fingermark grades. The effect sizes were compared to Cohen's d classification of effect sizes.

Chapter 3. Results

3.1. Participant fingermarks deposited on glass microscope slides, developed using iron oxide wet powder suspension; pilot study

3.1.1. Inter person variation on glass microscope slides

Nine out of the ten participants had a modal value of 0. However, some participants had a higher frequency of fingermarks graded 0 than others. Fingermarks that were graded 0 had no development visible to the human eye. Iron oxide WPS was very ineffective at developing fingermarks from participants 01, 02, 03, and, 05, with over half of their 135 fingermarks scoring 0. Figure 13 shows an example of the data from two of the participants who had over half of their developed fingermarks graded 0. Participants 01 and 03 both deposited fingermarks that when developed graded between 0 and 16, with 105 and 113 out of their 135 fingermarks respectively, being graded 0. Participants 01 and 03 had mean grades of 1 out of 20. All data for participants with over half of their fingermarks graded 0 had strong positive skew. The positive skew indicated that the mean value (fingermark grade) for each participant was higher than the median value. Positive skew was to be expected as the modal value for each participant was 0, with some of the developed fingermarks gaining higher grades, giving the tail to the right of the histograms.

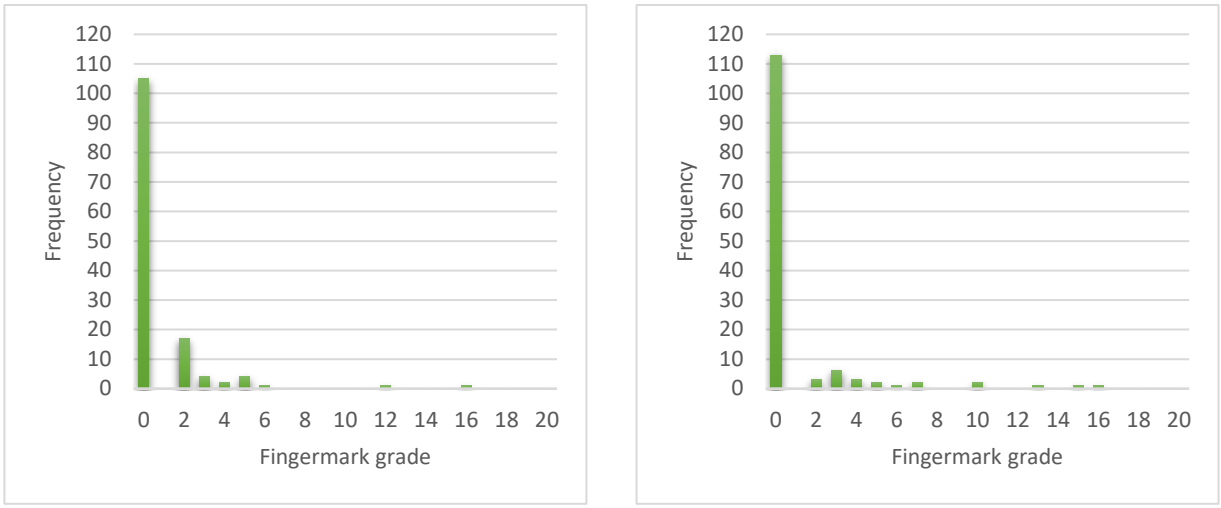


Figure 13. The frequency of grades 0 to 20 for participants 01 and, 03 respectively.

Iron oxide WPS developed some participants' fingermarks more effectively. Participants 04 and 10 still had a modal grade of 0, although they had the lowest frequencies of fingermarks graded 0, with 37 and 38 out of 135 respectively. Figure 14 shows the fingermark grades for participants 04 and 10. Both had a mean grade of 7, with mild positive skew. None of the ten participants' fingermark grades displayed negative skew.

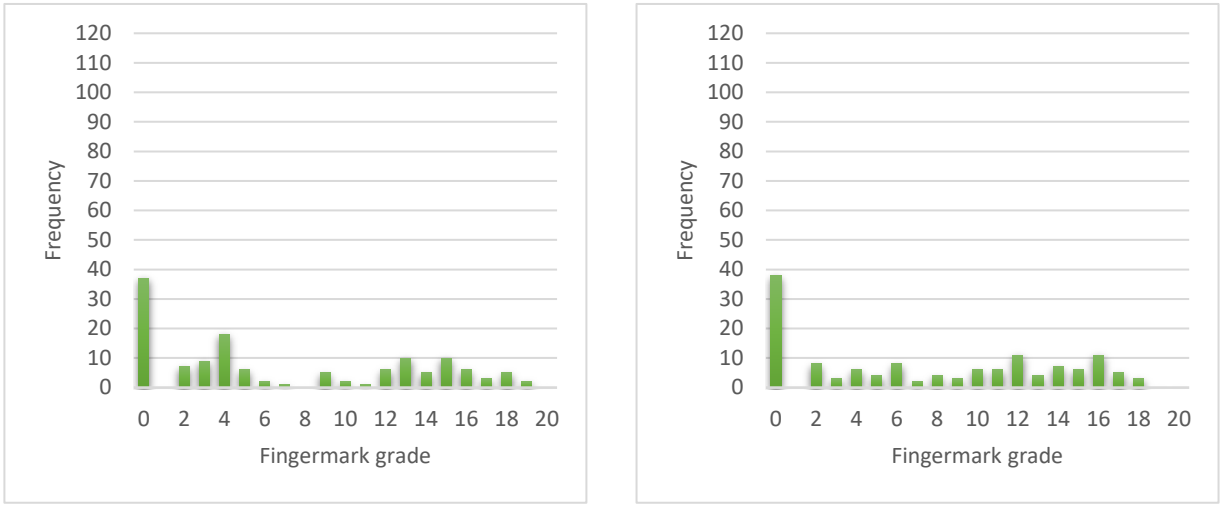


Figure 14. The frequency of grades 0 to 20 for participants 04 and, 10 respectively.

Participant 06 was the only participant whose modal fingermark grade was not 0. Participant 06 had a mean fingermark grade of 8. Figure 15 shows the fingermark grades for participant 06 were more normally distributed than other participant fingermark grades, showing no skew.

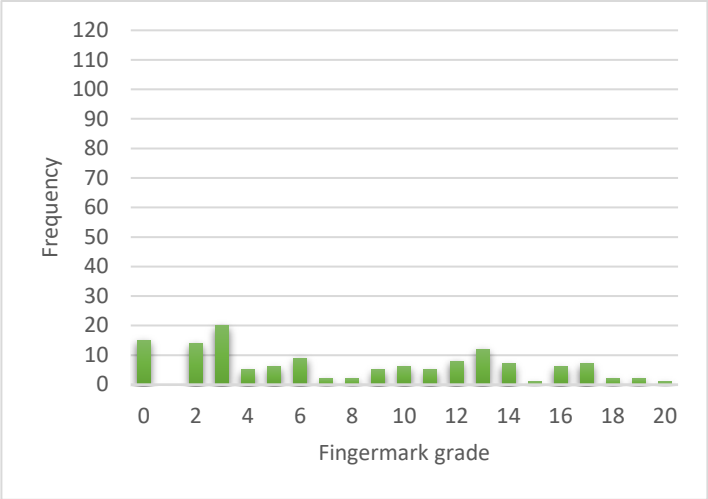


Figure 15. The frequency of fingermark grades 0 to 20 for participant 06.

Figure 16 illustrates the inter person variation observed from the fingermark grades in the pilot study. Overall, all participants achieved average grades of below 10 (half of the total marks available), showing generally poor quality development. The standard deviations in Figure 16 show that the participants with lower grades such as participants 01 and 03, were only able to achieve a highest grade equivalent to the lowest grades for the participants who produced higher grades as their average, for example participant 06.

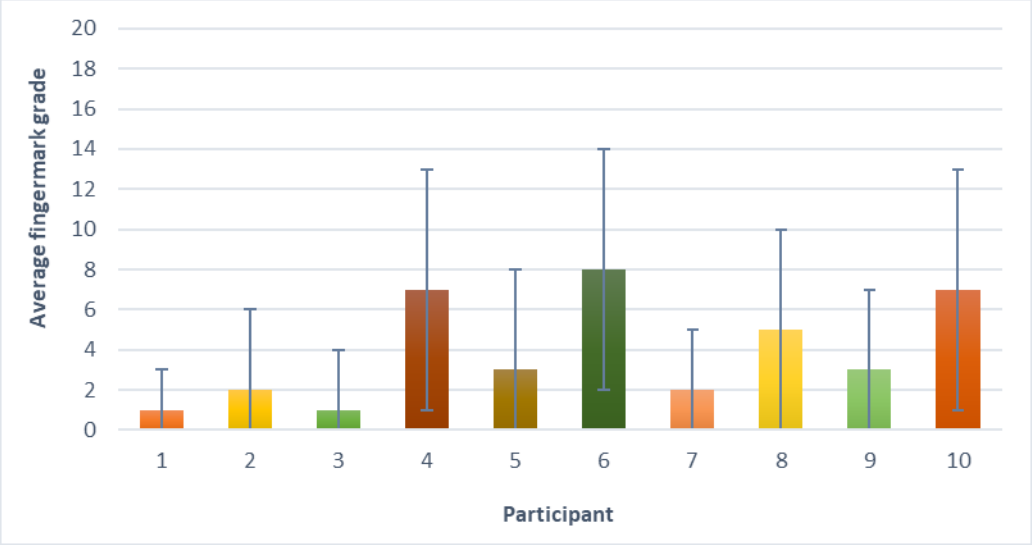


Figure 16. The average fingermark grades for each participant with the individual sweat types combined (n=1350, error bars=SD).

3.1.1.1. Statistical analysis of the inter person variation on glass microscope slides

A test for statistically significant difference was carried to analyse the significance in the difference between participant fingermark grades.

The results of a Shapiro-Wilk test showed that the data was not normally distributed ($p \leq 0.05$), so a Friedman test for significant difference was applied. The results of the Friedman test provided evidence of a significant difference between the participants' fingermark grades ($p \leq 0.05$).

To locate the specific areas of significant differences, forty-five pairwise post hoc tests were carried out between each participant. A Bonferroni correction applied to adjust the alpha level. Forty-five post-hoc tests were carried out therefore, the original alpha level of 0.05 was divided by 45 to give a new alpha level of 0.001. The results from the post hoc Wilcoxon Signed Rank tests showed that 11 pairs of participants had no significant differences in their fingermark

grades (p> 0.001). Thirty-four pairs of participants did show significant differences (p≤0.001). Out of these 34 pairs, 12 had a large effect size according to Pearson's r (r= -0.5), and 17 had a medium effect size (r= -0.3 to -0.4).

Table 76 details the effect sizes of the pairwise post hoc tests between participants. Omitting the small effect sizes, participants 05 and 09 are the only participants to have just medium effect sizes, all other participants have at least one pair with a large effect size. Participants 06 and 10 have the most, large effect sizes.

Table 7. Effect sizes using Pearson's r, of the pairwise post hoc tests, with participant as the variable being tested for the pilot study. NS indicated no significant difference at the adjusted alpha level of 0.001.

	01	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
01										
02	NS									
03	NS	NS								
04	Large	Medium	Large							
05	Medium	NS	Medium	Medium						
06	Large	Large	Large	NS	Medium					
07	Medium	NS	Medium	Large	NS	Large				
08	Medium	Medium	Large	Small	NS	Small	Medium			
09	Medium	Small	Medium	Medium	NS	Medium	Small	Small		
10	Large	Large	Large	NS	Medium	NS	Large	Medium	Medium	

3.1.2. Analysis of the sweat types on glass microscope slides

A breakdown of the total fingermark grade frequencies into sweat type showed that, for eight out of the ten participants their eccrine groomed fingermarks gave the most 0's, showing the least development. Participants 05 and 06 natural fingermarks gave the most 0's, showing the least development for these two participants out of the three different sweat types. For all of the 10 participants, fingermarks of a natural sweat condition gave the highest average fingermark grade.

Figure 17 shows the frequency of fingermark grades of developed eccrine rich marks for each of the participants. The fingermark grades have been grouped into categories of fingermarks graded 0, 1-10 and, 11-20.

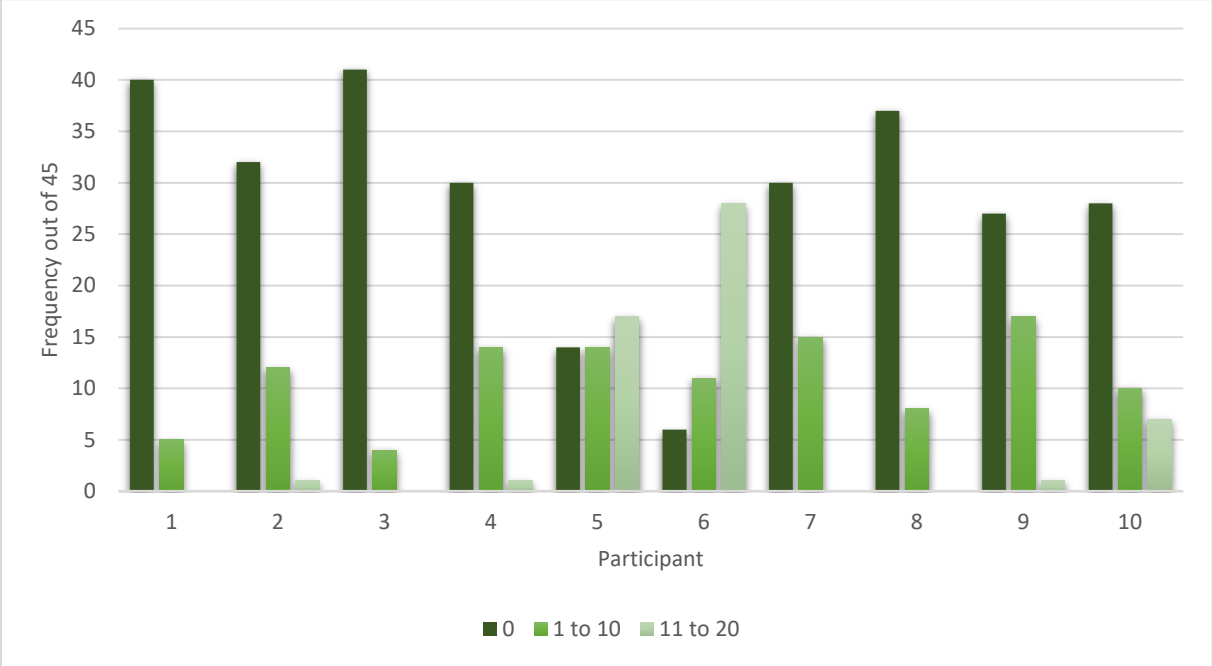


Figure 17. Frequency of fingermark grades for each participant's eccrine rich fingermarks.

Figure 17 illustrates that for 8 out of the 10 participants, over half of their 45 eccrine fingermarks graded 0. Each of these 8 participants deposited some fingermarks that were graded between 1 and 10 although, the frequency of these grades was generally less than 15 out of 45. Just 4 out of the 8 participants whose modal value for eccrine fingermarks was 0,

graded above 10. Three out of these 4 achieved only one fingermark graded above 10. Eccrine fingermarks for participants 01, 07 and, 08 were not graded above 3, showing extremely poor development. Participant 03 graded no higher than 7, participants 02 and 09 gave some eccrine fingermarks that were graded up to 12, and participants 04 and 10 deposited eccrine fingermarks that scored as high as 16.

Participants 05 and 06 developed eccrine fingermarks did not display the same pattern in their grades as the other 8 participants. Figure 17 demonstrates that participants 05 and 06 gave frequencies of 17 and 28 eccrine fingermarks out of 45 respectively, that were graded above 10. Fingermarks graded between 1 and 10 for these two participants were not dissimilar to the other 8 participants' however, the frequency of eccrine fingermarks graded 0 was significantly less.

Figure 18 shows the frequency of fingermark grades for each participant's developed sebaceous rich marks.

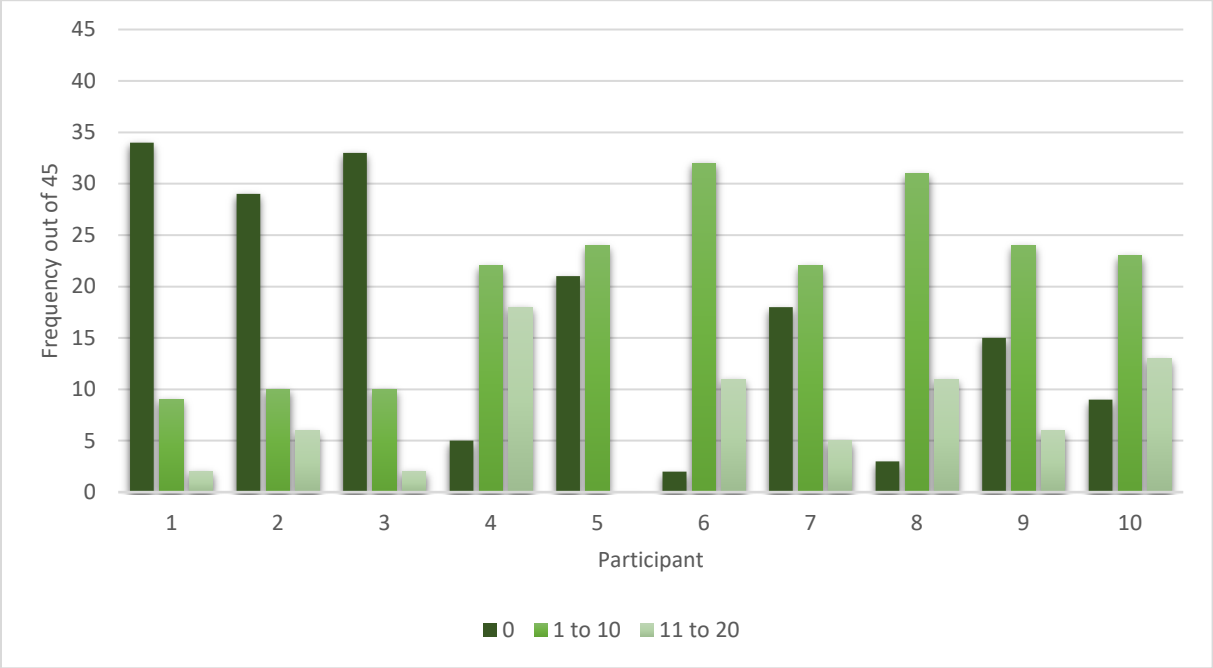


Figure 18. Frequency of fingermark grades for each participant's sebaceous rich fingermarks.

Figure 18 shows that participants 01, 02 and, 03 had the highest frequencies of sebaceous fingermarks graded 0, with over half of their 45 marks showing no development. The remaining 7 participants show the highest frequency of grades for developed sebaceous fingermarks, between 1 and 10. When observing the 7 participants where the highest frequencies were above 0 and, focusing only on the sebaceous fingermarks that were graded 1 or above (showing development), there was a large difference between the highest grade given and the modal grade. Participants 04 and 08 graded as high as 19 for their sebaceous fingermarks yet, with a modal grade of 4/5 and 3 respectively. Participants 06, 09 and, 10 deposited sebaceous fingermarks that graded up to 17 however, over the data set displayed modal grades of 3, 4 and, 2 respectively. Participant 07 gave sebaceous fingermarks that graded up to 13, with a modal grade of 4. Participant 05 was the only participant to have no sebaceous fingermarks being graded above 10. Their sebaceous fingermarks only graded as high as 8, with a modal grade of 2.

Figure 19 shows the frequency of fingermark grades for each participant developed natural marks.

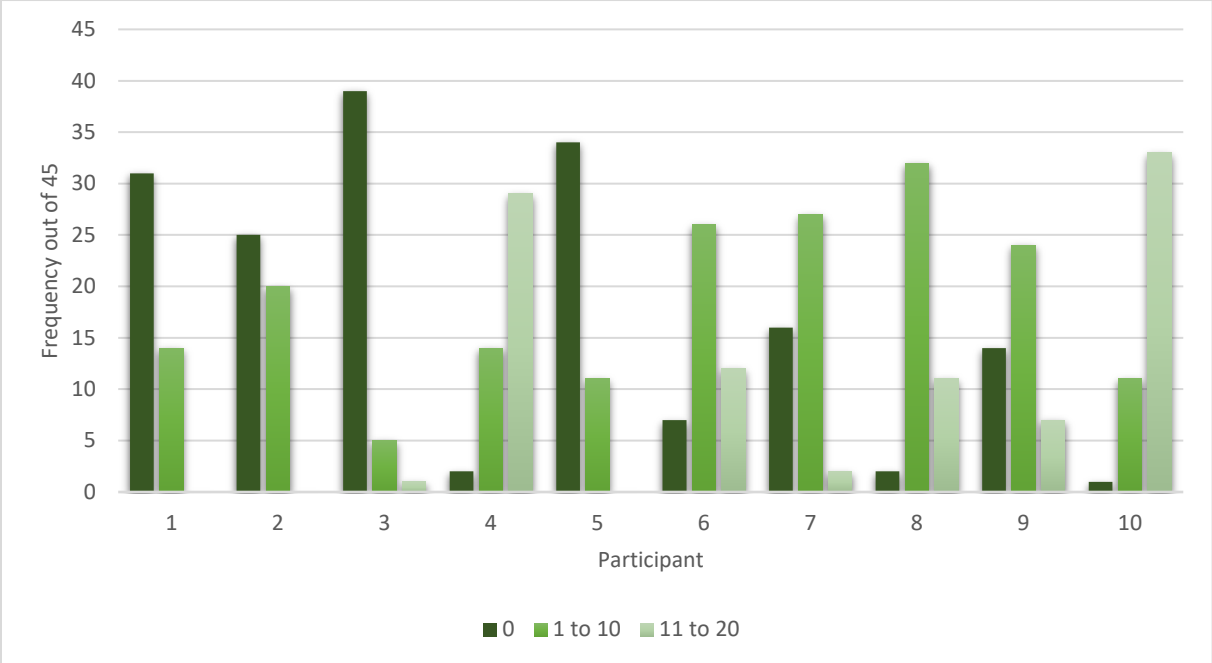


Figure 19. Frequency of fingermark grades for each participant's natural fingermarks.

Similarly to the data for sebaceous fingermarks, participants 01, 02 and, 03 with the addition of participant 05, had over half of their natural fingermarks showing no development. Out of these 4 participants, only participant 03 gave a fingermark that was graded above 10. Participants 06, 07, 08 and, 09 had their highest frequency grades between 1 and 10, with significantly fewer fingermarks graded above 10. Participants 04 and 10 were the only participants to have over half of their 45 natural fingermarks graded above 10. These two participants had just 2 and 1 of their 45 natural fingermarks respectively, showing no development.

It can be seen from Figure 17, Figure 18 and Figure 19 that the fingermark grades progressively improved from eccrine to sebaceous, with natural fingermarks giving the highest graded fingermarks overall.

3.1.2.1. Statistical analysis of the different sweat types on glass microscope slides

A test for significant difference was applied to the data to investigate if there was a difference between the fingermark grades for each sweat type. A Shapiro-Wilk test indicated that the data was not normally distributed so an independent, Kruskal Wallis test was applied. The results showed that there was a significant difference $p \leq 0.05$. Three Mann-Whitney U pairwise post hoc comparisons were carried out to detail the specific areas of significant difference. A Bonferroni correction was applied (0.05/3) to give an adjusted alpha level of 0.017. The output from the post hoc tests showed that there was a significant difference ($p \leq 0.017$) in fingermark grades between natural and eccrine rich marks and, between sebaceous and eccrine rich marks; however, both pairs only showed small effect sizes, $r = -0.2$. There was no significant difference in fingermark grades between natural and sebaceous rich marks ($p > 0.017$).

3.1.3. Intra person variation on glass microscope slides

Figure 20 shows the frequency of fingermarks graded 0 to 20 for participants 05 and 08. The histograms illustrate the wide range of fingermark grades that could be attained by one participant, demonstrating intra person variation. The histogram for participant 05 showed that over half (69) of their 135 fingermarks were graded 0. However, on two occasions the same participant produced fingermarks that were graded 19 out of 20. Similarly, the histogram for participant 08 showed that on one occasion a fingermark was graded as high as 19, yet still on some occasions (<50/135) their fingermarks showed no development at all.

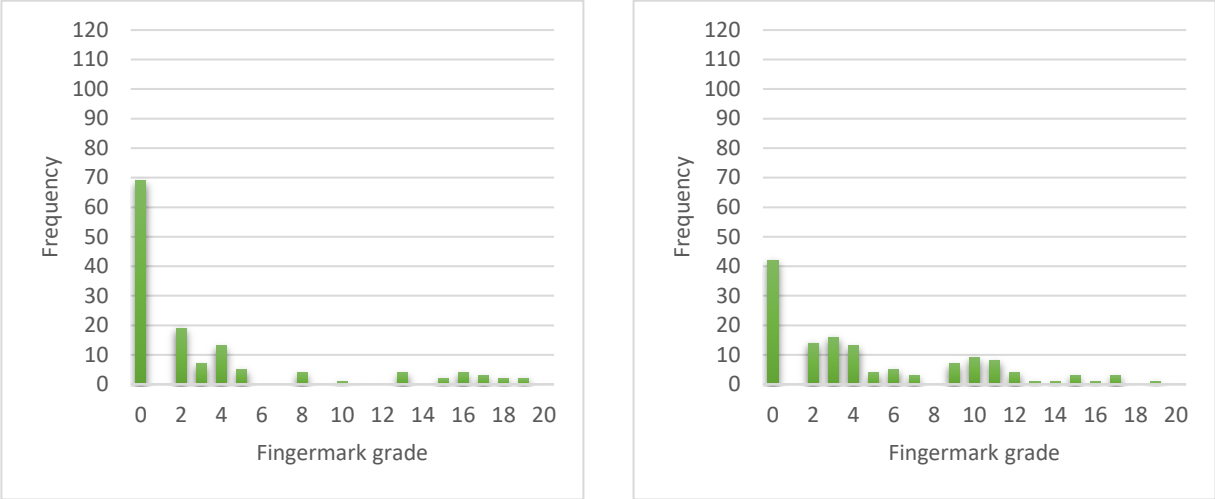


Figure 20. The frequency of fingermarks graded 0 to 20 for participants 05 and 08.

3.1.4. Effect of additional independent variables on the fingermark grades on glass microscope slides

When analysing the depletions for the sensitivity of deposition of iron oxide WPS, some participants produced fingermarks that showed development from the 1st mark of the depletion series through to the 10th as demonstrated in Figure 21. However, this was not a common occurrence given the high number of fingermarks that did not develop.

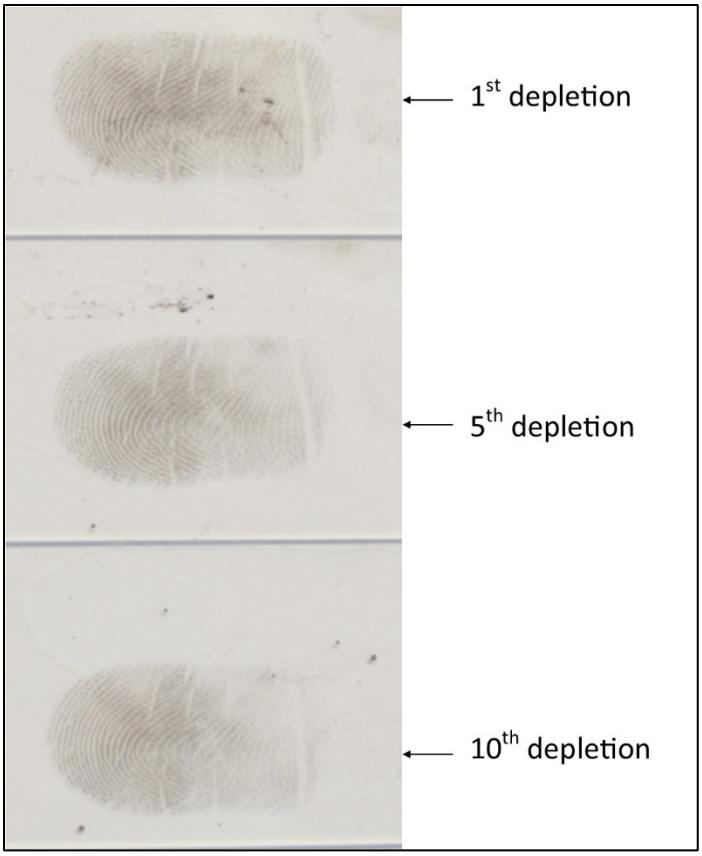


Figure 21. Depletion fingermarks 1, 5 and 10; participant 05, eccrine rich, 24 hours (aged time period).

Figure 22 shows the frequency of fingermark grades for each of the three time periods used to age the fingermarks; within 1 hour, after 24 hours and 1 week of deposition. Fingermarks developed within one hour of deposition gave the least development, evidenced by the most marks graded 0. One fingermark developed within 1 hour after deposition was graded at 20 out of 20, with the rest of the fingermarks in that category achieving a range of all possible grades. Similarly, fingermarks developed after 24 hours and, 1 week achieved a range of all of the grades however, with a highest grade of 19 and 18 respectively. Although there is a variation in the frequencies of each grade between the three time periods, the mean grade for all three periods was 4, all with standard deviations of 5.

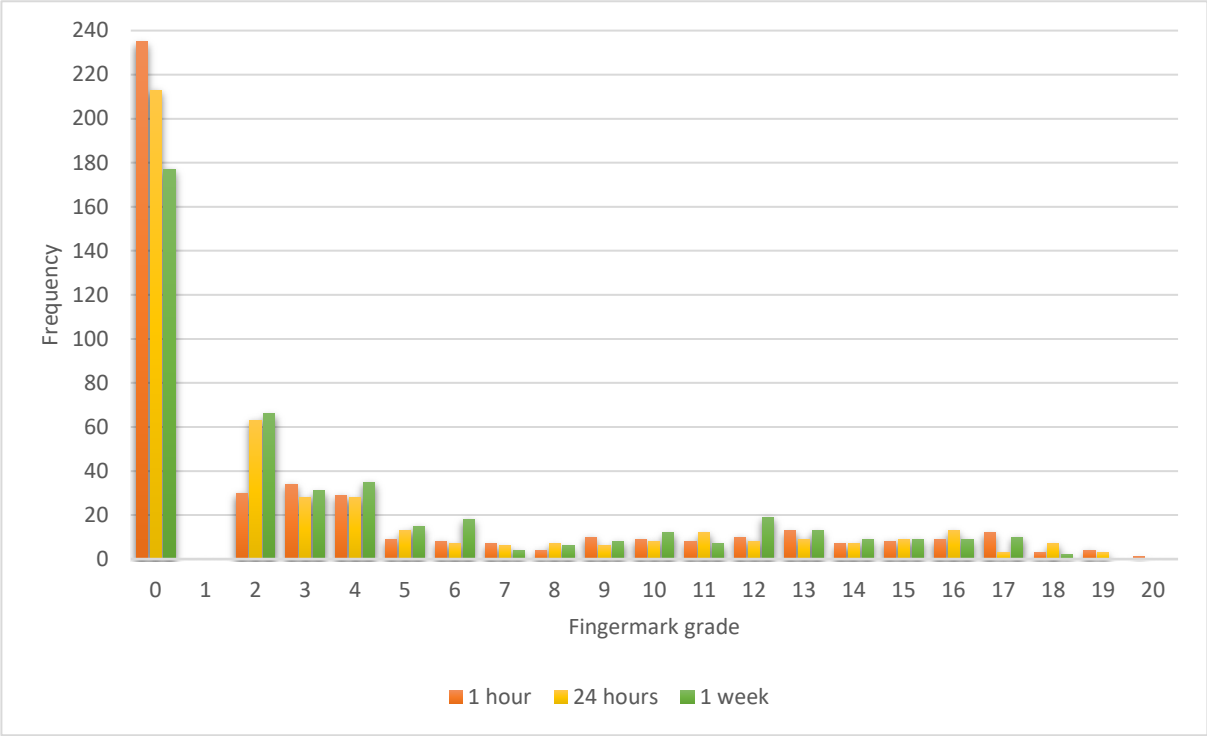


Figure 22. Frequency of fingermark grades for participant fingermarks developed within 1 hour, after 24 hours and 1 week of deposition.

A test for significant difference was applied to the data to establish if there was a difference between the fingermark grades for the three time periods. A Shapiro-Wilk test showed that the data was not normally distributed, so a Friedman test was applied. The results indicated that there was a significant difference ($p \leq 0.05$). Three Wilcoxon Signed Rank pairwise post hoc tests were applied to locate the areas of difference. A Bonferroni correction was applied to the post hoc tests (0.05/3) to give an adjusted alpha level of 0.017.

The results of the post hoc tests showed that there was no difference between 1 hour and 24 hours and, 1 hour and 1 week ($p > 0.017$). There was a significant difference between 24 hours and 1 week ($p \leq 0.017$), however with only a small effect size ($r = -0.1$).

Multiple regression analysis was carried out to analyse the effect the remaining variables (time since deposition, depletion number and condition of sweat) had on the quality of developed fingermarks/fingermark grades. The results from Pearson's correlation matrix generated by the multiple regression show that both the depletion number and time since deposition had a weak negative relationship with the fingermark grade r = -0.212 and r = -0.142 respectively, when looking at the individual variables. The condition of sweat had a weak positive relationship with the dependent variable (r = 0.035). The weak relationships indicated that the changes in the independent variables were not correlated with the changes from the fingermark grades.

The results of the multiple regression showed that each independent variable only had a small effect on the grade of the developed fingermark (dependent variable) when taking the other independent variables in to consideration. This small effect size was evidenced by an absolute R value of 0.257. According to Cohen's classification of effect size as cited in Field (2018), if the absolute R value is less than 0.3 then the independent variables have a small effect size on the dependent variable.

3.2. Results of eccrine constituent test spots and spiked fingermarks on multiple substrates, developed using iron oxide wet powder suspension

3.2.1. Eccrine constituent test spots deposition, without a fixing agent

Figure 23 shows the average grades (out of 8) for the constituent test spots on each substrate. The deionised water test spots (control) showed no development. Serine showed no development on six substrates, with only 2 test spots out of 10 showing development on glass. Glucose demonstrated very little development, with test spots only developing on PE sheet, PVC and painted metal. The test spots that developed on these substrates achieved average grades of 1 out of a possible 8, with relatively high standard deviations.

Alanine gave the best development over all the constituents, with the highest average grades on uPVC, PVC, ABS and painted metal, and relatively low standard deviations. Urea gave the next best development, with the highest average grade on PE sheet, yet all with large standard deviations. On PE bag, urea, alanine and sodium fluoride all gave the same average grade of 3 out of 8, yet again all had large standard deviations. Apart from alanine, all the constituents that showed development had high standard deviations, resulting in the potential for low quality or no development. Where test spots (of any constituent) showed no development (graded 0), it appeared that the spots were not able to remain on the surface and had been washed off during the development process.

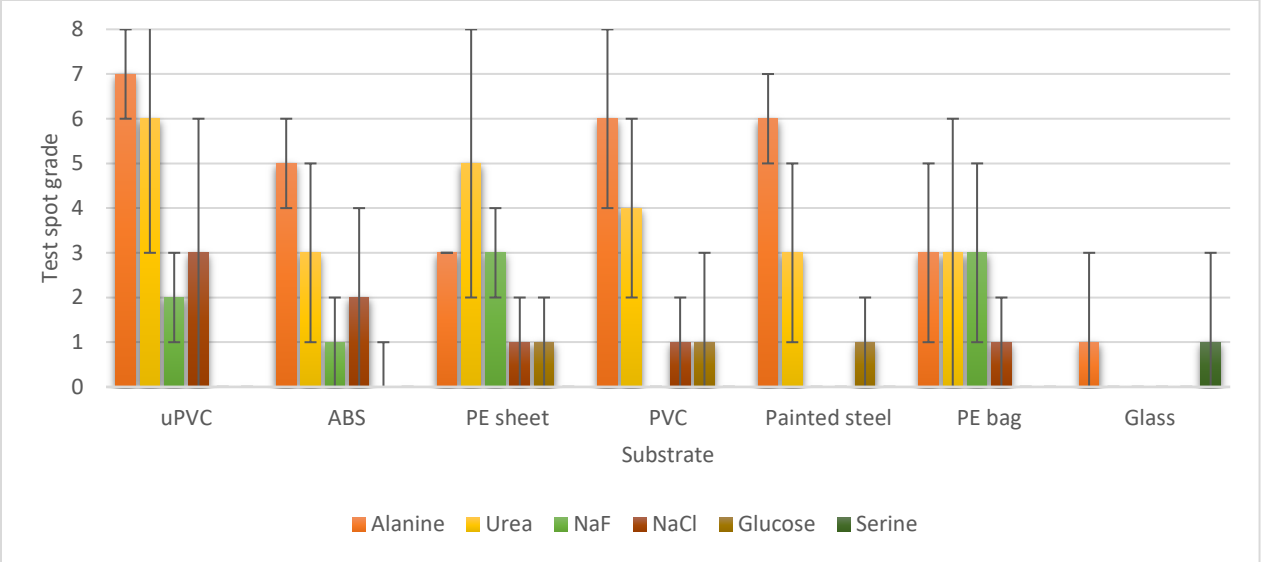


Figure 23. The average grades for the constituent test spots on each substrate (n=420, error bars=SD).

All of the substrates displayed some development, with glass showing the least and PE sheet showing the most. When grouping all constituent grades together to investigate if the substrate type had an impact on the quality of development, glass gave an average grade of 0, uPVC had an average of 3 and, the remaining 5 substrates all gave an average grade of 2. This could indicate that uPVC had slightly more/better quality development than the other substrates

Visual observations of the constituents showed that they varied in the intensity of development over the different substrates. Figure 24 shows alanine test spots on the PVC and PE sheet, and urea test spots on uPVC and ABS. Alanine on PVC developed with the entire of the dried spot attracting the iron oxide, with a good contrast. Alanine spots on the PE sheet developed with only the outline of the spot attracting the iron oxide, with a much lighter contrast. Similarly, urea test spots on uPVC developed with a better contrast than those on ABS.

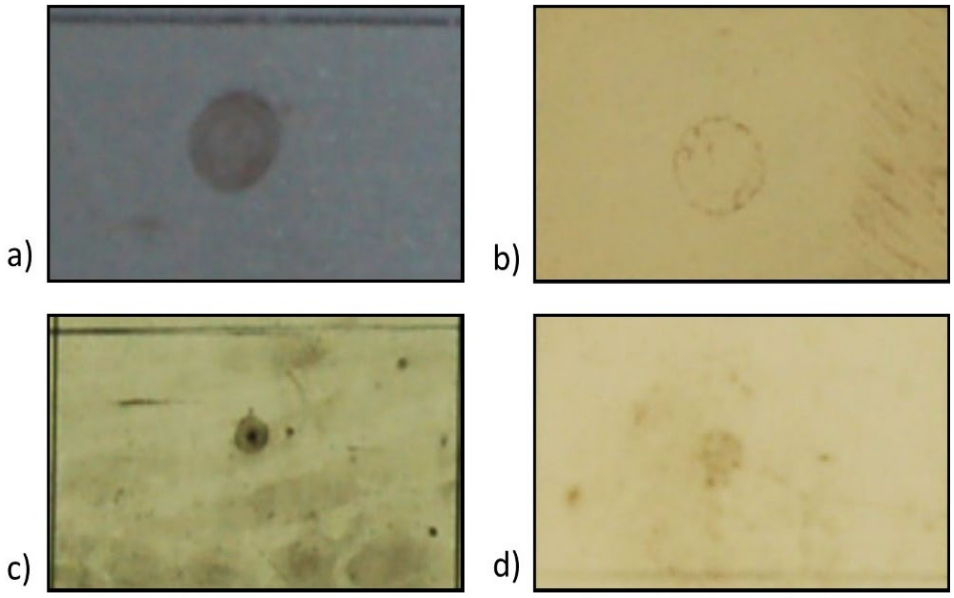


Figure 24. a) alanine on PVC, b) alanine on PE sheet, c) urea on uPVC, d) urea on ABS.

Figure 25 shows that different constituents on the same substrate varied in development. Both urea and alanine developed on PVC, whilst demonstrating different characteristics; urea developed as a small spot, only a fraction of the size of the original deposit, whereas, alanine developed as a larger spot, a similar size to the spot that was originally deposited.

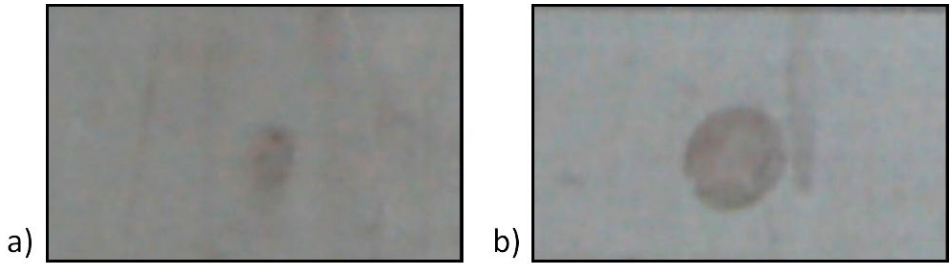


Figure 25. a) urea, b) alanine, both on PVC, after development.

Figure 26 illustrates a dried, undeveloped test spot for both urea and alanine. From this it is evident that the properties of the constituents cause them to dry differently, which then correlates to the developed mark.

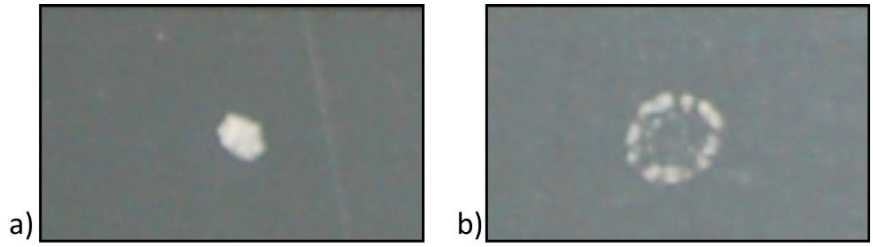


Figure 26. a) urea, b) alanine, both on PVC, before development.

It was thought that the characteristics of the dried test spots may be attributed to their solubility. Figure 27 shows the difference in dried test spot characteristics, dependent upon the solubility of the constituent.

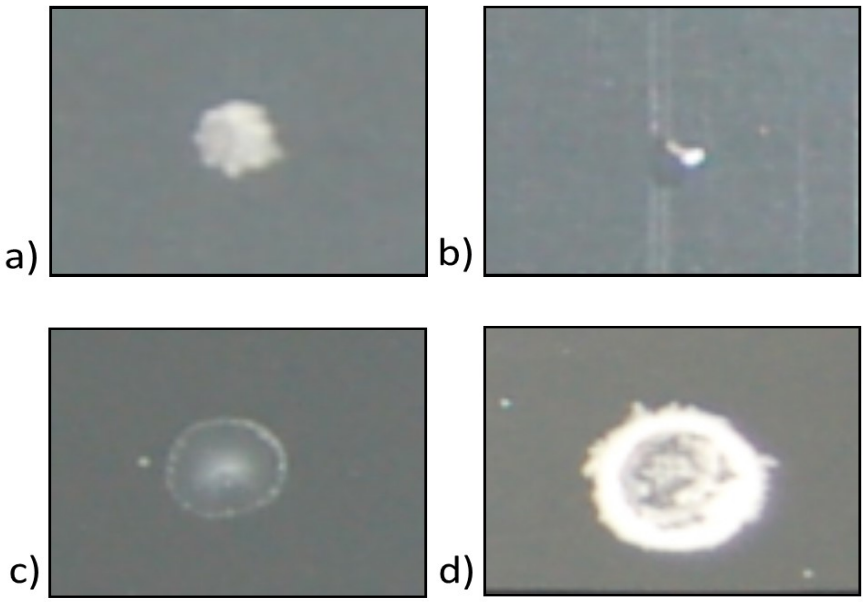


Figure 27. an illustration of the difference in dried test spot characteristics and their solubility. a) urea 1079 g/L, b) glucose 909 g/L, c) sodium fluoride 36 g/L, d) serine 50 g/L, demonstrating the drying characteristics.

3.2.1.1. Statistical analysis of eccrine constituent test spots deposition, without a fixing agent

The graded test spots were statistically analysed to further investigate the apparent visual differences between the constituents on the various substrates.

Analysis was carried out to establish if there was a statistically significant difference between the quality of development between the six constituents, over all the substrates. A Shapiro Wilk test showed that the data was not normally distributed, therefore a Friedman test was carried out. The results showed that there was a significant difference in the quality of development between the constituents ($p \leq 0.05$). Consequently, fifteen Wilcoxon Signed Rank pairwise post-hoc tests were carried out to identify the exact areas of significant difference. A Bonferroni correction was applied (0.05/15), creating a new alpha level of 0.003. Using this adjusted alpha level, the post-hoc tests identified that 13 pairs had a statistically significant difference ($p \leq 0.003$), with medium to large effect sizes according to Pearson's r, ranging from -0.3 to -1.4.

Table 87 details the effect sizes for the pairwise post hoc tests. The two pairs that did not show a statistically significant difference between them were, serine and glucose, and sodium fluoride and sodium chloride. The pairs that did not show a statistically significant difference were perhaps to be expected as, they were the pairs of constituents that visually appeared to develop to a similar quality. Out of the 13 pairs with significant differences, 9 of these had a large effect size.

Table 8. Effect sizes using Pearson's r, of the pairwise post hoc tests, with the constituent as the variable. NS indicated no significant difference at the adjusted alpha level of 0.003.

	Alanine	Glucose	NaCl	NaF	Serine	Urea
Alanine						
Glucose	Large					
NaCl	Large	Medium				
NaF	Large	Medium	NS			
Serine	Large	NS	Medium	Medium		
Urea	Large	Large	Large	Large	Large	

A test for significant difference was applied to analyse the difference between substrates. A Shapiro Wilk test showed that the data was not normally distributed so, a Friedman test was applied. The results showed that there was a statistically significant difference between the substrates ($p \leq 0.05$). Twenty-one Wilcoxon Signed Rank post-hoc tests were applied to locate the specific areas of difference. A Bonferroni correction was applied (0.05/21) prior to analysing the post-hoc results, giving an adjusted alpha level of 0.002. Ten pairs showed no statistically significant difference. Eleven pairs had significant difference with effect sizes again ranging from medium to large ($r = -0.3$ to -0.9).

Table 98 illustrates the effect sizes for the pairwise post hoc tests. The eleven pairs with a significant difference ($p \leq 0.002$) were seen where uPVC and glass were tested against each of the other substrates (individually).

Table 9. Effect sizes using Pearson's r, of the pairwise post hoc tests, with the substrate as the variable. NS indicated no significant difference at the adjusted alpha level of 0.002.

	ABS	Glass	PE bag	PE sheet	uPVC	Painted metal	PVC
ABS							
Glass	Large						
PE bag	NS	Medium					
PE sheet	NS	Medium	NS				
uPVC	Large	Medium	Medium	Medium			
Painted metal	NS	Medium	NS	NS	Medium		
PVC	NS	Medium	NS	NS	Medium	NS	

Each substrate was analysed individually to see if there was a statistically significant difference in the quality of development between the constituents on each individual substrate. For all substrates, a Shapiro Wilk test was carried out for normality of distribution, followed by a Friedman test for statistically significant difference, finishing with fifteen Wilcoxon Signed Rank post hoc tests. The Friedman test indicated a statistically significant difference between the constituent test spots on each individual substrate apart from glass. Glass showed no significant difference from the Friedman test ($p>0.05$).

Although the Friedman test indicated a significant difference between the constituents on the remaining substrates, when the Bonferroni correction was applied (0.05/15) to adjust the alpha level for the post hoc tests ($p\leq0.003$) ABS, painted metal, PE bag, PVC and, uPVC, did not show the specific areas of significant difference. There was one apparent pair with a significant difference on PE sheet; alanine and serine showed a statistically significant difference ($p\leq0.003$) with a large effect size ($r= -0.7$).

Finally, each individual constituent was analysed across each of the seven substrates, to see if there was a statistically significant difference in the quality of development for that one constituent between substrates. The same statistical analysis that was used to analyse the difference between substrates was applied, however with 21 pairwise post hoc tests and an

adjusted alpha level of 0.002 (0.05/21). As a result of the Friedman test, only glucose and serine showed no significant difference ($p>0.05$) therefore, no post hoc tests were necessary. Sodium chloride and sodium fluoride showed significant differences as a result of the Friedman test ($p\leq0.05$) yet, when the adjusted alpha level $p\leq0.002$ was applied to the Wilcoxon Signed Rank post hoc tests, the specific differences were not identified. The result of the Wilcoxon Signed Rank post hoc test for urea showed that 2 out of 21 pairs had significant differences ($p\leq0.002$) with large effect sizes ($r= -0.6$). Alanine had 5 out of 21 pairs with significant differences at the post hoc level, again all with large effect sizes ($r= -0.6$).

3.2.2. Eccrine constituent test spots deposition, with the application of 3M Spray Mount™ as a fixing agent

The fixing agent caused heavy background staining, post development on all substrates as shown in Figure 28.

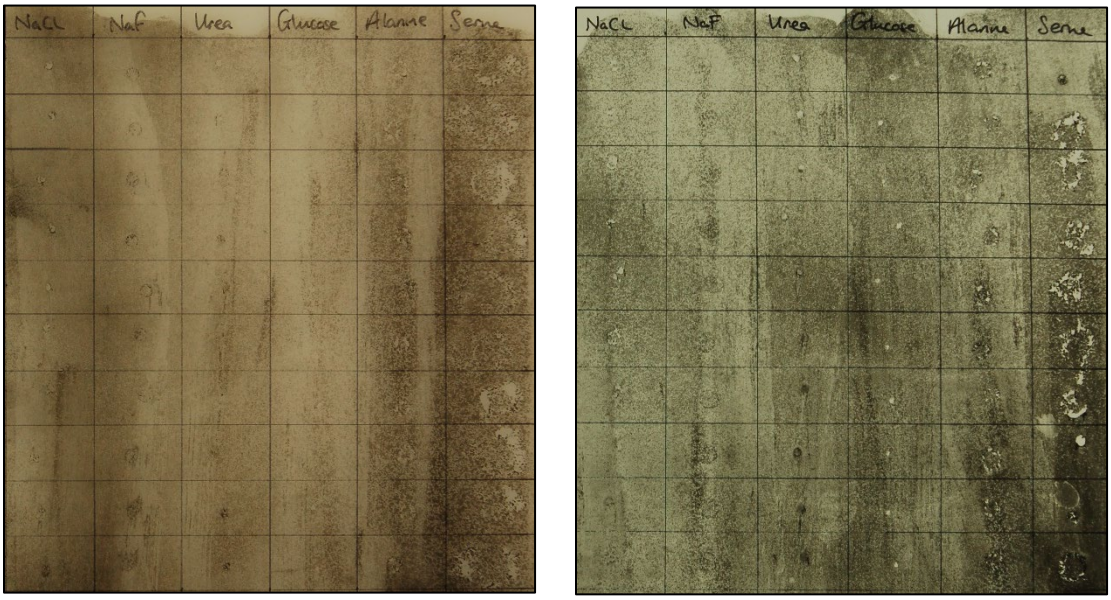


Figure 28. left to right; an example of the background staining observed on PE sheet and uPVC.

Even with heavy background staining, it was evident where the original test spots were deposited on the substrate. It was possible to see where some constituents such as urea and sodium fluoride, had developed with a darker appearance than those without a fixing agent, at the location of the test spot. However, most of the test spots appeared to repel the spray mount from the substrates after the iron oxide WPS had been rinsed off; thus, not completely fixing the constituents in place.

Although the results of this study were inconclusive, they did demonstrate that more development may be possible with the application of a fixing agent.

3.2.3. Eccrine constituents deposited as 'spiked' fingermarks

Figure 29 shows the average contrast values for the fingermarks spiked with constituents found in eccrine residue, on multiple substrates. For the purpose of this report, the marks with higher contrast values will be referred to as darker marks with better contrast.

ABS had some of the highest contrast values, followed by uPVC and PE bag. Painted metal and PVC had some of the lowest contrast values overall. Natural fingermarks showed the lowest contrast values on 5 out of the 7 substrates; ABS, glass, PE sheet, painted metal and PVC. Deionised water fingermarks showed the lowest contrast values on the remaining two substrates, PE bag and uPVC. Painted metal gave the smallest standard deviations followed by PE sheet; the remaining substrates had marginally larger standard deviations.

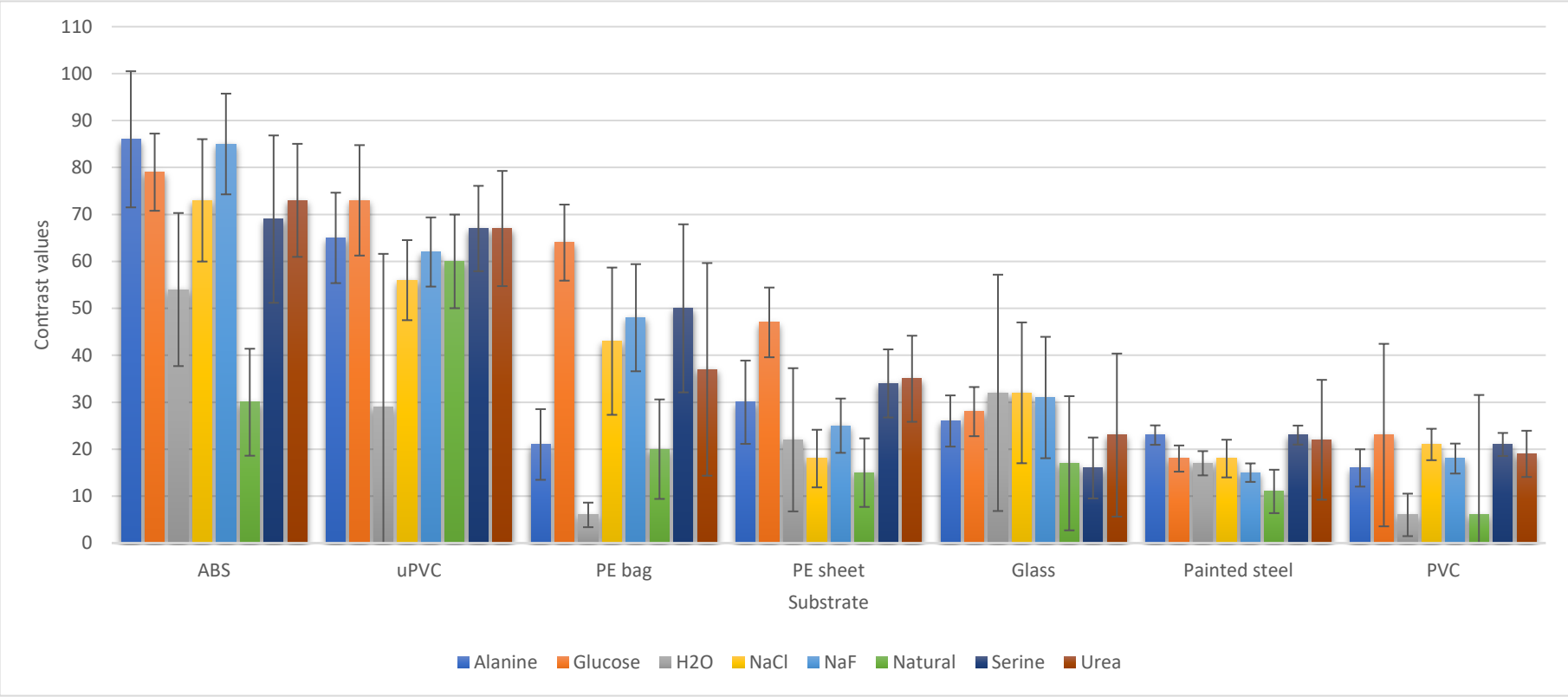


Figure 29. The average contrast values from 0 to 255, for spiked fingermarks on each substrate (n=560, error bars=SD).

Glucose achieved the highest contrast value on PE bag, PE sheet, uPVC and PVC. Alanine had the highest contrast value on ABS and painted metal, with deionised water and sodium chloride jointly scoring the highest contrast value on glass.

Sodium chloride, was only in the top three developed constituents with the highest contrast values for glass and PVC. Although, sodium chloride achieved higher contrast values with other substrates, it was not one of the highest compared to other constituents on those substrates. Whereas, for glass and PVC, it ranked more highly.

Deionised water fingermarks had large standard deviations on uPVC and glass, and natural fingermarks had a large standard deviation on PVC.

All of the fingermarks spiked with a constituent developed with more ridge continuity and enhanced, yet still varying contrasts, in comparison to the natural, unspiked fingermarks. The fingermarks with larger contrast values were the marks that visually appear darker. Figure 30 demonstrates the average contrast values for each individual constituent, where it is evident how similar the average values were across the different constituents.

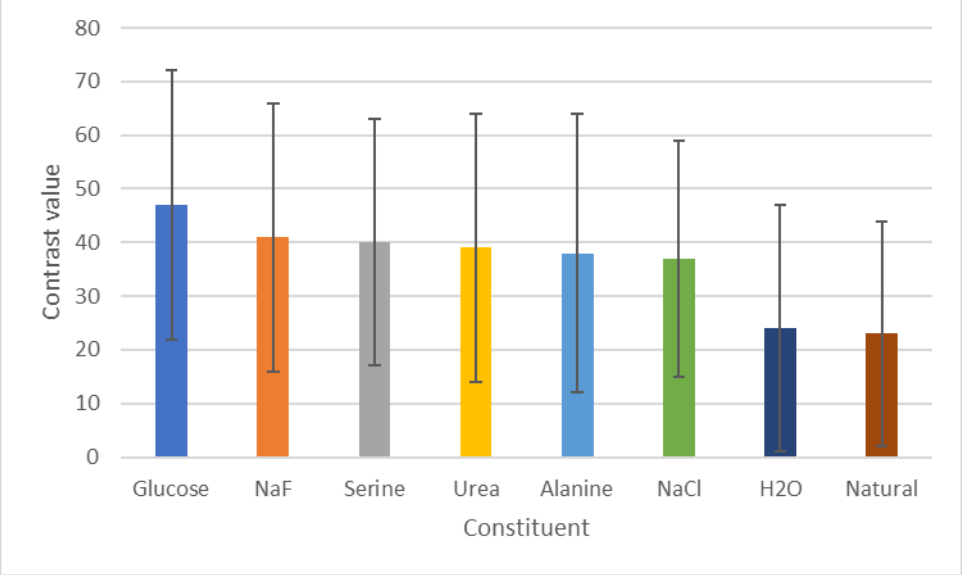


Figure 30. Illustrates the average contrast values for each constituent; omitting the substrate as a variable (n=560, error bars=SD).

Figure 31 and Figure 32 demonstrate the participant's natural fingermarks on each substrate, compared to their fingermarks spiked with each of the six constituents and deionised water.

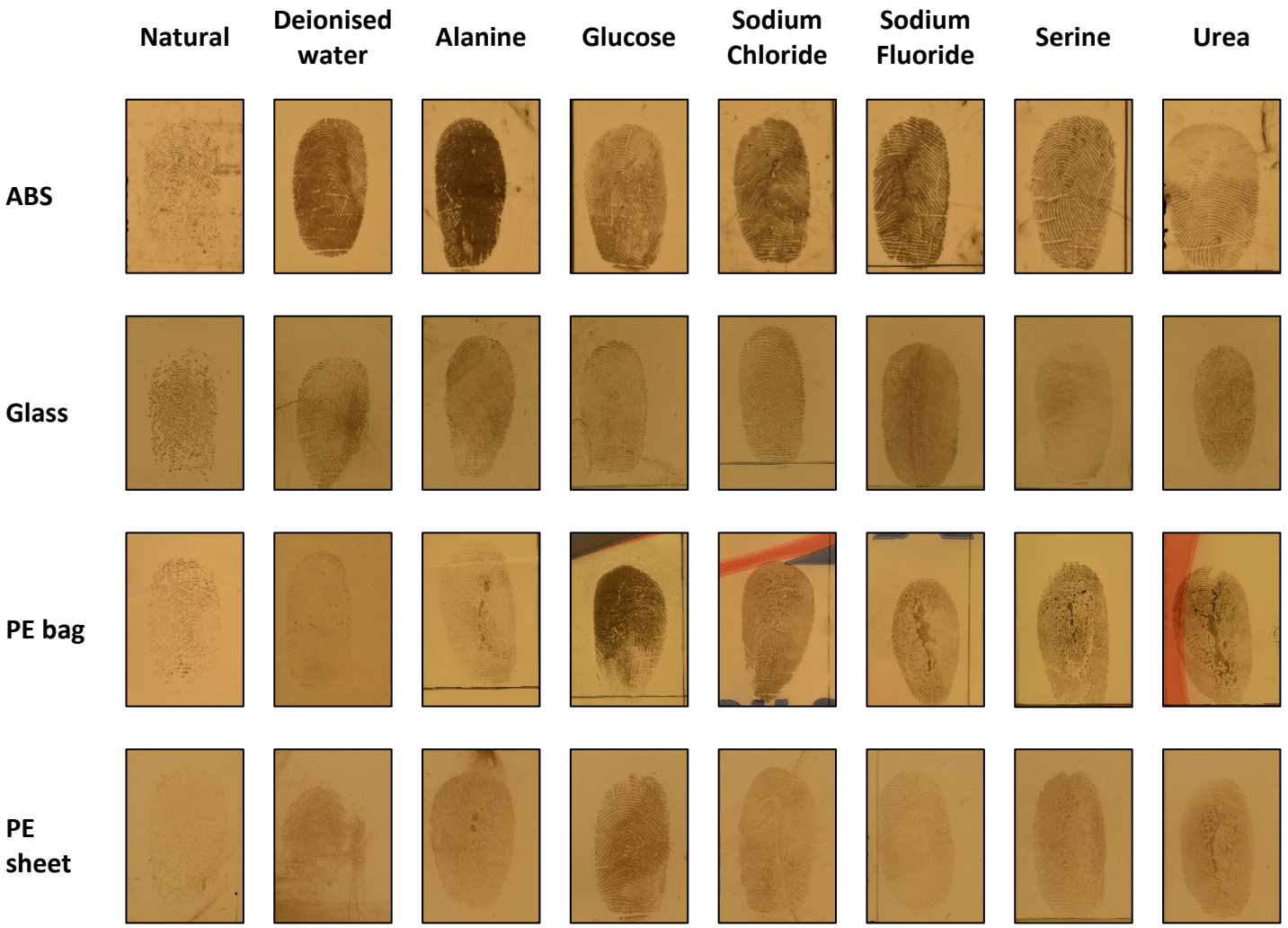


Figure 31. Natural fingermarks compared to spiked fingermarks, on ABS, glass, PE bag and PE sheet.

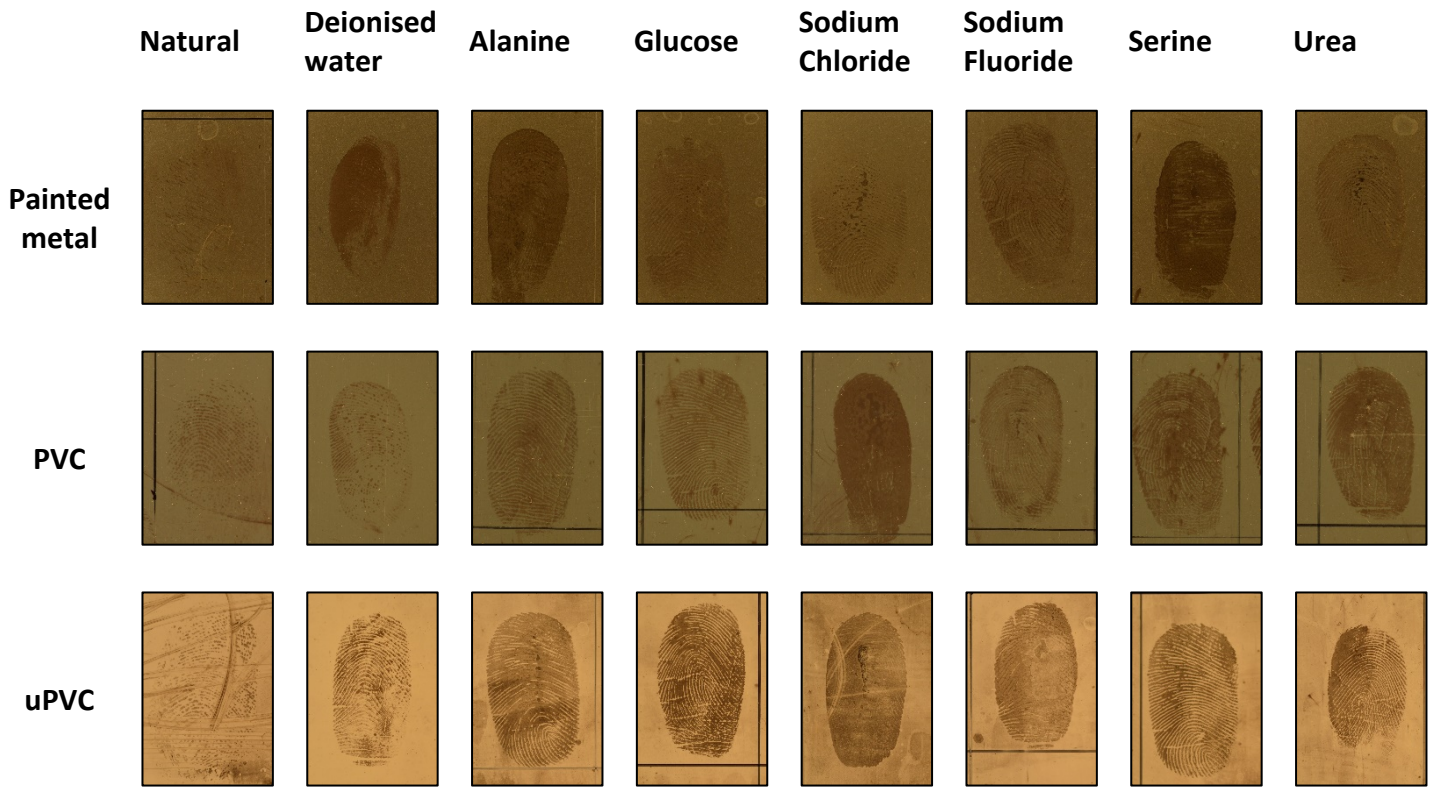


Figure 32. Natural fingermarks compared to spiked fingermarks, on painted metal, PVC and uPVC.

Natural fingermarks on all substrates showed some development, although with poor ridge continuity and generally poor contrast. Although the quality of ridge detail was consistently poor over all of the substrates, the quality of contrast varied. PE sheet and glass showed poor contrast between the fingermark ridges and background. Whereas, the natural fingermarks on uPVC visually showed better contrast.

Fingermarks spiked with deionised water showed enhanced ridge continuity and enhanced contrast, when compared to the natural fingermarks on ABS, PE sheet, uPVC and painted metal. PE bag had poor contrast however, darker areas could be seen where some of the pores were present along the ridges. PVC did not show a difference between the natural fingermarks and the deionised water fingermarks. The development of deionised water fingermarks had improved qualities compared to the natural fingermarks for one of the two depletions; the second depletion did not carry the same improvement. Figure 33 demonstrates the differences observed between the two repeats of fingermarks spiked with deionised water.

Depletion number	Repeat (finger) 1	Repeat (finger) 2
1		
2		
3		
4		
5		

Figure 33. Repeat 1 and 2 depletion series of deionised water spiked fingermarks.

3.2.3.1. Statistical analysis of eccrine constituents deposited as spiked fingermarks

Statistical analysis was applied to the contrast values generated in this study to identify if there were any significant differences in the data.

A test for statistical difference was applied to see if there was any difference between the constituents (grouping all substrates), including natural fingermarks and fingermarks spiked with deionised water. The results of a Shapiro-Wilk test indicated that the data was not

normally distributed, so a Friedman test was applied. The results showed that there was a significant difference in the data set ($p \leq 0.05$). Twenty-eight Wilcoxon Signed Rank, pairwise post hoc tests were applied to locate the specific areas of difference. A Bonferroni correction was applied (0.05/28), to give an adjusted alpha level of 0.002.

The results of the post hoc tests showed that 11 out of the 28 pairs had no significant difference at the new alpha level of 0.002. Of the remaining pairs, 6 had large effect sizes (r= -0.5 to -0.6) and, 11 pairs had medium effect sizes (r= -0.3 to -0.4).

Table 10 details the results of the pairwise post hoc tests and the corresponding effect sizes. Glucose had a significant difference with all the other constituents, with large effect sizes when paired with deionised water spiked fingermarks and natural marks. The natural fingermarks had a significant difference when tested against all the constituents, apart from the fingermarks spiked with deionised water. All pairs with a significant difference for the natural fingermarks had a large effect size, other than sodium chloride which had a medium effect size.

Table 10. Effect sizes using Pearson's r, of pairwise post hoc tests, with the constituent as the variable being tested. NS indicated no significant difference at the adjusted alpha level of 0.002.

	Alanine	**Glucose**	**H_2O**	**NaCl**	**NaF**	**Natural**	**Serine**	**Urea**
Alanine								
Glucose	Medium							
H_2O	Medium	Large						
NaCl	NS	Medium	Medium					
NaF	NS	Medium	Medium	NS				
Natural	Large	Large	NS	Medium	Large			
Serine	NS	Medium	Medium	NS	NS	Large		
Urea	NS	Medium	Medium	NS	NS	Large	NS	

The data was also tested for significant differences between the substrates (grouping all constituents). A Shapiro Wilk test was applied to test for normality of distribution of the data. The results indicated that the data was not normally distributed, so a Friedman test was applied. The results showed that there was a significant difference within the data set ($p \leq 0.05$). Twenty-one Wilcoxon Signed Rank, pairwise post hoc tests were applied to identify the areas of difference. Again, a Bonferroni correction was applied (0.05/21) to give an adjusted alpha level of 0.002.

The output of the post hoc tests indicated that only 2 out the 21 pairs had no significant difference. Twelve pairs had large effect sizes (r= -0.5 to -0.6), 6 pairs had medium effect sizes (r= -0.3 to -0.4) and, only 1 pair had a small effect size; Table 11 details the effect sizes of the post hoc tests.

The only two pairs to have no significant difference were glass paired with PE bag and, PVC paired with painted steel. ABS and uPVC had significant differences with large size effects against all the other substrates, apart from the pair against each other (ABS and uPVC) which had a medium effect size. PE sheet also showed a significant difference between with either medium or large effect sizes for all pairs, apart from PE sheet where only a small effect size was generated.

Table 11. Effect sizes using Pearson's r, of pairwise post hoc tests, with the substrate as the variable being tested. NS indicated no significant difference at the adjusted alpha level of 0.002.

	ABS	Glass	PE bag	PE sheet	uPVC	Painted metal	PVC
ABS							
Glass	Large						
PE bag	Large	NS					
PE sheet	Large	Medium	Small				
uPVC	Medium	Large	Large	Large			
Painted metal	Large	Medium	Medium	Medium	Large		
PVC	Large	Medium	Large	Large	Large	NS	

Following on from this, statistical analysis to find significant differences for one constituent (individually) between substrates was carried out. The results of a Shaprio-Wilk test showed that the data for all constituents apart from serine were not normally distributed. For the constituents where the data was not normally distributed, a Friedman test was applied to each set of data. The Friedman tests for each individual constituent over all the substrates resulted in significant differences ($p \leq 0.05$) for each set of data. Twenty-one Wilcoxon Signed Rank, pairwise post hoc tests were applied to each data set to locate the specific areas of difference. A Bonferroni correction was applied (0.05/21) to give a new alpha level of 0.002.

Table 12 to Table 18 illustrate the results from the pairwise post hoc tests and the corresponding effect sizes using Pearson's r, for each individual constituent over all the substrates. All significant differences identified for each data set had large effect sizes. There were no pairs with medium or small effect sizes. There appeared to be very little consistency in the specific areas of difference. ABS showed the most pairs of significant differences for alanine (Table 12), deionised water (Table 14), sodium chloride (Table 15) and urea (Table 18). Sodium fluoride (Table 16) only had significant differences where painted metal and PVC were paired with the other substrates and, the natural fingermarks (Table 17) only had significant differences where uPVC was paired against the other substrates.

Table 12. Effect sizes of pairwise post hoc tests, with alanine as the variable being tested. NS indicated no significant difference at the adjusted alpha level of 0.002.

	ABS	**Glass**	**PE bag**	**PE sheet**	**uPVC**	**Painted metal**	**PVC**
ABS							
Glass	Large						
PE bag	Large	NS					
PE sheet	Large	NS	NS				
uPVC	NS	Large	Large	Large			
Painted metal	Large	NS	NS	NS	Large		
PVC	Large	NS	NS	Large	NS	NS	

Table 13. Effect sizes of pairwise post hoc tests, with glucose as the variable being tested. NS indicated no significant difference at the adjusted alpha level of 0.002.

	ABS	Glass	PE bag	PE sheet	uPVC	Painted metal	PVC
ABS							
Glass	Large						
PE bag	NS	Large					
PE sheet	Large	Large	NS				
uPVC	NS	Large	NS	Large			
Painted metal	Large	NS	NS	Large	Large		
PVC	Large	NS	NS	NS	NS	NS	

Table 14. Effect sizes of pairwise post hoc tests, with deionised water as the variable being tested. NS indicated no significant difference at the adjusted alpha level of 0.002.

	ABS	Glass	PE bag	PE sheet	uPVC	Painted metal	PVC
ABS							
Glass	NS						
PE bag	Large	NS					
PE sheet	Large	NS	NS				
uPVC	Large	NS	NS	NS			
Painted metal	Large	NS	Large	NS	NS		
PVC	Large	NS	NS	NS	Large	Large	

Table 15. Effect sizes of pairwise post hoc tests, with Sodium Chloride as the variable being tested. NS indicated no significant difference at the adjusted alpha level of 0.002.

	ABS	Glass	PE bag	PE sheet	uPVC	Painted metal	PVC
ABS							
Glass	Large						
PE bag	Large	NS					
PE sheet	Large	NS	Large				
uPVC	NS	NS	NS	Large			
Painted metal	Large	NS	NS	NS	Large		
PVC	Large	NS	NS	NS	Large	NS	

Table 16. Effect sizes of pairwise post hoc tests, with Sodium Fluoride as the variable being tested. NS indicated no significant difference at the adjusted alpha level of 0.002.

	ABS	Glass	PE bag	PE sheet	uPVC	Painted metal	PVC
ABS							
Glass	NS						
PE bag	NS	NS					
PE sheet	NS	NS	NS				
uPVC	NS	NS	NS	NS			
Painted metal	Large	Large	Large	Large	Large		
PVC	Large	NS	Large	NS	Large	NS	

Table 17. Effect sizes of pairwise post hoc tests, with natural fingermarks as the variable being tested. NS indicated no significant difference at the adjusted alpha level of 0.002.

	ABS	Glass	PE bag	PE sheet	uPVC	Painted metal	PVC
ABS							
Glass	NS						
PE bag	NS	NS					
PE sheet	NS	NS	NS				
uPVC	Large	Large	Large	Large			
Painted metal	NS	NS	NS	NS	Large		
PVC	NS	NS	NS	NS	Large	NS	

Table 18. Effect sizes of pairwise post hoc tests, with urea as the variable being tested. NS indicated no significant difference at the adjusted alpha level of 0.002.

	ABS	Glass	PE bag	PE sheet	uPVC	Painted metal	PVC
ABS							
Glass	Large						
PE bag	NS	NS					
PE sheet	Large	NS	NS				
uPVC	NS	Large	NS	Large			
Painted metal	Large	NS	NS	NS	NS		
PVC	Large	NS	NS	NS	Large	NS	

Serine was the only constituent to show normally distributed data as a result of a Shapiro-Wilk test. Therefore, a one-way, repeated measures ANOVA was applied. Mauchly's test of sphericity indicated that the assumption of sphericity was violated ($p \leq 0.05$), so a Greenhouse-Geisser correction was used. The results indicated that there was a significant difference in the data set, with a medium effect size (0.835, partial eta-squared). Twenty-one pairwise post hoc tests were carried out to find the specific areas of difference. A Bonferroni correction was applied (0.05/21) to give an adjusted alpha level of 0.002.

Table 19 shows the results of the pairwise post hoc comparisons. ABS, glass and, uPVC showed the most differences, with four pairs each having a significant difference. PE bag had the fewest differences, with only one pair having a significant difference.

Table 19. Results of pairwise post hoc tests with serine as the variable being tested. NS indicated no significant difference, Sig. diff indicated a significant difference.

	ABS	Glass	PE bag	PE sheet	uPVC	Painted metal	PVC
ABS							
Glass	Sig. diff						
PE bag	NS	Sig. diff					
PE sheet	Sig. diff	Sig. diff	NS				
uPVC	NS	Sig. diff	NS	Sig. diff			
Painted metal	Sig. diff	NS	NS	NS	Sig. diff		
PVC	Sig. diff	NS	NS	NS	Sig. diff	NS	

After the individual constituents had been statistically analysed over all the substrates, each substrate was individually analysed to see if there were any significant differences in the contrast levels between the constituent spiked fingermarks (including natural and deionised water). A Shapiro-Wilk test indicated that the data sets for ABS, uPVC, painted metal and PVC were not normally distributed. A Friedman test was applied to each dataset; the results indicated that there was a significant difference ($p \leq 0.05$) for each dataset. Twenty-eight Wilcoxon Signed Rank, pairwise post hoc comparisons were carried out for each data set to locate the specific areas of difference. A Bonferroni correction was applied (0.05/28) to give a new alpha level of 0.002 for the post hoc results. Table 20 to Table 23 illustrate the effect sizes using Pearson's r, of the pairwise post hoc comparison tests for ABS, uPVC, painted metal and PVC. All of the significant differences located for each data set had large effect sizes; there were no significant differences with medium or small effect sizes. ABS (Table 20) had significant differences where the natural fingermarks were analysed against all the spiked fingermarks. Additionally, there was a significant difference between alanine and serine. uPVC (Table 21) and PVC (Table 23) had just 3 out of 28 pairs of data with significant differences; the pairs of

data with significant differences were not the same for both substrates. Painted metal (Table 22) had differences where the natural fingermarks were analysed against alanine, serine and urea. There were also significant differences where sodium fluoride was analysed against alanine and serine.

Table 20. Effect sizes of pairwise post hoc tests, with ABS as the variable being tested. NS indicated no significant difference at the adjusted alpha level of 0.002.

	Alanine	**Glucose**	**H_2O**	**NaCl**	**NaF**	**Natural**	**Serine**	**Urea**
Alanine								
Glucose	NS							
H_2O	NS	NS						
NaCl	NS	NS	NS					
NaF	NS	NS	NS	NS				
Natural	Large	Large	Large	Large	Large			
Serine	Large	NS	NS	NS	NS	Large		
Urea	NS	NS	NS	NS	NS	Large	NS	

Table 21. Effect sizes of pairwise post hoc tests, with uPVC as the variable being tested. NS indicated no significant difference at the adjusted alpha level of 0.002.

	Alanine	**Glucose**	**H_2O**	**NaCl**	**NaF**	**Natural**	**Serine**	**Urea**
Alanine								
Glucose	NS							
H_2O	NS	Large						
NaCl	NS	Large	NS					
NaF	NS	Large	NS	NS				
Natural	NS	NS	NS	NS	NS			
Serine	NS	NS	NS	NS	NS	NS		
Urea	NS	NS	NS	NS	NS	NS	NS	

Table 22. Effect sizes of pairwise post hoc tests, with painted metal as the variable being tested. NS indicated no significant difference at the adjusted alpha level of 0.002.

	Alanine	**Glucose**	**H_2O**	**NaCl**	**NaF**	**Natural**	**Serine**	**Urea**
Alanine								
Glucose	NS							
H_2O	NS	NS						
NaCl	NS	NS	NS					
NaF	Large	NS	NS	NS				
Natural	Large	NS	NS	NS	NS			
Serine	NS	NS	NS	NS	Large	Large		
Urea	NS	NS	NS	NS	NS	Large	NS	

Table 23. Effect sizes of pairwise post hoc tests, with PVC as the variable being tested. NS indicated no significant difference at the adjusted alpha level of 0.002.

	Alanine	**Glucose**	**H_2O**	**NaCl**	**NaF**	**Natural**	**Serine**	**Urea**
Alanine								
Glucose	NS							
H_2O	NS	NS						
NaCl	NS	NS	Large					
NaF	NS	NS	NS	NS				
Natural	NS	NS	NS	Large	NS			
Serine	NS	NS	NS	NS	NS	Large		
Urea	NS	NS	NS	NS	NS	NS	NS	

For the remaining substrates, the results from a Shapiro-Wilk test indicated that the data was normally distributed. Therefore, one-way, repeated measures ANOVA tests were applied to the data sets. For the data on glass, Mauchly's test for sphericity indicated that the assumption of sphericity had been violated ($p \leq 0.05$). A Greenhouse Geisser correction was applied; the results indicated that there was no significant difference ($p > 0.05$).

Mauchly's test for sphericity indicated that the data from PE bag did not violate the assumption of sphericity ($p>0.05$). The results for a sphericity assumed test showed that there was a significant difference in the data ($p\leq0.05$); partial eta squared 0.713. Twenty-eight pairwise post hoc comparisons were carried out, and a Bonferroni correction was applied to give an adjusted alpha level of 0.002 (0.05/28). The results of the pairwise post hoc tests are illustrated in Table 24. Seven out of the 28 pairs showed a significant difference; five of the 7 pairs with a significant difference were identified where the deionised water fingermarks were compared to the constituent spiked fingermarks (apart from urea).

Table 24. Results of pairwise post hoc tests with PE bag as the variable being tested. NS indicated no significant difference, Sig. diff indicated a significant difference.

	Alanine	**Glucose**	**H_2O**	**NaCl**	**NaF**	**Natural**	**Serine**	**Urea**
Alanine								
Glucose	NS							
H_2O	Sig. diff	Sig. diff						
NaCl	NS	NS	Sig. diff					
NaF	Sig. diff	NS	Sig. diff	NS				
Natural	NS	Sig. diff	NS	NS	NS			
Serine	NS	NS	Sig. diff	NS	NS	NS		
Urea	NS	NS	NS	NS	NS	NS	NS	

Finally, Mauchly's test for sphericity detailed that the data from PE sheet violated the assumption of sphericity. A Greenhouse Geisser correction was applied, showing a significant difference ($p\leq0.05$), partial eta squared 0.656. Again, twenty-eight pairwise post hoc tests were carried out and a Bonferroni correction was applied to give a new alpha level of 0.002. The output showed that just 5 out of the 28 pairs had a significant difference ($p\leq0.002$).

Table 25 shows the specific areas of difference for the pairwise post hoc tests. Four out of the 5 pairs identified with a significant difference were when the natural fingermarks were analysed against alanine, glucose, serine and urea. The final difference was between sodium chloride and glucose.

Table 25. Results of pairwise post hoc tests with PE sheet as the variable being tested. NS indicated no significant difference, Sig. diff indicated a significant difference.

	Alanine	**Glucose**	**H_2O**	**NaCl**	**NaF**	**Natural**	**Serine**	**Urea**
Alanine								
Glucose	NS							
H_2O	NS	NS						
NaCl	NS	Sig. diff	NS					
NaF	NS	NS	NS	NS				
Natural	Sig. diff	Sig. diff	NS	NS	NS			
Serine	NS	NS	NS	NS	NS	Sig. diff		
Urea	NS	NS	NS	NS	NS	Sig. diff	NS	

3.3. Participant fingermarks deposited on multiple substrates, developed using iron oxide wet powder suspension

3.3.1. Variation between participant fingermarks on multiple substrates

This study had a bigger sample size than the pilot study, with multiple substrates and different time periods; inter person variation was still an apparent feature. Figure 34 shows the average fingermark grade for each participant, grouping all variables together to analyse the participant variable. The data showed that on average, half of the participants gave fingermarks graded above 10; all participants apart from 01 and 04 had large standard deviations of either 4 or 5. Participant 01 had a standard deviation of 3 and, participant 04 had a small standard deviation of 2.

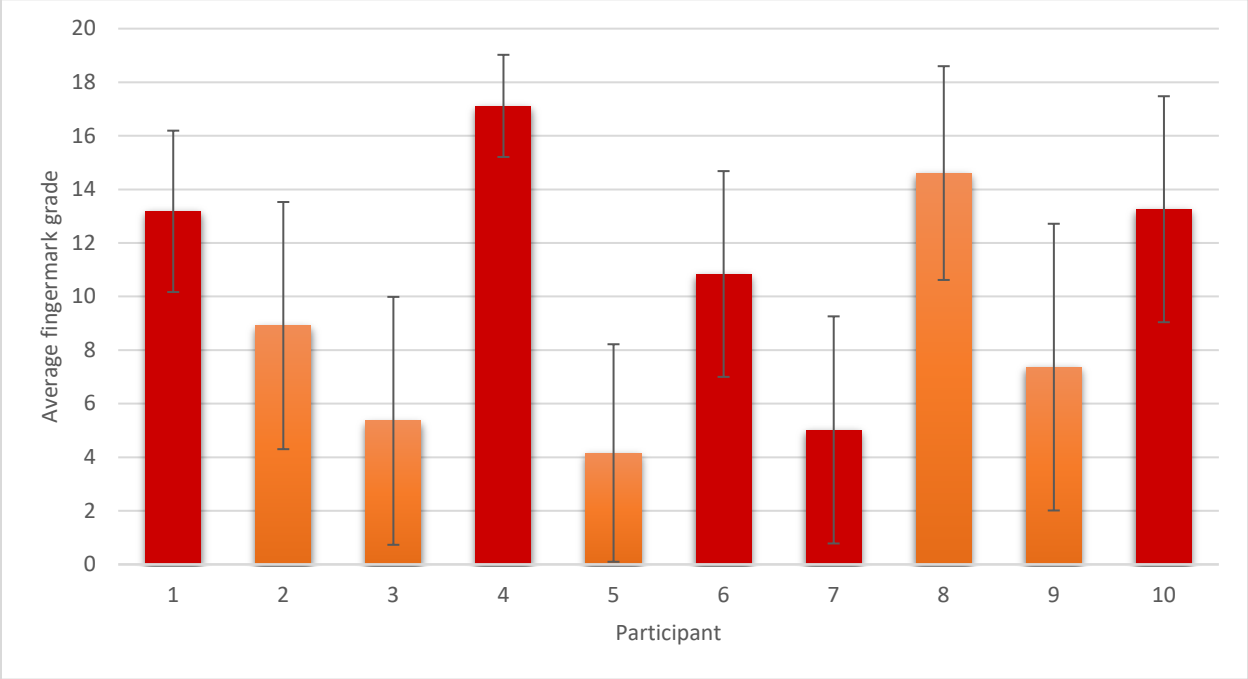


Figure 34. Average fingermark for each participant, combining all variables (n=1890, error bars=SD); red indicates the male participants and orange indicates the female participants.

Figure 34 also demonstrates the difference between male and female participants. Red represents the male participants and orange represents the female participants. Except for participants 07 and 08, it is the male participants that achieve an average grade above 10, and the female participants that achieve average grades below 10.

A test for a significant difference between the male and female fingermark grades was carried out. A Mann-Whitney U test was applied. The results showed that there was a statistically significant difference between the fingermark grades for male and female participants ($p \leq 0.05$), with a medium effect size ($r = -0.3$).

It was found that donors who deposited lower (below 10) graded fingermarks tended to produce marks that when developed gave a dotty appearance with no/very little ridge continuity. Figure 35 illustrates a range of developed fingermark ridges that would be

associated with the types of fingermarks expected from the participants who gave lower graded fingermarks.

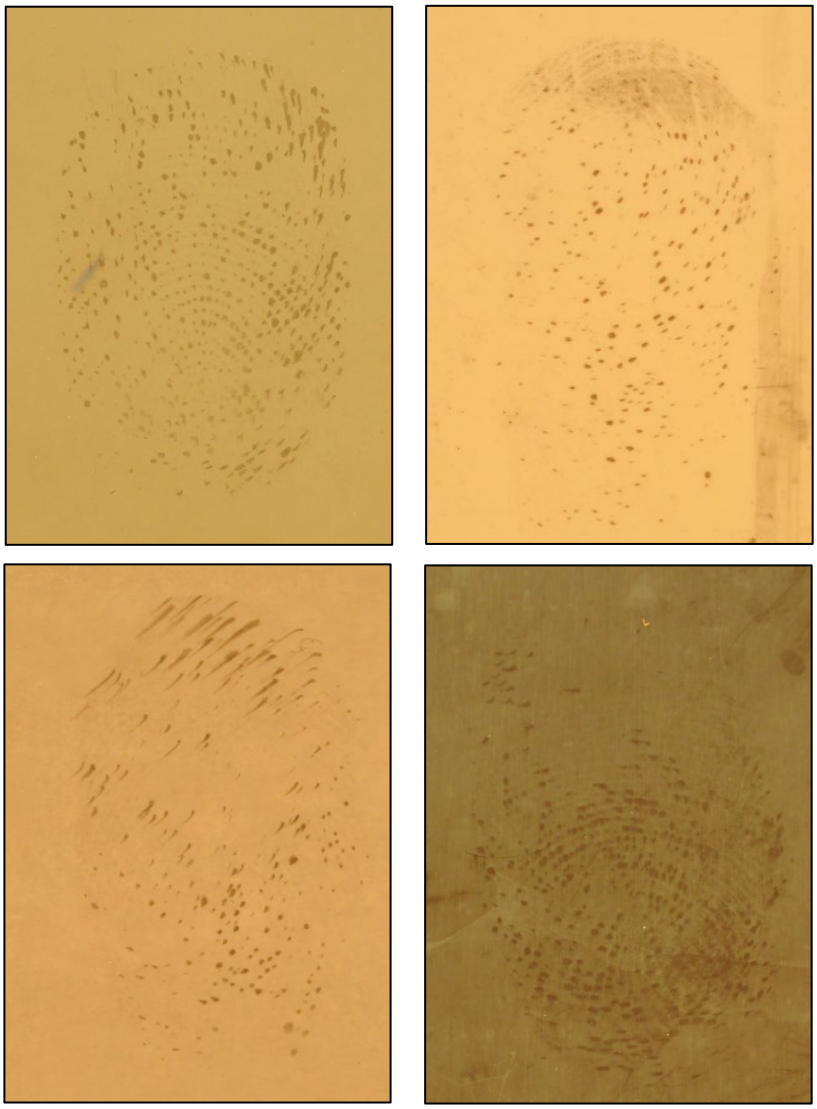


Figure 35. Developed fingermark ridges from participants who scored on average below 10.

Fingermarks that scored below 10 often scored low on criterion 1, 2 and 3. They frequently showed less than the full area of fingermark that would be expected (criterion 1) and, of the fingermark area that was present, very little of it contained friction ridge detail (criterion 2). Criterion 3 scored low due to the dotty appearance however, the developed 'dots' tended to have good contrast against the background, scoring relatively well for criterion 4; yet, overall

participant fingermarks that were graded below 10, scored very low for contrast. Figure 36 shows the average grade for each criterion for the 5 participants who gave fingermarks that were on average graded below 10.

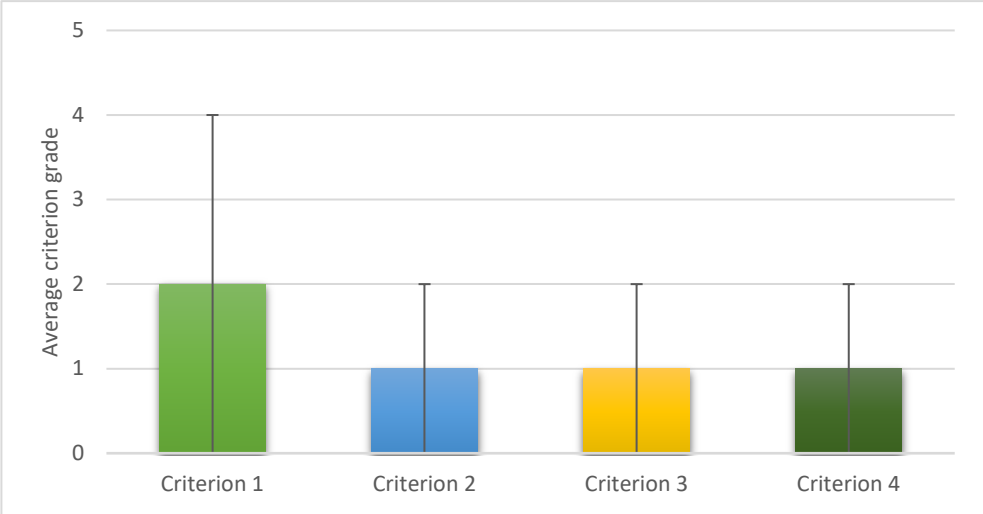


Figure 36. Average grade for each individual criterion based on participants who scored, on average, below 10 (n=945, error bars=SD).

A characteristic often seen with some of the participants that gave on average lower graded fingermarks, shows good ridge continuity with extremely poor contrast, with darker 'dots' present along the ridges. Figure 37 illustrates 4 fingermarks from separate donors that display these characteristics.

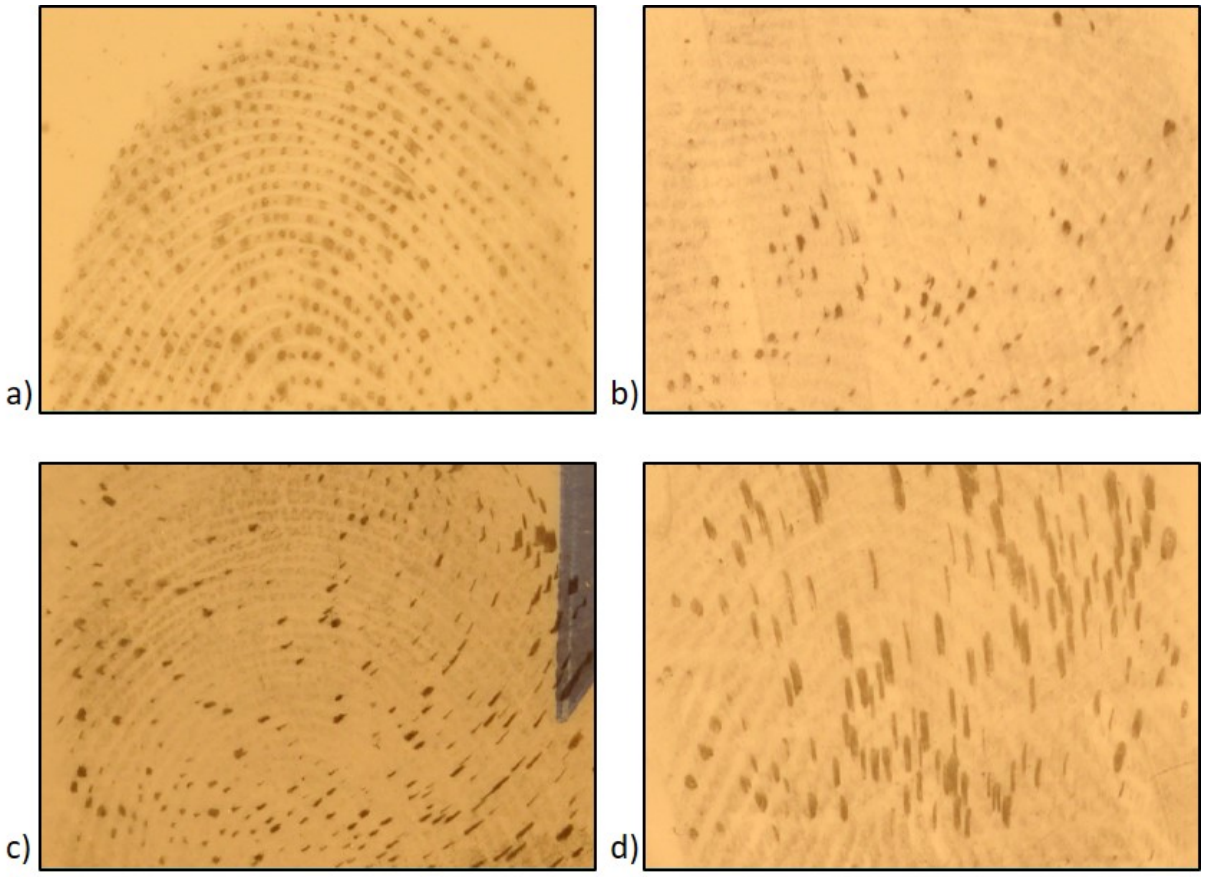


Figure 37. Fingermarks with excellent ridge continuity yet poor contrast, with darker dots present.

When observing developed fingermarks from the participants that gave, on average higher graded fingermarks (above 10), they tended to have much better ridge continuity (criterion 3) than the participants who gave lower graded fingermarks. They generally also had more complete fingermarks (criterion 1). Figure 38 shows the average grade for each criterion for the 5 participants who gave on average, fingermarks graded above 10. Higher graded participants appeared to vary in quality of contrast. Some participants gave good quality fingermarks, however scoring low in contrast, yet other good participants gave good quality fingermarks with good contrast; Figure 39 illustrates developed fingermarks for some of those participants who, on average, scored above 10.

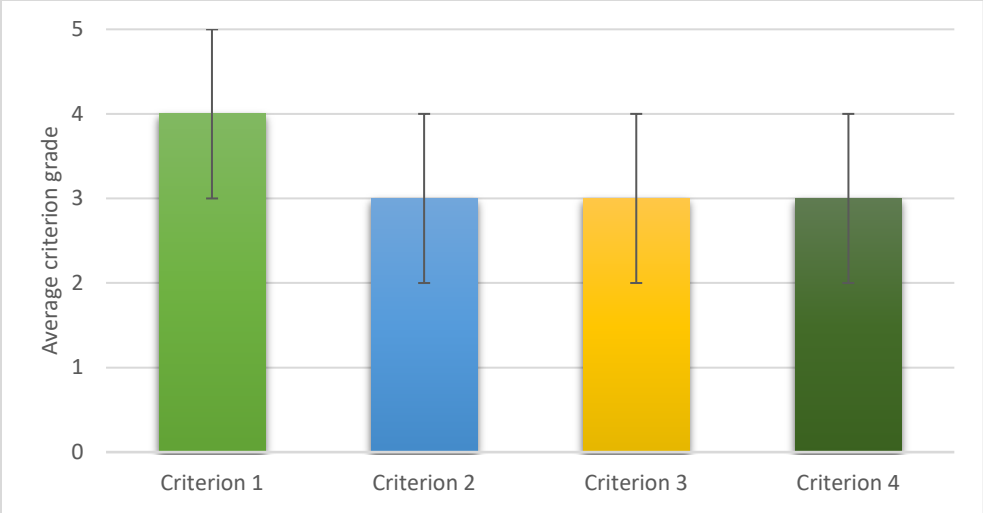


Figure 38. Average grade for each individual criterion based on participants who scored, on average, above 10.

Figure 39. Developed fingermarks from participants who scored, on average above 10.

3.3.1.1. Statistical analysis of the inter person variation on multiple substrates

To investigate the inter person variation, a test for statistically significant difference was carried out. For the first test, the data over all substrates and time periods was grouped, to solely test the participant variable. A Shapiro-Wilk test indicated that the data was not normally distributed so, a Friedman test was applied. The results showed that there was a significant difference between participant fingermark grades ($p \leq 0.05$). Forty-five Wilcoxon Signed Rank, pairwise post hoc tests were carried out to establish where the specific

differences were present. A Bonferroni correction was applied (0.05/45) to give an adjusted alpha level of 0.001. The results of the post hoc tests showed that 42 out of the 45 pairwise comparisons had a significant difference ($p \leq 0.001$). Twenty-seven of the 42 pairs had large effect sizes according to Pearson's r, ranging from -0.5 to -0.6 and, 9 of the 42 pairs had medium effect sizes of -0.3 to -0.4. Only 6 of the 42 pairwise comparisons with a significant difference gave small effect sizes; subsequently, being grouped with the pairs that showed no statistically significant difference.

Table 26 details the pairs where significant differences existed, including the effect size. Participant 04 had a significant difference with all the other participants, 8 of which had a large effect size, with only the pair with participant 08 showing a medium size effect. Participant 06 had a medium or large effect size with all participants apart from participant 02 where there was only a small effect size. The remaining 8 participants had either 2 or 3 pairs where there was either no significant difference between the data sets or, only a small effect size.

	01	02	03	04	05	06	07	08	09	10
01										
02	Large									
03	Large	Medium								
04	Large	Large	Large							
05	Large	Large	Small	Large						
06	Medium	Small	Large	Large	Large					
07	Large	Medium	NS	Large	NS	Large				
08	Small	Large	Large	Medium	Large	Medium	Large			
09	Large	Small	Small	Large	Medium	Medium	Medium	Large		
10	NS	Large	Large	Large	Large	Medium	Large	Small	Large	

Table 26. Effect sizes using Pearson's r, of the pairwise post hoc tests, with participant as the variable being tested for the multiple substrate study. NS indicated no significant difference at the adjusted alpha level of 0.001.

3.3.2. Substrate effect on quality of development

Figure 40 details the overall fingermark grades for each substrate. Grouping all participant fingermark grades together to get an average grade for each substrate, the results showed that ABS and PE bag achieved the highest average grade of 12 out of 20. Painted metal achieved the lowest average fingermark grade with 7 out of 20. ABS and uPVC showed the smallest spread of fingermark grades; with painted metal showing the largest spread of fingermark grades. Four out of the seven substrates contained fingermarks that achieved the highest fingermark grade of 20; with the remaining 3 substrates still producing fingermarks that were graded as high as 19 out of 20. All 7 substrates produced fingermarks that showed no development, giving the lowest grade of 0.

The results from Figure 40 demonstrate that on any of the seven substrates it is possible to obtain fingermarks that achieve a high fingermark grade, indicating an excellent level of detail/quality of fingermark, as well as fingermarks that show no development at all.

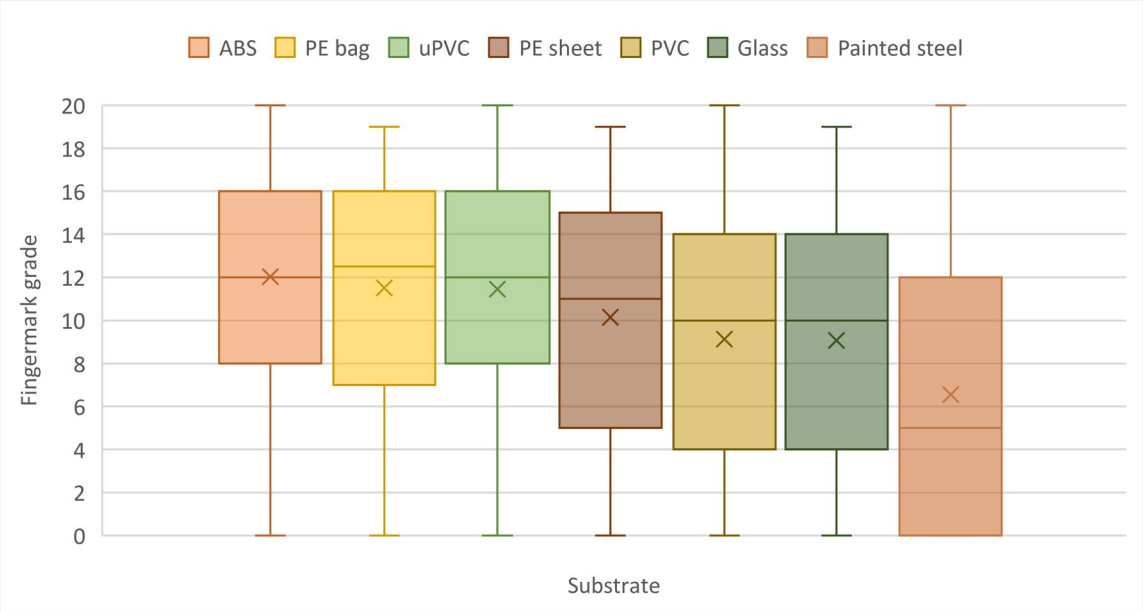


Figure 40. The overall fingermark grades for each substrate.

The characteristics described in Figure 37, in section 3.2.1 appeared to be more prevalent on uPVC however, they also appeared on ABS and PE bag. Figure 40 shows that these three substrates gave the highest average fingermark grades.

Figure 41 shows the average fingermark grade each individual participant achieved on each substrate, grouping the data by participant. The results show that for some participants, multiple substrates attained the same average fingermark grade. For example, participant 10 had 4 out of the 7 substrates all with the same average fingermark grade. Figure 41 indicates that PE bag, ABS and uPVC commonly gave the highest average fingermark grades, although not in a consistent manner for all participants. PE sheet, glass and PVC tended to give lower average fingermark grades but, again this was not consistent for all participants. Painted metal consistently gave the lowest average fingermark grade for all participants (apart from participant 06 who had PVC with an equally low grade). The standard deviation error bars for each individual participant all overlap, with the exception of participant 03's painted metal result. Indicating that while it is possible to get higher graded fingermarks on each substrate, it is possible to get equally low graded fingermarks on each substrate. This suggests that on some occasions there could be no distinguishable difference between the quality of fingermarks from one substrate to another.

The data showed that participants 03, 05 and 07 achieved the lowest fingermark grades on most of the substrates, with the exception of PE sheet, where participant 09 had a lower average grade. Participants 01, 04, 08 and 10 consistently achieved the highest fingermark grades on all substrates.

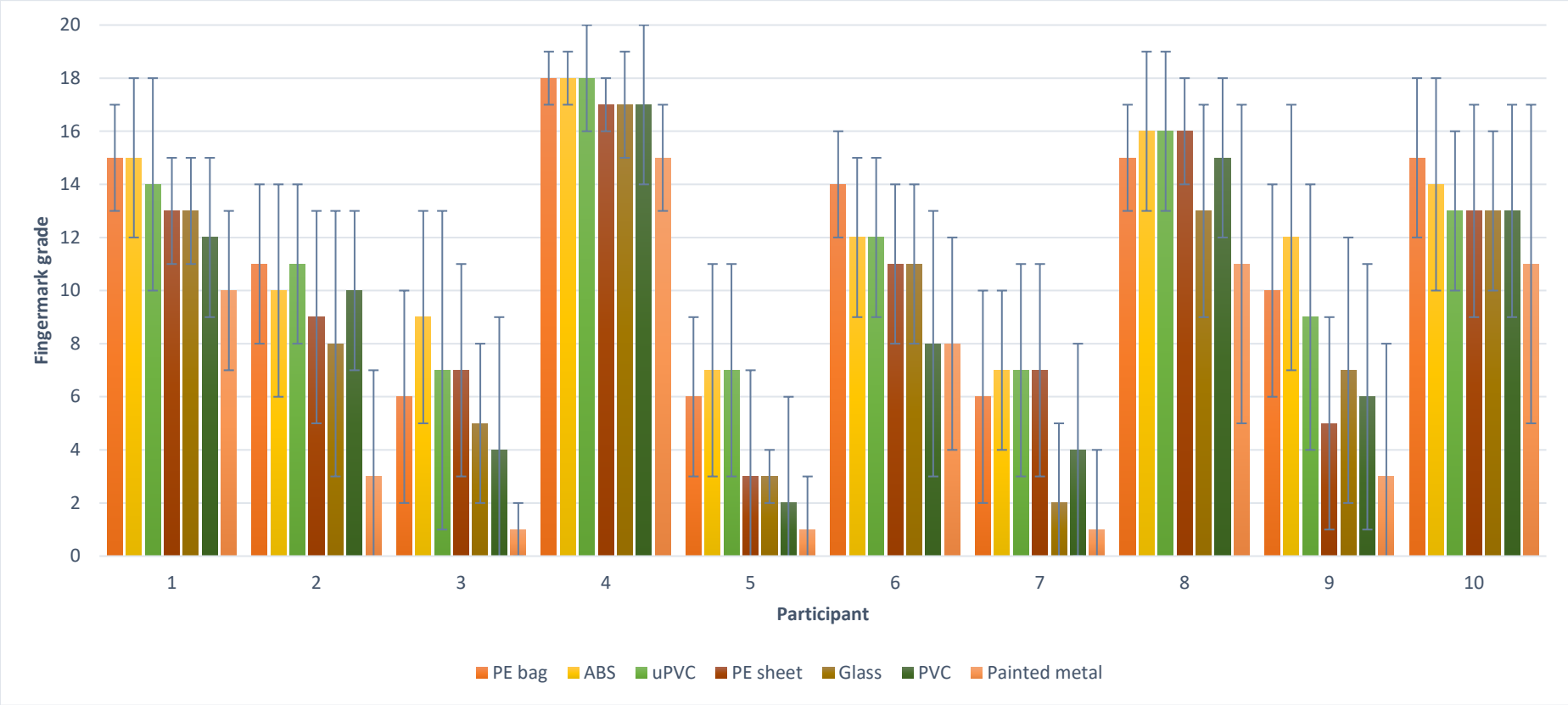


Figure 41. The average fingermark grades each individual participant achieved on each substrate, grouping the data by participant (n=1890, error bars=SD).

3.3.2.1. Statistical analysis of the fingermark grades with substrate type as the variable

A test for significant difference was applied to the data to test for a significance in difference between the fingermark grades on the seven substrates. A Shapiro-Wilk test indicated that the data was not normally distributed ($p \leq 0.05$), therefore, a Friedman test was applied. The results showed that there was a significant difference between the fingermark grades on the different substrates ($p \leq 0.05$). Twenty-one Wilcoxon Signed Rank, pairwise post hoc tests were applied to locate the specific areas of difference between the substrates. A Bonferroni correction was applied to give a new alpha level of 0.002 (0.05/21). Four of the 21 pairs showed no significant difference ($p > 0.002$), with a further 4 pairs showing a significant difference but with a small effect size ($r = -0.02$). The 13 remaining pairs showed a significant difference ($p \leq 0.002$), 10 of the pairs with a significant difference had medium effect sizes ($r = -0.03$ to -0.04) and only 3 pairs had a large effect size ($r = -0.05$).

Table 27 details the effect sizes of the pairwise post hoc tests. The three pairs that showed a significant difference with a large effect size were when the substrates with the highest median grades ABS, uPVC and PE bag were tested against painted metal, the substrate with the lowest average grades. Painted metal was the only substrate to show a significant difference with medium or large effect sizes when compared to all the other 6 substrates. Each of the other substrates had at least one comparison with no significant difference or, a difference but with only a small effect size. Three of the four pairs of substrates with no significant difference in the fingermark grades were when ABS, PE bag and uPVC were tested against each other.

Table 27. Effect sizes using Pearson's r, of the pairwise post hoc tests, with participant as the variable being tested for the multiple substrate study. NS indicated no significant difference at the adjusted alpha level of 0.002.

	ABS	Glass	PE bag	PE sheet	uPVC	Painted metal	PVC
ABS							
Glass	Medium						
PE bag	NS	Medium					
PE sheet	Medium	Small	Small				
uPVC	NS	Medium	NS	Small			
Painted metal	Large	Medium	Large	Medium	Large		
PVC	Medium	NS	Medium	Small	Medium	Medium	

3.3.3. Effect of ageing on the quality of developed participant fingermarks on multiple substrates

Initial visual observations implied that the quality of developed fingermarks improved from 24 hours to 2 weeks, with no further improvement from 2 to 4 weeks for most of the participants. However, following analysis of the fingermark grades it was evident that all three time periods had the same mean grade (when rounded to a whole grade). As Figure 42 illustrates, the fingermarks for 24 hours had higher median grade but, all three time periods have relatively close median values. Figure 42 also shows that 24 hours and 4 weeks achieved the full range of grades from 0 to 20, with 2 weeks achieving a full range but only as high as grade 19.

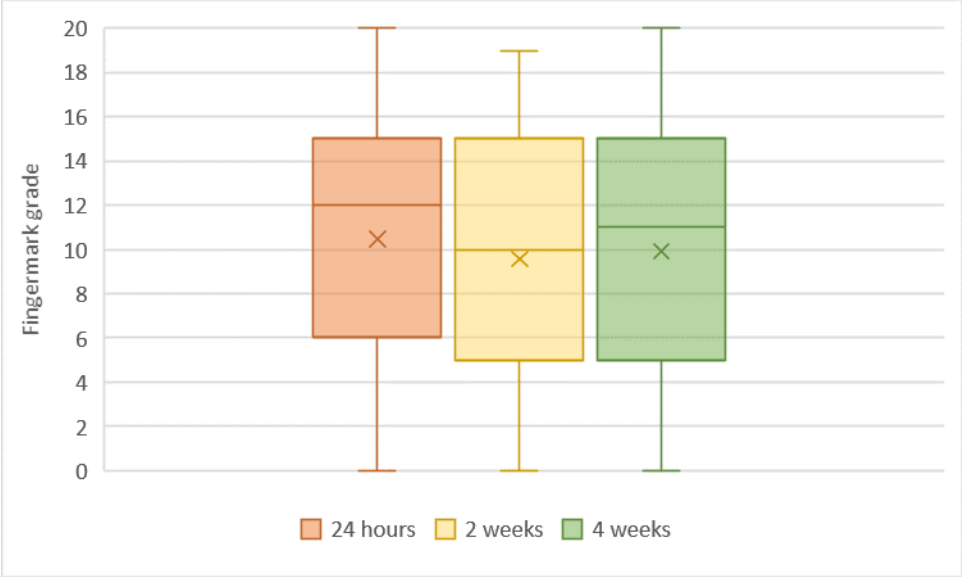


Figure 42. An overview of the fingermark grades for the three time periods; 24 hours, 2 weeks and 4 weeks.

A Friedman test was applied to the data to test for the significance in difference, following a Shapiro-Wilk test which indicated that the data was not normally distributed. The results showed that there was a difference between the fingermark grades for the different time periods ($p \leq 0.05$). Wilcoxon Signed Rank pairwise post hoc tests were applied to identify the areas of significant difference. A Bonferroni correction was applied to give an adjusted alpha level of 0.017. The output of the pairwise post hoc tests showed that there was a statistically significant difference between 24 hours and 2 weeks, and 24 hours and 4 weeks ($p \leq 0.017$). However, the significant differences only had small effect sizes, $r = -0.1$. There was no statistically significant difference in fingermark grades between 2 weeks and 4 weeks which corroborates the visual analysis.

Chapter 4. Discussion

4.1. The quality of developed participant fingermarks on glass microscope slides; phase 1 study

The aim of the pilot study was to gather an understanding of the quality of development between iron oxide WPS and fingermark residue. The study was similar to 'phase 1' studies described in fingermark research literature (Sears *et al.*, 2012; IFRG, 2014). The participant (4.1.1 and 4.1.3), type of sweat (4.1.2), depletion series (4.1.4) and, age (4.1.4) of the fingermarks were controlled to analyse the quality of development with iron oxide WPS when a variety of variables were applied to a fingermark. The substrate was kept as a constant, to help investigate whether any change in the development ought to have been caused by one of the other variables.

A fundamental understanding of what causes the selective deposition of the iron oxide particles to develop latent fingermarks is unknown. The phase 1 study was used to generate an initial and novel understanding of what may cause the interaction between iron oxide WPS and latent fingermarks.

4.1.1. Inter person variation

Inter person variation was observed from the developed fingermarks between the participants in the pilot study. Figure 16 in 3.1.1 illustrates the average fingermark grade for each participant, showing the variation in grades between participants. The large standard deviations on the graph show the intra person variation which will be discussed in 4.1.3. In addition, the statistical analysis (3.1.1.1) indicated significant differences with large or medium effect sizes, between 29 out of the 45 pairs of participants. It was interpreted that the inter person variation being observed was a result of differences in either the chemical or physical characteristic of the fingermarks, or both. Although a complete and thorough understanding of latent fingermark residue is still relatively lacking, as described in 1.1.2.1 it has been

reported in literature that the composition of sweat between participants varies (Cadd *et al.*, 2015; Frick, Fritz and Lewis, 2016). It has been suggested in literature that the variation between participants can be due to factors such as age, sex, race and, diet.

The variation observed in this study illustrates why it is necessary to use a representative sample of participants. The donors asked to participate in this study were selected with the aim of trying to achieve a representative sample. Five male and five female participants between the ages of 22 and 52 were used in this study as literature suggest that 10 participants are a reasonable number to achieve a representative sample (Kent, 2010). Research (although limited in some areas) suggests that sex and age can impact on the variation of the chemical composition of sweat so, it was key to obtain participants with a range of ages from both sexes. Equal numbers of male and female participants were selected with the aim of being able to analyse any differences that may occur in the quality of development between sexes. Cadd *et al*. (2015) explains that although not widely explored, research has indicted that differences between male and female composition of fingermarks have been noted. In contrast, Croxton *et al.* (2010) and, Fritz *et al.* (2013) reported that in their studies that the variations in fingermark composition were not attributed to the sex of the participants. Due to the number of fingermarks deposited in the pilot study/phase 1 study, differences in the quality of fingermarks from male and female were not explored at this stage; further discussion on this topic can be found in the more extensive, phase 2 study in 4.3.1.

Literature suggests that donor age can also affect residue composition however the largest differences are usually seen between children and adults and, the elderly (Ramotowski, 2001). The participants selected for this study were all adults past the stage of puberty and before the age where it is believed significant changes start to occur due to increasing age (Ramotowski, 2001). It was thought that with all participants in this study being within a relatively small age range, age was not a major cause for the inter person variation observed. Comparably, Croxton *et al.* (2010) and, Fritz *et al.* (2013) also found that the variations in their studies were not attributed to age.

Similarly, to sex, race is believed to be influential on the composition of a fingermark however, has also not been widely explored (Cadd *et al.*, 2015). Michalski, Shaler and Dorman (2013) reported that a difference in the chemical composition of participant residue was observed between the races analysed in their study (Caucasian origin, n=29 and, 'minority races', n=8), with Caucasian and African American males displaying the largest difference. Problematically, the difference detected may have been due to a small sample size. In this study only 1 out of the 10 participants was of a different race. It could be anticipated that this limited the study in the representation of the sample. The one participant of a different race was highest graded female who (almost consistently) displayed the best quality development (out of the female participants) throughout this study and the further study (4.3.1). Problematically, as the composition of residue was not investigated, and the sample of participants was relatively small, it was not possible to determine if the quality of development for this participant was as a result of race or sex. It should perhaps be considered that in a sample set as small as the one in this study (n=10), participants should be from a single race to eliminate the variable as a potential cause for variation in development quality. Further studies could then be designed to incorporate larger groups of participants from a variety of races to investigate any differences in development quality resulting from fingermark variation from different races.

In addition to the composition of residue being an influencing factor for the inter person variation observed, it was thought that the quantity of residue or distribution of residue may have also influenced the variation. Literature states that inter person variation in composition of fingermarks deposited on a surface could be as a result of the pressure applied during deposition (Girod *et al.*, 2012; Cadd *et al.,* 2015). Jasuja *et al.* (2009) found that the more pressure that was applied on deposition, resulted in darker development with ninhydrin, indicating that larger quantities of amino acid had been deposited as a result of the pressure applied. Problematically, as Jones *et al.* (2001) explains, without quantitative analysis of a sample, the pressure applied to a surface on deposition is usually only noticed when considerable changes in development quality are observed; for example, distortion of ridge detail.

During this study the deposition method was controlled to eliminate pressure as a variable causing inter person variation. It was anticipated that because the force and angle at which each participant's finger made contact with the surface was kept consistent, the inter variation observed was as a result of the participant's fingermark composition and not an effect of the forced applied during deposition. Controlling the deposition of fingermarks has been widely used in fingermark research, with a variety of methods being applied to control the pressure applied (Girod and Weyermann, 2014; Sutton *et al.* 2014, Fieldhouse, 2015). Not all fingermark studies choose to control the method of deposition, allowing for natural variation representative of that which may be encountered at crime scenes. In phase 1/pilot studies such as this, it may be deemed beneficial to control the deposition pressure, so that any variation in the quality of development should be from the fingermark composition. Although in this instance, the pressure of deposition was controlled, it was thought that the force applied to the surface would only affect the quantity of residue deposited if a reasonable quantity existed on the friction ridges prior to deposition. If a participant was a low secretor and only had a small quantity of residue present on the finger available for deposition, it is logical to think that no matter how hard the finger touched the surface, there would be a limit to the amount of residue that could deposit. The pressure at which a finger touches a surface would have a large impact on the quality of ridge detail available however, the effect on the quantity of residue would be limited.

The inter person variation observed resulted in iron oxide WPS developing fingermarks between participants with different qualities. These findings suggest that iron oxide WPS is very selective in the characteristics of a fingermark it has an affinity to and, may suggest that it is a chemical enhancing technique rather than a physical technique, such a powder dusting. Iron oxide WPS is recommended in the Fingermark Visualisation Manual (Centre for Applied Science and Technology, 2014) within a sequence of treatments; the findings from this study support the recommendation for using iron oxide WPS in a sequence with other physical and chemical development techniques given the selective nature of the powder suspension. This knowledge is key to informing the recommended applications of iron oxide WPS as problematically, the composition of a latent fingermark is almost always unknown. Therefore,

if iron oxide WPS remains selective in its development nature, it may not always be the most relevant technique to use independently of a sequence.

4.1.2. The effect of sweat type on the quality of development

Eccrine rich, sebaceous rich and natural fingermarks were developed with iron oxide WPS then analysed to investigate if the iron oxide particles had an affinity to a specific type of residue. To date, there has been no previous research investigating the way iron oxide WPS interacts with eccrine rich and sebaceous rich fingermarks; with minimal research specifically focusing on iron oxide WPS's interaction with natural fingermarks. Most research studies that include wet powder suspensions as a development technique do not focus on the interaction between the fingermark residue and WPS or, the quality of development of WPS. The studies generally focus on comparing WPS to other development techniques in different scenarios (Au *et al*, 2011; Ferguson *et al*, 2013; Gardner, Cordingley and Francis, 2016; Goldstone, Francis and Gardner, 2015). These studies generally use natural fingermarks. Whilst natural fingermarks are more representative of operational marks, the knowledge gained does not give a fundamental understanding of the interaction taking place between the fingermark and iron oxide WPS. This section of the pilot study aids in providing a fundamental foundation of the way iron oxide WPS interacts with different types of residue.

It was interpreted that, in the cases where there was no development (graded 0), the fingermarks did not contain any interacting chemical constituents that the iron oxide particles may have an affinity for or, no residue was deposited. It was also interpreted that, where there was some development but with very low grades, the interacting constituents were present but in small quantities.

From the visual examination of the eccrine rich fingermarks resulting in a 0 grade (3.1.2, Figure 17), it appeared that in some instances fingermarks were being removed from the glass slide during the development process; resulting in no constituents remaining on the glass slides for the iron oxide to interact with. Literature has suggested that eccrine residue is largely comprised of water, containing variable amounts of water soluble constituents (1.1.2.1),

although this has recently been disputed (Kent, 2016). New research proposes that upon deposition, eccrine fingermarks may not be 98% water as previously suggested but only 20% water. This is due to the rate at which the hands secrete sweat and the rate at which such small amounts of water are evaporated (Kent, 2016).

Given its aqueous nature, it was thought that during the rinsing stage of the WPS development process the aqueous part of the fingermark containing the interacting constituents was being dissolved. With fingermarks contaminated with sebaceous secretions it is logical to assume that the rinsing process would affect the marks to a lesser extent due to the insoluble nature of the residue, a theory that has been raised in literature, and which the results of this study would support.

Literature suggests that WPS could be used following visual and fluorescence examination and, powder dusting for non-porous substrates as an alternative option to cyanoacrylate fuming (superglue fuming), with the assumption that it interacts with constituents found in eccrine residue (Centre for Applied Science and Technology, 2014). Although this assumption may be true, the results from this study would imply that without the 'fix' of sebum or equivalent contaminating residue, the interacting constituents are likely to be lost. Therefore, WPS would not provide a robust means of development for eccrine rich fingermarks on items of evidence. It is not known or possible to establish how many fingermarks deposited at crime scenes are eccrine rich, but literature would suggest that they are likely to represent a minority of marks given that marks are likely to be contaminated with sebaceous secretions or contaminants containing water insoluble constituents. In these circumstances the results from this study would infer that WPS may not always be suitable.

Powder development precedes WPS in the sequential development chart recommended in the Fingermark Visualisation Manual (Centre for Applied Science and Technology, 2014), and as a physical method of development may adhere to any residue present, negating the selectiveness issues that iron oxide WPS has for the desirable characteristics in a fingermark. However, powders which adhere to the moisture and fatty content of a fingermark, are believed to be less sensitive than chemical approaches, which often target specific

constituents of fingermark residue. As the fingermark loses moisture over time, the powder has very little/no moisture to adhere to whereas, some constituents remain on a substrate over time, enabling the more sensitive chemical techniques to continue to develop the fingermarks (Centre for Applied Science and Technology, 2014 and, Ramotowski, 2013).

It was thought that larger quantities of residue upon deposition aided in the persistence of constituents on the surface during the development process as illustrated in Figure 43. The development and rinsing process was very brief with only small amounts of water being used to rinse the surface. It was interpreted that where the marks were being dissolved, there were such small quantities of residue deposited on the surface initially, that they were unable to persist during rinsing. Where eccrine rich marks did develop, it was thought that they had larger quantities of residue on the surface prior to development resulting in the ability for some (if not all) of the residue and thus interacting constituents to persist during the rinsing process.

a)  b) 

Figure 43. Eccrine rich fingermarks with excellent development, indicating the persistence of residue potentially as a result of larger quantities of residue present on deposition.

A factor which may have affected the quantity of eccrine residue upon deposition was the amount of movement each participant performed whilst producing the sweat. The amount of movement prior to deposition of eccrine rich fingermarks appeared to result in the biggest difference in quality of developed fingermark. Most of the participants remained reasonably stationary inside a building during the production of eccrine residue. The 8 participants who remained reasonably stationary were the participants who obtained a modal value of 0 for their eccrine rich fingermarks (3.1.2, Figure 17). The two participants (05 and 06) who had a majority of eccrine rich fingermarks graded above 10 were the only two participants to substantially move whilst wearing the gloves to produce eccrine sweat. It is widely known that factors such as emotion, exercise/movement and the environment participants are exposed to prior to deposition can affect the rate at which sweat is produced (IFRG, 2014, Jones *et al*, 2001, Taylor and Machado-Moreira, 2013). So, where little movement is performed or, particularly cool or dry environments are experienced prior to deposition, it is expected that participants would sweat at a reduced rate. In this study it was though that the limitation in movement resulted in less residue being deposited on to the surface, limiting the constituents available for the iron oxide WPS to interact with. This is an important consideration for individuals conducting fingermark research because in circumstances where realistic and representative samples are required there is some evidence to suggest that the environment itself caused differences in development with the marks.

The method chosen to produce eccrine sweat was to create a false environment by wearing gloves in the anticipation of speeding up the secretion of sweat. Although literature suggests that encouraging the body to sweat in unnatural environments can alter the composition of sweat, it was thought that the process would not hinder the study. The purpose was to see if iron oxide particles had an affinity to eccrine constituents (as a mixture) not to investigate the composition. It was hoped that encouraging the hands to sweat rapidly by wearing gloves would result in good quantities of eccrine residue being secreted, deposited and available for development if the iron oxide particles had an affinity to the chemical properties present. However, as previously stated, it appeared that the movement and environment surrounding the participant prior to deposition had the biggest impact on the results. In addition, the use

of gloves was required to prevent contamination from items participant hands may come in to contact with whilst waiting for the hands to sweat. An alternative approach to the false sweating environment would be for participants not to wear gloves and to secrete eccrine residue at a natural rate. In this instance participants would be required not to touch anything with their hands to prevent contamination. If participants chose to remain stationary to prevent the risk of contamination, as seen with this study the hands would likely take a longer time to produce a sufficient quantity of sweat. Again, as the results of this study indicated motion/exercise would speed up the rate of sweating naturally however, it would be difficult for the hands to remain contaminant free.

For some participants, when the eccrine rich fingermarks did develop they often had a very dotty discontinuous appearance to the ridge continuity but, with good (dark) contrast as shown in Figure 44. It was taken that, where a developed area was darker (had better contrast), more iron oxide had deposited there, indicating that those areas had an interacting property present. Given the nature of these fingermarks, it was anticipated that these areas contained an abundance of eccrine constituents which had been directly secreted from the pores. The quantity of the interacting constituents was also deemed to be significant in the quality of development. The contrast was thought to be a result of the quantity of constituents present in those areas. Kent (2016) suggests that in the absence of other types of sweat and, as the water content of a fingermark evaporates, the residue on the surface becomes more concentrated in constituents. At this point of the research there was evidence to suggest that either the quantity of eccrine residue, or the presence of one or more chemical constituents, or both affected the efficacy of WPS for latent fingermark development. Problematically, the quantity of residue was not measured given that participants were used to create the marks and no measures were taken to control the quantity of latent residue transferred during deposition. The chemical composition is likely to vary between individuals, and the results would suggest this, but without specific investigation of differences in the chemical composition of the marks the actual differences were unknown. To alleviate this issue and to perform a detailed and informative investigation, individual constituents commonly found in eccrine residue were studied. The results will be discussed in 4.2.

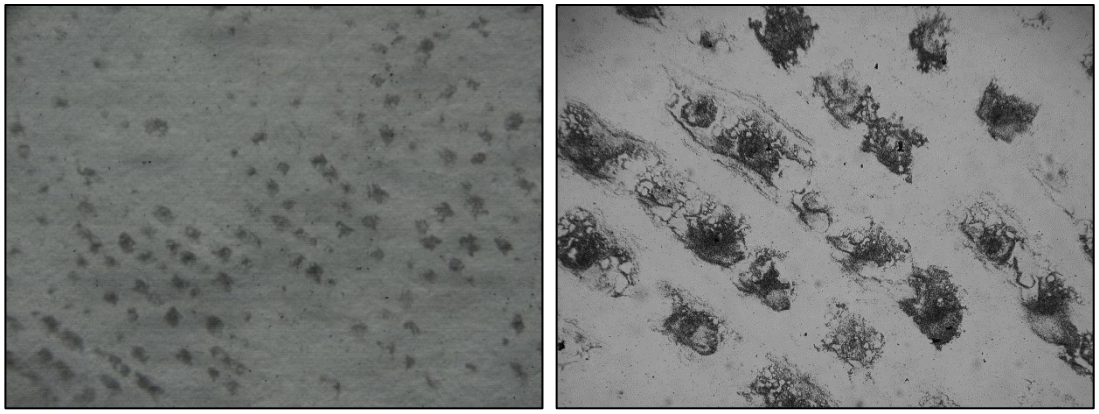


Figure 44. Developed eccrine rich friction ridges illustrating discontinuous ridge detail.

Similarly, to the eccrine rich fingermarks, the initial interpretation of sebaceous rich fingermarks which showed no development, was that sebaceous residue did not contain any chemical constituents that iron oxide particles have an affinity to or, no residue was deposited. In some instances, sebaceous rich fingermarks did develop but with low grades (less than 10 (3.1.2. Figure 18), suggesting that there were interacting constituents present but not in large enough quantities to produce good quality developed fingermarks or, that the interacting constituents were not easily accessible to the iron oxide particles. On observation of the latent fingermarks prior to development, some sebaceous rich fingermarks appeared to have an increased quantity of residue compared to other sebaceous fingermarks. These fingermarks often showed no (or very little) development following the application of iron oxide WPS. Unlike the eccrine rich fingermarks, the lack of development did not appear to be a result from the fingermark being washed away; the latent sebaceous rich fingermarks were still visible on the surface following development. In these instances, it seemed that the oily sebaceous secretions were too thick to permit contact between the iron oxide particles and the interacting constituents, so the iron oxide particles could not interact with any constituents which may have been present as they were being concealed by the oily sebaceous residue. Sebaceous residue is largely comprised of water insoluble constituents (1.1.2.2). It was interpreted that the water insoluble sebaceous residue was repelling the iron oxide WPS

during the development process, preventing the iron oxide particles from interacting with and selectively depositing on the fingermark.

The sebaceous rich fingermarks that tended to give better development, visually appeared less heavy prior to development. During the collection of sebaceous residue, participants were asked to rub their fingertips on their face and back of the neck. It was not specified to participants how many times to rub their fingertips to collect the residue which could have resulted in the difference in development quality between participants. Even if the participants had been instructed to rub their fingertips on the face and neck a specific number of times, it could not be guaranteed that each participant would collect the same amount of residue as each other or as themselves on every occasion. Natural, human inter and intra person variation means that this is a variable that cannot be controlled. One possible way to control this variable would be to load the participants fingertips with a consistent amount of artificial residue. However, as stated in 1.3.2 the use of artificial residue should be exercised with caution as the composition of residue is usually not known and, artificial fingermarks cannot replicate the complex matrix of a real fingermark (Girod, Ramotowski and Weyermann, 2012, Sears *et al*, 2012). A controlled, artificial method such as this was not used for this study as an understanding of the interaction between iron oxide WPS and human residue was a crucial part of being able to establish a rudimentary understanding of the development nature of iron oxide WPS (Kent, 2010). This includes the necessity to observe how the technique behaves with human fingermarks, similar in nature to those that may be found at crime scenes.

Although participants were asked to wash their hands prior to loading their fingertips with sebaceous residue from the face and neck, it could not be guaranteed that all eccrine residue was absent from the sebaceous rich depositions. Due to the heavy sebaceous rich fingermarks often showing no development, where development was observed it was thought that it was an interaction between the iron oxide particles and eccrine constituents that may still be present after washing or, had been secreted in the time from washing the hands to deposition of the fingermarks. Taylor and Machado-Moreira (2013) state that fingers sweat at a rate of 0.62 $mg.cm^{-2}.min^{-1}$ so, it was possible for a small amount of eccrine secretions to be present in the sebaceous rich fingermarks, or there was a constituent within sebum that interacted

with the iron oxide. Figure 45 gives an example of a developed sebaceous rich fingermark which indicated that the iron oxide particles had an affinity for a chemical property that was not consistent within sebaceous residue. Continuous ridges are visible although with very poor contrast indicating those areas are not abundant in the interacting chemicals. This visual appearance suggested that the fatty, water insoluble lipids present in sebaceous residue were aiding the water soluble eccrine constituents to persist on the substrate, allowing those constituents to develop, or there was something in sebum which equally interacted. De la Hunty *et al* (2015(b)) found the behavior between sebum and eccrine constituents to be similar for physical developer (PD). The study reported that it appeared PD was targeting eccrine/water soluble constituents but when they were 'held in place' on a surface by sebaceous lipids. The interaction between constituents found in sebum and iron oxide WPS could have been studied in a similar way to those found in eccrine residue (4.2) however, were not investigated as part of this study. This investigation would be recommended for further work.

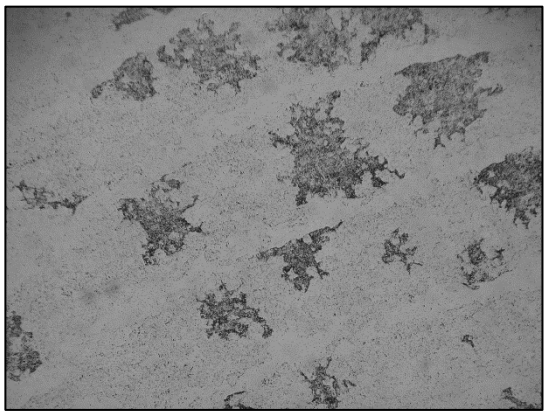


Figure 45. Developed sebaceous rich friction ridges illustrating localised areas of good contrast with continuous ridge detail visible although with very poor contrast.

As participants were instructed to wash their hands prior to creating eccrine rich and sebaceous rich fingermarks, consideration was given to theory that it was possible for any development to be caused by soap persisting on the fingertips (Jones *et al*, 2001). Research

has shown that the persistence of liquid hand soap can have an effect on fingermark luminescence and development interaction (IFRG, 2014). A small preliminary test was conducted to establish if iron oxide WPS developed dried deposits of the soap that participants used when washing their hands. The dried soap deposits showed some development, indicating that a property of the soap resulted in the iron oxide particles selectively depositing. Although an important finding, this result was not considered to be significant due to the number of eccrine and sebaceous rich fingermarks that did not develop. If soap residues had persisted on the participant fingertips resulting in the iron oxide particles interacting with the soap, not a property of the fingermarks, it would have been expected that a higher number of fingermarks would have shown development of some quality giving significantly less fingermarks graded 0. Additionally, participants dried their hands with paper towel following the washing process. Although it may have been possible for some development to have been caused by the persistence of soap, it was anticipated that the physical contact between the friction ridges and paper towel would have removed excess soap that may have remained.

It was anticipated that the natural fingermarks generated for the pilot study would contain a mixture of eccrine residue, sebaceous residue and contaminants (1.1.2). Visual examination and analysis of the grades (3.1.2. Figure 19) of the developed natural residue fingermarks indicated they were of a better quality than the eccrine or sebaceous rich fingermarks. Combining the theories established from observing the groomed and non-groomed fingermarks, it was interpreted that the quality of fingermark development improved when there was a mixture of eccrine constituents secreted from the pores, with some sebaceous residues and contaminants to aid in the fingermark persisting on the surface during the development process. Figure 46 illustrates the development quality that was observed in some natural fingermarks. The improvement in quality of development between eccrine fingermarks and natural fingermarks suggested that the addition of other residues and contaminants may have aided in the quality of development improving. Localised areas of darker (better) contrast can still be seen along the ridges similar to the eccrine rich fingermarks, suggesting the areas of abundant interacting constituents are still present.

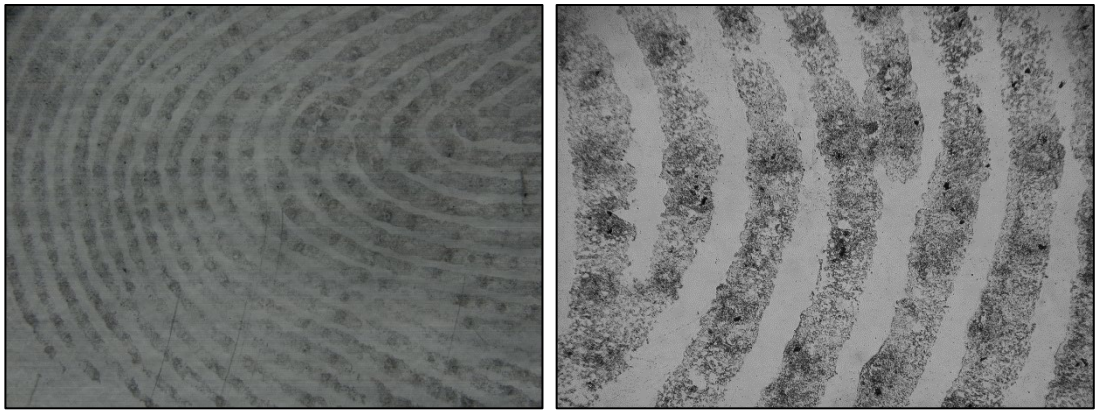


Figure 46. Developed natural friction ridges illustrating continuous ridge detail with localised darker areas along the ridges.

The depletion deposition method used for this study was a multiple depletion (Sears *et al*, 2012). This method required participants to use multiple fingers to deposit marks within the same repeat due to the number of depositions required during one occasion. This deposition method resulted in each depletion series for each participant being from different sources (fingers). To make the deposition from the different sources as similar as possible, participants were asked to rub their fingertips together immediately prior to deposition (2.1.2). The aim of this process was to mix the residue across all fingers. The number of times participants were required to rub their fingertips together was not specified. Mixing the residue across all fingers was to try and minimise any differences in the composition of residue between fingers so that the depletions from each finger (for an individual participant) would be comparable. This is an assumption made within fingermark research projects, but without specific investigation the actual variation is unknown.

A multiple depletion method such as the one used in this study may not always be the most effective method to use depending on the overall aim of fingermark research due to the depositions being from different sources. Split depletions are the preferable method when comparing two different development and/or lifting techniques (IFRG,2014, Sears *et al*, 2012). This method allows a depletion series of fingermarks from the same finger to be split in half;

one half would be processed with one technique and the other half, a different technique. The split marks can then be directly compared as they have originated from the same finger, although again, it is entirely possible for variations to exist within the same fingermark.

It was anticipated that the process of rubbing the fingertips together prior to deposition would not only mix the residue from all fingers but, would also distribute the residue over the friction ridges. It was expected that this process would result in distributing the chemical constituents over the friction ridges resulting in good ridge continuity. It can be seen from the discontinuous ridge detail in Figure 47 that this method was not always successful, particularly for eccrine rich fingermarks.

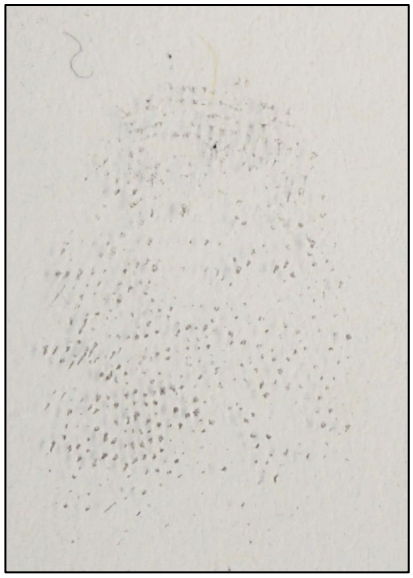
a)  b) 

Figure 47. a) participant 09 and b) participant 02 both illustrate the discontinuous ridge detail often observed with eccrine rich fingermarks.

Rubbing the fingertips together prior to deposition, to mix and distribute the residue is an approach that is widely used in fingermark research (Sears *et al*, 2012; Croxton *et al*, 2010; Kent, 2010; Jones, Downham and Sears, 2009). The method is largely detailed by Sears *et al* (2012); figures from Scopus, via PlumX (2018) show that Sears *et al* (2012) has been cited 69 times since publication. Although this is a widely used method, it could be suggested that the

process may have been unnecessary to this study, given the resulting discontinuous ridge appearance for some of the developed fingermarks. However, the lack of distribution resulted in aiding the study by indicating that iron oxide particles had an affinity to constituents found in abundance around the friction ridge pores.

The dotty, discontinuous ridge detail observed typically in the eccrine rich fingermarks indicated that the interacting constituents were present but, not in an even distribution over the friction ridges at the time of deposition. Problematically, it was thought that rubbing the fingertips together was not a successful method particularly for the eccrine rich depositions as, there was not enough residue/sweat being secreted to distribute along the ridges. As previously discussed, the lack of residue may have been a result of the method used to generate the eccrine rich fingermarks. To improve this method for future research, it would be suggested that when generating eccrine rich fingermarks, the participants should wear the gloves for a longer period before deposition and, where possible continue their daily activities whilst wearing the gloves. The continuation of activities would encourage the hands to sweat naturally, with the aim of producing a larger quantity of sweat resulting in a better distribution of residue, giving continuous ridge detail on development.

Sebaceous rich fingermarks reportedly have more continuous ridge detail than eccrine rich fingermarks. It was expected that secretions were collected by the whole distal portion of the finger that made contact with the face and neck prior to deposition, resulting in a larger quantity of residue being present than the eccrine rich secretions. This aided a more even distribution of residue and thus better continuous ridge detail. Figure 48 illustrates the distribution of residue and subsequent continuous ridge detail observed with developed sebaceous rich fingermarks.

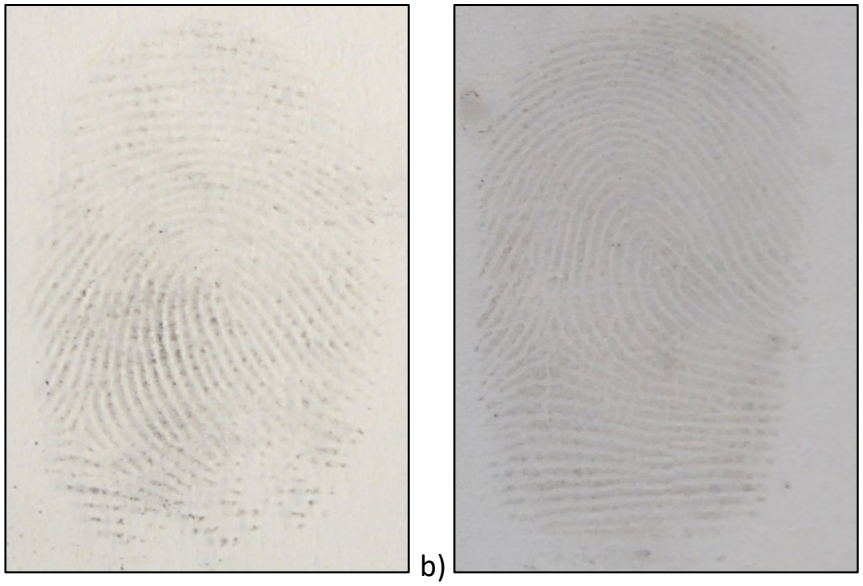


Figure 48. a) and b) both illustrate the continuous ridge detail often observed with sebaceous rich fingermarks.

The distribution of residue and continuity of ridge detail varied (as expected) between participants with natural fingermarks. However, even when natural fingermarks were discontinuous in ridge detail, they generally had more continuity than the eccrine rich fingermarks. It was perceived that the quantity of residue increased in the natural fingermarks for the participants who struggled to produce a sufficient quantity of residue for the eccrine rich marks. It would be logical to think that an increase in quantity of residue would be from the addition of contaminants such as sebum; as literature suggests natural fingermarks contain a mixture of residues and contaminants other than those secreted directly from the pores on the palmar surfaces (Girod, Ramotowski and Weyermann, 2012 and, Sears *et al.,* 2012). Additionally, the increase in quantity of sweat for the natural fingermarks for some participants may have been a result of the length of time the hands were able to sweat prior to deposition. For the natural fingermarks, participants were instructed to have not washed their hands within at least 30 minutes prior to deposition meaning that, some participants may have been in contact with contaminants and produced sweat naturally for more than this time frame. Whereas, for the eccrine rich fingermarks participants were instructed to wear the

powderless gloves for 30 minutes prior to deposition; which as previously described, may not have been a sufficient length of time for some participants. It was thought that increase in quantity of residue aided in the improvement of distribution of sweat along the ridges, resulting in (for some participants) improved ridge continuity. Figure 49a) illustrates a developed natural fingermark for a participant who's ridge continuity improved. Figure 49 b) shows an example of the same participants eccrine rich fingermark.

a)  b) 

Figure 49. a) A developed natural fingermark showing a slight improvement in ridge continuity compared to, b) An eccrine rich fingermark from the same participant.

The statistical analysis showed that there was no significant difference between the fingermark grades of sebaceous rich and natural marks (3.1.2.1). The statistical analysis also showed there was a significant difference between both natural and sebaceous rich fingermarks when compared to eccrine rich fingermarks, with eccrine rich fingermarks on average being of a lower quality. These results indicated that a property of natural and sebaceous rich fingermarks was preferential to the iron oxide particles, aiding in better quality development. It was thought that the most likely property to have aided in the quality of development was the quantity of residue. For both sebaceous and natural fingermarks, where it was thought

that larger quantities of sweat were present, the continuous ridges may have been a successful result of the rubbing process. However, it could be argued that in these instances the rubbing technique still achieved very little, there was simply enough residue present initially that the residue had naturally spread across the friction ridges prior to rubbing the fingertips together.

The interpretation of iron oxide WPS having an affinity to eccrine constituents was based on the visual difference in contrast observed between the developed sweat types. Where discontinuous ridges were observed, they generally displayed excellent contrast between the mark and background surface. Where continuous ridge detail was observed, the contrast between the mark and background surface tended to be of a lesser quality. In addition to the interpretation that the lipids had the potential to act as a barrier between the interacting constituents and the iron oxide particles, it was thought that distribution of residue along the friction ridges was potentially diluting the concentration of interacting constituents along the ridges; although this was not studied.

The results from the pilot study indicated that iron oxide WPS may have an affinity to constituents found in eccrine residue, with better quality development being observed when there were larger quantities of residue present and, when there were some lipids and/or contaminants present to aid the persistence of eccrine constituents during development. Natural fingermarks were chosen as the most appropriate residue type to continue to use in future studies. This decision was made as a result of the appearance of eccrine rich fingermarks being dissolved or generally being of poor quality, sebaceous rich fingermarks occasionally being heavy and overloaded with sebum and, the natural fingermarks producing the most successful results from the sample studied. In addition, published literature suggests that natural fingermarks are the most representative of operational fingermarks (IFRG, 2014, Sears *et al,* 2012).

4.1.3. Intra person variation.

For most participants, a large range of grades were observed (3.1.3) when analysing the fingermark grades for all sweat types grouped together. Within one participant it was not uncommon to see a range of grades, from fingermarks being graded 0 showing no development at all, to other fingermarks being graded 14 or above, showing good quality of development. Some participants achieved grades as high as 19 and 20 yet still with a range of fingermarks within their sample set being graded 0 with a range of grades in between. Additionally, the large standard deviations observed for some participants in Figure 16 in 3.1.1, demonstrate the intra person variation; the results imply that where a participant was able to achieve a reasonably high grade, demonstrating good development, the same participant was equally able to produce marks with very low grades showing poor or no development.

It was interpreted that the intra person variation of fingermark grades was as a result of the composition of fingermark residue or the quantity of residue varying on different occasions (days). Due to the rubbing process used prior to deposition (as previously discussed in 4.1.2), it was anticipated that fingermarks deposited on the same occasion were as similar as possible in the chemical composition so, it was thought that the intra person variation may have been most evident from fingermarks deposited on different occasions. Literature suggests that the composition of one person's residue can change somewhat from day to day as a result of factors such as diet, exercise and where natural fingermarks are tested, the contaminants present. Girod and Weyermann (2014) reported that although inter and intra person variation was evident in the chemical composition of fingermarks in their study, the standard deviations tend to be less when analysing intra person samples than the inter person samples. Archer *et al.* (2005) also experienced intra person variation within their study however, the fingermarks were deposited over the period of a working day, meaning that all fingermarks were deposited on the same day.

It was hoped if the time between repeats (days) was kept as short as possible (all depositions completed within 1 week of the initial deposition), there would be very little time for extreme changes to a participant's diet and routine between the repeats; resulting in the fingermark

composition from one repeat (day) to another being as similar as possible given the slight natural variation that would occur due to the depositions being on different days. It was anticipated that largest influencing factor would be the contaminants present in the natural fingermarks. It is expected that contaminants present on a person's fingers will change multiple times within a day following the washing of the hands and re-touching different surfaces, products and food with natural day to day activities. This variation would also be expected on different occasions as the surfaces, products and food touched are bound to vary from one day to another.

Within one repeat (occasion), participants were required to deposit such a high number of fingermarks that for the natural fingermarks, they were required to go about their daily routine for at least 30 minutes in between depositions after exhausting all fingers. Due to the expected variation in contaminants, participants were instructed to continue with their daily activities similar to those they were doing prior to depositing the first set of fingermarks, in the hopes of minimising intra person variation within one repeat. It was not possible to control or monitor the potential variation encountered as a result of different contaminants being present however, it was thought that the variation aided in creating samples that were representative of operational work.

In addition to the composition of the fingermarks resulting in intra person variation, it was interpreted that the quantity of sweat may have been an influencing factor. The intra person difference in quantity of residue was thought to be a result of the different sweat types encountered in the study as described in 4.1.2, not as a result of producing more or less sweat on different occasions. The higher graded fingermarks tended to be natural and sebaceous fingermarks for all participants apart from participants 05 and 06 as discussed in 4.1.2; it was interpreted for these sweats types that a larger quantity of residue was being deposited, resulting in the higher grades. All sweat types for all participants scored as low as 0 and as a result of the sebaceous and natural fingermarks achieving the highest grades for each participant, they were the sweat types that generally encountered the most intra person variation.

The intra person variation displayed indicates how challenging it is in fingermark research to create samples of a reproducible nature with the exact same composition when using participants. In fingermark research it is possible to gather a sample of fingermarks that are representative of those which may be found in operational work but as literature suggests, without the use of a controllable method such as artificial sweat, it is not possible to create reproducible sample.

At this stage of the research, the inter person variation was observed grouping the results for all three time periods and three sweat types. So, it was considered that one of these factors influenced the range of grades within each participant rather than the composition of the fingermark varying due to intra person variation. However, the statistical analysis detailed in 3.1.4 indicated that when considering depletion, sweat type and age of fingermark on the quality of the developed marks, none of these variables had a large effect. Due to the variation in sweat types observed for the pilot study and the implications the types of sweat can have on the quality of development as discussed in 4.1.2, intra person variation will be discussed more in 4.3.1 where, only natural fingermarks were analysed.

Similarly, to the inter person variation, the results of intra person variation demonstrated the selective nature of the iron oxide particles. If iron oxide WPS was less selective in the interacting properties it required to develop a mark and, was more of a physical development technique like powder dusting, it would be expected that there would be more consistency in development quality within one participants marks.

4.1.4. The effect of additional variables on the quality of development.

For the initial stage of research, glass was chosen as the sole substrate. In fingermark research, it is widely accepted that during 'phase 1' (IFRG, 2014, Sears *et al,* 2012), pilot study level for researching a new or relatively unknown development technique, glass is recommended for techniques that are suitable for non-porous surfaces and white photocopier paper for techniques that are suitable for porous surfaces (Sears *et al,* 2012). At this stage of the research project, the study was focused on how participant fingermarks or different types of sweat

interacted with iron oxide WPS, rather than how substrate type may affect the quality of development. The effect substrate type has on the quality of development will be discussed in 4.3.2.

In some cases, it is possible that crime scenes are processed less than 24 hours after the crime took place therefore, where a fingermark development technique is applied at the scene it needs to be successful in developing fingermarks that are potentially less than 24 hours old. Items of evidence that are recovered from a crime scene and sent to a laboratory to be treated, are not usually examined less than 24 hours after the scene has been processed and thus, assuming when the fingermarks were deposited. So, it is important for development techniques to be able to develop fingermarks that are older than 24 hours. As WPS is a technique that can have scene and laboratory applications, it was deemed necessary to establish the quality of development on freshly deposited fingermarks (within 1 hour), as well as slightly aged fingermarks (24 hours and 1 week).

As evidenced by the mean grade being the same for all three time periods and the statistical testing, the development quality did not appear to improve with age. This was perhaps due to the fact only relatively short time periods were observed during this part of the study. These findings would suggest that iron oxide WPS may not be the most successful development technique to use on fingermarks that are less than 1 week old. Problematically, as literature suggests it is very often impossible to determine how old a fingermark is prior to selecting a development technique (Centre for Applied Science and Technology, 2014). Thus, where WPS is concerned as much background information as possible to a case would be required to make an informed decision on the selection of development technique.

It has been widely stated that fingermark composition changes over time following deposition. Following deposition, the water content and more volatile constituents in fingermark residue begin to evaporate (Sodhi and Kaur, 2001); for physical development techniques such as powder dusting, the evaporation of moisture hinders development but, for techniques which require interactions with chemicals present in a fingermark, the ageing of a mark can aid in the desirable chemicals becoming more accessible. The statistical analysis between ageing time

periods for this study (3.1.4) indicated that there was no statically significant difference between most of the time periods and, where there was a significant difference between 24 hours and 1 week, only a small effect size was observed. For the results of this study it was interpreted that perhaps, due to only short time periods being observed, there was the potential for the interacting constituents within the fingermark residue not being fully accessible to the iron oxide particles due to the presence of constituents, contaminants or water content that had not yet been evaporated.

The ageing periods for the pilot study were chosen to investigate the way iron oxide WPS would interact with short term changes; studies following this were used to examine longer term changes (4.3.3).

A variable which may have affected the way the fingermarks aged was the storage conditions of the samples post deposition, prior to development. During the pilot study, the glass slides containing the latent fingermarks were stored in closed, plastic, microscope slide boxes in a laboratory cupboard when left to age. Sears *et al*, 2012 and others (Jones *et al,* 2001, Kent, 2010 and IFRG, 2014) state that storage conditions should be carefully considered and where possible, should be representative of case work where the technique being investigated is most likely to be required. The storage conditions for this study provided a limitation as they were not necessarily representative of open conditions with circulating air and varying light sources that may be found at scenes of crime. As Kent (2010) suggests, exposure to sun light and airflow can affect the rate at which the water content and more volatile constituents in a fingermark will evaporate. The above limitations were considered and changed for further studies.

Depletion series are often used when exploring a new or relatively unknown development technique to establish how sensitive it is at developing small quantities of residue. Literature suggests that the residue deposited on a surface diminishes for every consecutive depletion, although this has not been thoroughly explored (Sears *et al.,* 2014 and, IFRG, 2014). For this study, depletion series of 10 consecutive fingermarks were used to investigate the sensitivity of iron oxide WPS. The results (3.1.4) showed that, although not a frequent occurrence due to

the lack of development throughout this study, iron oxide WPS was able to develop good quality fingermarks on the 10th depletion in a series. Again, it was thought that the results were indicative of the quantity of residue present; where the 1st mark in a depletion series developed with a good quality, the 10th depletion was more likely to show some development. This indicated that where the quantity of residue was perhaps larger for the initial deposition, there was still a reasonable quantity of residue remaining by the 10th depletion. Whereas, when there was a lower quantity of residue on the initial depletion, resulting in poor quality development, the 10th depletion was less likely to show any development. The findings discussed in 4.1.2 suggest that quantity of residue has a large impact on the selective nature of iron oxide WPS.; so, the 1st fingermark in a depletion series for a participant who deposits small quantities of residue may develop in the same manner that the 10th depletion from a participant who deposits larger quantities of residue. The results indicate that iron oxide WPS has the potential to develop fingermarks much further on in a depletion series than the 10th mark but only for those participants who deposit larger quantities of residue. To test the sensitivity of iron oxide WPS to its fullest extent, especially where fingermarks with good quantities of residue are concerned, depletion series with a higher number of marks could be explored to further this area of research.

It is logical to think that in some instances an offender will have touched multiple surfaces and objects, perhaps multiple times during the commission of that crime. Multiple surfaces and objects may be touched consecutively, resulting in fingermarks of varying quantities of residue providing a need for a development technique that is sensitive to small amounts of residue. The results from this study indicated that when the interacting properties of a fingermark were present and in the desirable format, iron oxide WPS could be a sensitive technique. This knowledge is beneficial for the recommendations of the application of iron oxide WPS when developing fingermarks at crime scenes or from items of evidence.

4.2. Results of eccrine constituent test spots and spiked fingermarks on multiple substrates, developed using iron oxide wet powder suspension.

As literature suggests, studying participant fingermarks is vital to give a realistic representation of the type of residue compositions that may be found at crime scenes however, the composition of the residue cannot be controlled or easily monitored. During phase 1 studies it may be deemed necessary to investigate which specific constituent(s) cause the selective deposition of or, cause an interaction with a new or relatively unknown development technique; this was the necessity for this study as very little is known about what causes the selective deposition of iron oxide WPS to develop latent fingermarks. It is necessary to investigate these fundamental workings of a development technique to understand how successful it will be at developing latent fingermarks found at crime scenes or on items of evidence. If a development technique has an affinity for a constituent that is not commonly found in fingermark residue, it may not have a wide enough application for operational use. A fingermark development technique must be efficient in developing a reasonable amount of the populations fingermarks, to make it more cost effective; so, if a technique has an affinity for constituents that are scarcely found in the general population, it may be deemed unsuitable.

Literature suggests that individual 'test spots' of constituents that may be found in fingermark residue can be an effective way of investigating this cause of interaction, as they can be controlled, therefore, consistent samples can be created and the cause of interaction can be observed more specifically (Sears *et al.,* 2012). Whilst other studies have also employed this technique (De la Hunty *et al.,* 2015a; Wargacki, Lewis and Dadmun, 2007), it must be noted that whilst this type of study can be very informative, individual 'test spots' of constituents may differ in the way they interact to whole fingermarks which are a complex matrix of constituents and contaminants (Sears *et al.,* 2012).

The results from the pilot study indicated that iron oxide WPS may have an affinity to constituents found in eccrine residue. The six constituents used in this study were selected as literature suggests that they are some of the most commonly found and abundant in eccrine residue (1.1.2). This phase 1 study was designed to investigate what may be causing the selective deposition of iron oxide WPS to develop latent fingermarks, and not how the constituents were interacting with the development technique (chemically or physically). This was a continuation of the phase 1 pilot study so, the information generated from this part of the study was also an original contribution to knowledge as, prior to this, very little was known about what causes the selective deposition of iron oxide WPS. Additionally, methods such as these have not been used to investigate iron oxide WPS prior to this study.

4.2.1. Eccrine constituent test spots deposition, without a fixing agent.

This study focused on quality of development of the six eccrine constituents, without the addition of any form of 'adhesive', aiding the water soluble constituents to adhere to the substrates. Literature that suggests the use of constituent test spots, do not give a recommended form of analysis therefore, a grading system was created for the purpose of this study to enable a quantitative value to be given to the developed test spots, so that the quality of development could be statistically analysed (2.2.7.1). The grading system used was unique to this study and has the potential for being used in other studies analysing the quality of development for constituent test spots. Problematically, the grading system has not yet been rigorously tested beyond this study and may require some revisions prior to wider use.

The results showed that serine and glucose gave limited development on all substrates (3.2.1); the remaining constituents showed varying quality of development over the different substrates, with alanine showing the highest overall mean grade closely followed by urea. The statistical analysis (3.2.1.1) showed that the only significant differences with large effect sizes were when alanine and urea were tested against all other constituents; indicating that these constituents may have a property that iron oxide has an affinity for or, they were able to persist

on the substrates during the development process more successfully than the other constituents.

It was thought that the lack of development for serine could either be because the constituent did not interact with the iron oxide particles or, because the constituent was being dissolved during the development process and so, was not able to persist on the surface to show development. When visually observing the surfaces post development, in some instances it appeared that the serine test spots had been dissolved and washed off the surface. As with the eccrine rich fingermarks, it was interpreted that the dissolving of the constituent could have been because there was no water insoluble lipids or contaminants present to aid in the persistence of the water soluble test spots. During this study, the persistence of the test spots was relying on the way the constituents would dry on and potentially interact with a surface, without the aid of fatty lipids or contaminants to 'hold' them in place. It was interpreted that the constituents which showed development were able to persist on the substrates during development due to a chemical property (such as solubility) of that constituent or, because of an interaction between the constituent and substrate.

It was interpreted that the visual appearance of the dried test spots may be attributed to their solubility. Sodium fluoride started to crystalise immediately because it was almost a saturated solution and so dried with a larger, more full appearance than other constituents; Sodium fluoride was the least soluble constituent (36 g/L), followed by serine (50 g/L), which demonstrated the same drying characteristics. When the urea and glucose spots (the most soluble constituents, 1079 g/L and 909 g/L respectively) started to evaporate as they dried, the spots began to shrink. The urea and glucose stayed in solution as the spots shrank, and therefore they became more concentrated until they crystalised in a smaller area. These observations had to be taken into consideration when assigning a grade to the completeness of the test spots.

Visual analysis indicated that glass appeared to give the least development, with uPVC providing the best quality development. The statistical analysis (3.2.1.1) corroborated the visual results, as the only significant differences observed were when glass and uPVC were

tested against the other substrates. From these results it was interpreted that uPVC may have a characteristic (chemical or physical) that either, some of the individual constituents had an affinity to and so were able to persist on the substrate more effectively or, the iron oxide particles had an affinity to enabling better quality development than on other substrates. These findings support those of Bacon *et al.* (2013), who reported that chemical variations within a substrate can affect the efficacy of a development technique. Operationally, plastics are commonly encountered surfaces and, with iron oxide particles being a dark coloured development technique, it is most suitable for application on light coloured plastics.

Although uPVC facilitated the best quality development, background staining was evident. Some constituent test spots developed with a good contrast against the background staining, (Figure 50 (a)), glucose appeared to show a void in colour where the test spot had been deposited. It was interpreted that this could be because the test spot had repelled the iron oxide particles or, the test spot had dissolved leaving a 'clear' void on the substrate. The glucose test spots on the other substrates appeared to have dissolved during the development process so, it was reasonable to interpret that this may also be the case on uPVC.

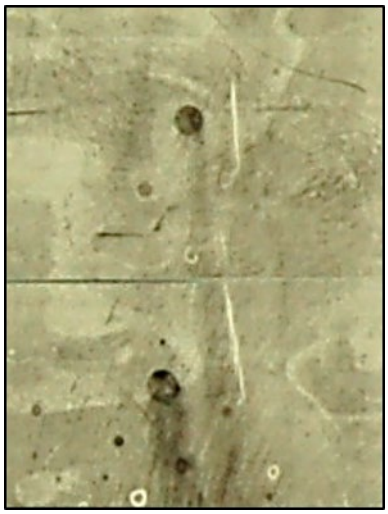
a)  b) 

Figure 50. a) Urea test spots on uPVC demonstrating where development is evident over the background staining, b) Glucose test spots on uPVC appearing to 'repel' the iron oxide WPS.

It was considered possible that individual constituents may interact with substrates and/or the iron oxide WPS in a different manner when isolated away from the complexed matrix of a natural fingermark. This may be a reason for the lack of development in this study; it was thought that without the combination of other residues and contaminants, most of the eccrine constituents that were tested would give little or no development. If iron oxide WPS is unable to develop eccrine residue effectively, it could be problematic to its operational applications as the hands secrete eccrine sweat and so, as literature suggests, would be in abundance in fingermark depositions. However, due to the ease and frequency of collecting contaminants on the hands (providing gloves are not worn), as literature suggests it is logical to think that it would be very uncommon for fingermarks found at a crime scene to be composed of only eccrine constituents. Therefore, whilst this study is a necessity to investigate what may cause the selective deposition of iron oxide WPS, the findings must be used in conjunction with the findings from studies on natural fingermarks.

The purpose of this phase 1 study was to investigate which (if any) constituents found in fingermark residue iron oxide WPS may have an affinity to. This knowledge was vital to corroborate towards a thorough understanding of the way the development technique works; however, as demonstrated by some of the large standard deviations (3.2.1, Figure 23) the method used in this part of the study did not produce consistent results making a definitive conclusion difficult. As the test spots were of individual constituents and not a mixture of components, it was interpreted that repeats of test spots of the same chemical composition on the same substrates would have developed with some consistency. This would have aided in giving a reasonable indication as to which constituent(s) iron oxide WPS may have an affinity to. Problematically, the inconsistency of development quality made it difficult to interpret the results. Therefore, adaptations were made to the method to further investigate what may be causing the selective deposition of iron oxide WPS.

4.2.2. Eccrine constituent test spots deposition, with the application of 3M Spray Mount™ as a fixing agent.

As the constituent test spots from the method discussed in 4.2.1 gave so little development, perhaps due to the water soluble constituents' inabilities to persist effectively on the substrate during development, the addition of a water insoluble coating was introduced. This study was designed as a preliminary method to investigate whether the addition of a water insoluble fixing agent would help to hold the water soluble constituents in place, aiding in better quality of development. The aim was to loosely imitate the water insoluble material found in fingermark residue, to aid the constituent's adherence to the surface during the development process. It was hoped that if this method was successful, the constituents that interact well with iron oxide WPS would be observed and, further understanding of the way iron oxide WPS interacts with fingermark residue would be obtained.

Visual observations showed that the application of the 3M Spray Mount™ appeared to have aided better quality development for some constituents. The specific chemical composition of 3M Spray Mount™ is unknown due to 'trade secrets' however, it is known to contain Acetone, Propane, Cyclohexane, Petroleum distillates, Hexane and, non-volatile components (3M, 2004). Perhaps due to its chemical composition, the 3M Spray Mount™ facilitated fairly heavy background staining as illustrated in Figure 28 in 3.2.2. Although background staining was evident, it was visually apparent where the test spots did develop and, it was thought that this was due to an interaction between the development technique and constituent, not the 3M Spray Mount™ alone. This was generally evidenced by a darker contrast between the developed test spots and the background. As with the participant fingermarks, it was thought that the darker contrast was as a result of more iron oxide particles depositing in those areas; suggesting that the iron oxide particles had an affinity for those constituents. There was little change in the shape or completeness of the developed spots from those discussed in 4.2.1; as the 3M Spray Mount™ was applied after the test spots were dry, it was interpreted that the improvement in development was due to the persistence of the constituents during the development process. The improvement in contrast for some constituents inferred that the

cause of interaction between iron oxide WPS and fingermark residue may be between the chemical constituents and the development technique. The results were the first encouraging suggestion towards the theory that if a constituent was able to persist on a substrate, it could interact with the iron oxide particles, enabling development.

Although consistency was maintained with the constituent solutions and the quantity of constituent deposited on the substrates, problematically, the method of applying the fixing agent was not as consistent. There was a lack of control available when applying the fixing agent due to the nature of aerosol dispersal when dispensed by a spray nozzle. The limitation was caused by the movement of the 3M Spray Mount™ can when pressure was applied to the nozzle (to create the spray) and the way the 3M Spray Mount™ was released from the can; the nozzle did not allow for a consistent, even coat, well angled spray each time. Problematically, this means that this method would not be entirely reproducible if the experiment were to be repeated. As literature suggests (Sears *et al.,* 2012), studies such as this are used to create a fundamental and basic understanding of a development technique. As such, they should be repeatable and reproducible, so that the observations made are based on samples that are consistent without the added complication of inter and intra person variation.

As a result of this method showing some positive indication that when the constituents were able to persist on a substrate they gave better quality development, the method was adapted further to simulate a sample more realistic to fingermark residue.

4.2.3. Eccrine constituents deposited as 'spiked' fingermarks.

Following on from the positive indication in 4.2.2 that, if a water insoluble component was applied to the water soluble constituents, it would aid in better quality development; a more realistic method of adhesion was considered to further investigate what causes the selective deposition of iron oxide WPS. The aim of this method for this study was to replicate the fatty lipids and contaminants that can be found in natural fingermarks and, are thought to aid the water soluble eccrine constituents to persist on the substrates. To achieve this, the eccrine constituents were fixed using the natural fingermark residue from a single participant as

detailed in 2.2.6. This method showed some promising results and may be a method to consider for recommendation for phase 1 studies where the cause of development interaction is necessary to understand; as far as a review of the literature shows, this method has not been used before in published works.

It must be noted that the analysis of the spiked fingermarks differed from the analysis of all other test spots or fingermarks within this report; the analysis focused on the contrast of developed marks giving an objective value as described in 2.2.7.2, rather than assigning a subjective grade. It was thought logical to assume that if a constituent mark visually appeared darker, there was perhaps more of the colouring agent, in this case, iron oxide particles deposited in the developed areas. It was thought that if a constituent mark had a higher contrast value and more iron oxide had selectively deposited on that mark, there must be a characteristic of the constituent or substrate that the iron oxide WPS had an affinity to. It was anticipated that this would then indicate what may be causing the selective deposition of iron oxide WPS.

All fingermarks spiked with an individual constituent were compared to controls of the participant's natural fingermarks and, fingermarks spiked with deionised water to ensure that the quality of development being displayed was not due to the quality of participant. The results in Figure 29 (3.2.3) illustrate that the natural fingermarks showed the lowest contrast values on four of substrates with deionised water fingermarks giving the lowest contrast values on three substrates (jointly with the natural fingermark on PVC). These results indicated that any improvement in quality of development in the spiked fingermarks when compared to the natural and deionised water fingermarks, was likely to be from the addition of the constituents. The only exception to the natural or deionised water fingermarks not giving the lowest average contrast grades was on glass; serine gave the lowest contrast value which will be discussed further later in this section.

ABS and uPVC gave the highest average contrast values overall, achieving values of almost double of more than the other substrates; indicating the darkest marks. As previously mentioned, due to the darker contrast, it was anticipated that more iron oxide deposited on

the marks on those substrates. Painted metal and PVC had some of the lowest contrast values, inferring lighter marks with less iron oxide adhering to the marks on those substrates. These observations were corroborated by the post hoc statistical analysis detailed in Table 11, 3.2.3.1. The vast difference in contrast values between substrates, strongly suggested that substrate type had an effect on quality of development.

The variation in mark contrast and presumed adherence of iron oxide particles suggests that the substrate type may have had an impact on the quality of development. As this study did not investigate the chemical or physical interactions taking place, it was unclear whether the quality of development was a result of an interaction taking place between the substrate and iron oxide particles, the substrate and constituent(s) or, constituent(s) and iron oxide particles; it was thought that perhaps a combination of all three interactions were having an impact on the quality of development. It has been widely reported that, substrate type can influence the way fingermark residue behaves post deposition (Bond, 2008a; Bobev, 1995; Bond, 2008b), some development techniques have an affinity to specific constituent (Ramotowski, 2013; Lee and Gaensslen, 2001) and, substrate type can affect the abilities of a development technique (Jones, Downham and Sears, 2009; Bacon *et al.*, 2013). So, it was reasonably logical to think that all of these influencing factors may have impacted the quality of development.

Glass was the only substrate where the deionised water fingermarks gave a higher average contrast value than any of the constituent marks. This perhaps indicates that the constituents do not interact with that surface, again indicating that substrate type does have an impact on what causes the selective deposition of iron oxide WPS. The apparent lack of interaction with the constituents may indicate why such poor development was observed on glass in the pilot 1 study discussed in 4.1.

This novel method led to new knowledge inferring that substrate type may have an effect on the quality of development with iron oxide WPS. This information could aid in the recommended use for the application of iron oxide WPS. This part of the research suggests that, in particular ABS and uPVC plastics facilitate development with good contrast, making visualisation of latent marks easier on those substrates. Although some substrates facilitated

better contrast (deposition of more iron oxide), it must be noted that constituent marks were visible on all substrates, inferring that iron oxide WPS should not be dismissed for use on any of the substrates used in this study. To enhance the quality of development for those substrates where poorer contrast was observed, iron oxide WPS could be used as a sequential technique as mentioned in 4.1 or, further research could be conducted in to the chemical and physical interactions that may be an underlying cause of the development quality.

Glucose gave the best average contrast value, and subsequent darkest marks (indicating more iron oxide) over all of the substrates. This result conflicted with those discussed in 4.2.1, where glucose showed very little development, potentially due to being dissolved during the development process. The vast improvement in development quality would suggest that the change in method facilitated the constituents' ability to persist on the surface during development enabling an interaction with the iron oxide particles; resulting in successful development. Figure 30 in 3.2.3 illustrates that the specific substrates where glucose had the highest contrast values above the other constituents were PE bag, PE sheet, uPVC and PVC. Due to the properties of the substrates, it was unclear which specific characteristic(s) of a substrate may be influencing the development. It was noted that PE bag and PE sheet have different physical characteristics; one being a rigid, reasonably thick board and, the other being a supple, thin carrier bag. Whereas, uPVC and PVC have slightly different chemical characteristics; uPVC being unplasticised and, PVC being plasticised. When looking at Table 13 in 3.2.3.1, as well as the above pairs having no significant difference in the contrast values for glucose, 10 additional pairs of substrates also had no significant difference. This suggests that although substrate type may have an influence on the quality of development, the correlation between what is causing selective deposition is unclear. The purpose of this study was to investigate what causes the selective deposition so, although a conclusion can be drawn from these findings to suggest this, an investigation into how the interaction may be occurring should be considered for further work.

Figure 30 in 3.2.3, illustrates the average contrast values of the constituents, removing substrate type as a variable. The results show that the 6 constituents all had average contrast values very similar to each other. Glucose had a marginally better average contrast value but,

the remaining 5 constituents all had very similar average values. This indicates that perhaps the type of constituent does not have a large effect on the cause of development and iron oxide WPS has an affinity to multiple constituents found in eccrine residue; this can be inferred for the constituents that are isolated from the matrix of a fingermark, not necessarily how the same constituents will behave when combined with other constituents or contaminants. This new knowledge is of benefit to the recommendations for operational use of iron oxide WPS as it suggests that some of the most abundant and commonly found constituents secreted from the pores on the fingers, all interact with iron oxide WPS. As literature suggests, fingermarks that are found at crime scenes may be highly likely to contain one or more of the constituents tested in this study (Ramotowski, 2001; Girod, Ramotowski and Weyermann, 2012; Kent, 2016). Operationally, this indicates that there is a possibility that a large portion of the population fingermarks should show some form of development with iron oxide WPS so, the development technique could have a wide application.

Statistical analysis in 3.2.3.1 testing each individual constituent over all of the substrates, showed that the areas of significant differences with large or medium effect sizes were not consistent between constituents. This indicates that different constituents behave differently on different substrates. As the method of deposition was kept as consistent as possible, the inconsistency in quality of development may be attributed to the change in substrate

The results in 3.2.3 showed that in general, each substrate had a different constituent with the highest contrast value. It was interpreted that this may have been due to the interaction between the constituent and substrate. It was thought that the interaction may have been chemical or physical however, the interactions were not assessed as part of this study; this study was to investigate what causes the selective deposition of iron oxide WPS.

Following development it became clear that grading the marks with a system such as that used throughout the rest of the study, would be ineffective. Although some fingermarks were ‘complete’ (criterion 1), it was apparent that ridge detail would be difficult to analyse because, the detail was lost perhaps due to the finger still being slightly wet when the marks were deposited on to the surface. Therefore, in some instances, depletions 1 and 2 showed no

friction ridge detail, whereas depletions 3 and 4 improved in ridge detail as the excess solution had diminished. So, as previously discussed, the samples for this study were analysed by assessing the contrast between the developed mark and background, as it was deemed important to understand which constituents were causing more iron oxide to selectively deposit. The method used in this study was similar to that by Matuszewski and Szafalowicz (2013), which also utilised a histogram function on easily accessibly computer software package.

Other contrast indexes have been used for the analysis of developed fingermarks, all generally with positive results in consistency and objectivity (Vanderwee *et al.,* 2011; Humphreys, 2007; Pulsifer *et al.,* 2013; Atherton, 2013). Vanderwee *et al.,* 2011 found that using a relative contrast index to assign quantitative values to a fingermark was effective in its objectivity and reproducibility. As with, Humphreys (2007), these methods require the specialist use of a spectrophotometer and, although this method produced promising results, the relevant equipment may not be accessible to all researchers.

The new knowledge generated from this study showed that substrate type can affect the quality of development and, indicated that six of the most abundant constituents found in eccrine residue cause iron oxide to selectively deposit lead to phase 2 studies. For operational purposes, this suggests that iron oxide WPS has the potential to develop fingermarks from a large portion of population however, caution should be exercised when choosing the development technique based on substrate type. It could be suggested that iron oxide WPS should be used sequentially on the substrates known to give poorer quality development to ensure that fingermarks are not missed.

4.3. The quality of developed participant fingermarks deposited on multiple substrates; phase 2 study.

The aim of this study was to further the knowledge gathered in the pilot study to gain a deeper understanding of the quality of development between iron oxide WPS and fingermark residue. This study was similar to 'phase 2' robustness and selectivity studies described in fingermark research literature (Sears *et al.*, 2012; IFRG, 2014). Phase 2 studies state that it is important to consider three main variables when constructing a study to analyse the fundamental workings of a development technique; variation in fingermark composition achieved through a variety of participants, a range of surfaces and a variation of the ages of fingermarks. To achieve this, 10 participants were used to deposit fingermarks on a variety of seven different substrates (4.3.2), which were then left to age for three different time periods (4.3.3). Natural fingermarks were used throughout this study as it is recommended that where new knowledge is being obtained, samples should be representative of operational work should be used. In addition, the effect of different sweat types has been explored (4.1.2).

The phase 2 study was used to build on the knowledge obtained from the phase 1/pilot study. This study generated a novel understanding of the way iron oxide WPS interacts with fingermarks on a variety of substrates over longer periods of time, demonstrating the selectivity of the technique.

4.3.1. The quality of fingermark development as a result of participant variation.

The pilot study discussed in 4.1 was to evaluate the quality of development with a variety of fingermarks, with the substrate type remaining constant to eliminate substrate interaction as a cause of quality variation. For this study, multiple substrates were introduced to analyse how iron oxide WPS developed fingermarks on different surfaces. Although the aim of this study was to investigate the effect different substrates had on the quality of development, it was also imperative to continue analysing the inter person variation over all of the substrates. This

was to continue investigating inter and intra person variation as an influence on the quality of developed fingermarks; not the surface interaction.

Similarly, to the findings discussed in 4.1.1, inter and intra person variation was observed in this study from both visual observations and statistical analysis. Figure 34 in 3.3.1 illustrates that half of the participants' average fingermark grades were below 10; less than half of the total marks available (total out of 20) and, half were above 10. The visual differences between participants were corroborated by the statistical analysis of fingermark grades which showed that, 36 out of 45 pairs of participants had a significant difference between their fingermark grades with medium or large effect sizes (3.3.1.1).

The lack of overlap between some of the participants standard deviation bars in Figure 34 (3.3.1) indicates that for the participants with lower grades, over the entire of this study, they were not able to achieve grades as high as some of the other participants. This suggests that iron oxide WPS may have an affinity to a characteristic(s) within a fingermark that can vary broadly between participants. Again, it was thought that this could be the chemical composition of a fingermark, the quantity of residue deposited, the distribution of residue along the friction ridges immediately prior to deposition or, a combination of more than one of these characteristics as described in (4.1.2).

The participants whose fingermarks were graded, on average below 10 often displayed a discontinuous, dotty ridge characteristics post development. Figure 51 gives an example of the quality of fingermarks often observed for the participants 02, 03, 05, 07 and 09 who scored, on average below 10. The results of this study corroborate the findings from the pilot study as discussed in 4.1.1 and 4.1.3. It was again interpreted that the quantity and distribution of sweat, particularly the eccrine secretions, were significant to the quality of development. As with the pilot study, it was thought that the participants with the discontinuous, dotty appearance to their developed fingermarks did not produce enough sweat to distribute the interacting constituents along the entire friction ridge area to give continuous ridge detail.

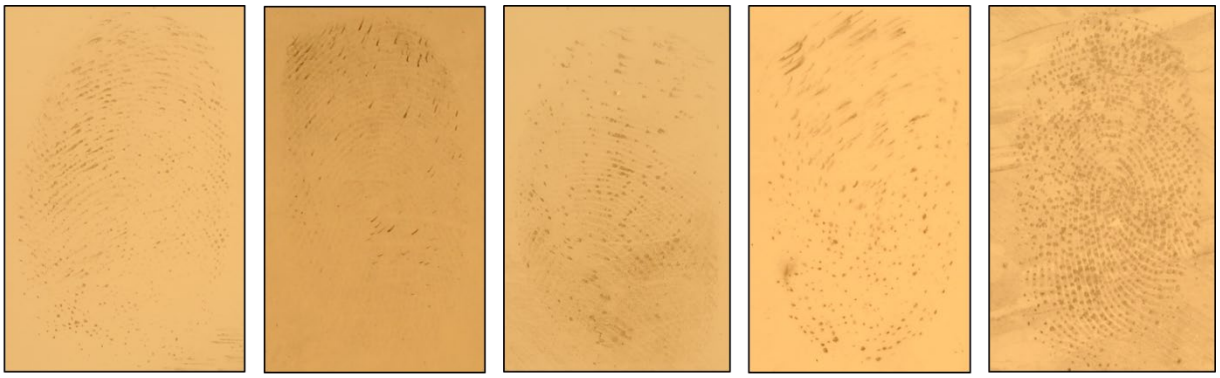


Figure 51. An example of developed fingermarks from the participants who, on average scored below 10.

The discontinuous ridge detail for these participants indicated that the iron oxide particles had deposited on the ridges but in localised areas, as was commonly observed with the eccrine rich fingermarks in the pilot study (4.1.2). It was anticipated that there was a property present in the latent fingermarks which the iron oxide particles had an affinity for but again, not distributed evenly over the fingermark. Due to the similarities between these fingermarks and the eccrine rich fingermarks (along with the results from 4.2), it was again thought that iron oxide WPS had an affinity to constituents found in eccrine residue. The interaction between eccrine constituents and fingermark development techniques is a common occurrence for chemical interaction techniques such as ninhydrin and superglue fuming (Almog, 2001; Almog, 2013; Lee and Gaensslen, 1984; Lewis, 2013). It has been well established that chemically interacting development techniques often interact with commonly encountered constituents such as amino acids (Ramotowski, 2013). Literature states that natural fingermarks contain a mixture of eccrine secretions, sebum and contaminants and, these fingermarks are the most likely to be encountered at crime scenes due to their nature. Although the most commonly encountered fingermarks contain a mixture of components, as the fingers secrete eccrine sweat, it would be logical to think that almost all, natural fingermarks (not specifically groomed) will contain eccrine constituents to some degree. Therefore, if iron oxide WPS is

similar to other chemical interaction techniques, and does interact with constituents found in eccrine residue, it will be beneficial in the uses of this technique to process fingermarks from crime scenes and items of evidence.

Again, intra person variation was evident throughout the study. The participants who on average were graded below 10 (Figure 51), on occasion were also able to provide better quality fingermarks. Figure 52 gives an example of the same participants but with improved quality of development. Based on literature and as reported in 4.1.3 it was thought that the intra person variation may be due to variation in the composition and quantity residue being deposited. This was particularly key in this study as the fingermarks being deposited were natural fingermarks. As previously described in 4.1.2 natural fingermarks are likely to encounter variation due to the contaminations collected during the day to day activities carried out by each participant prior to deposition and in between multiple depositions on one occasion. So, it was thought that, on the occasions where these participants achieved better quality development, their fingermarks had a larger quantity of residue present or, more or the interacting constituents present; perhaps as a result of the contaminants.

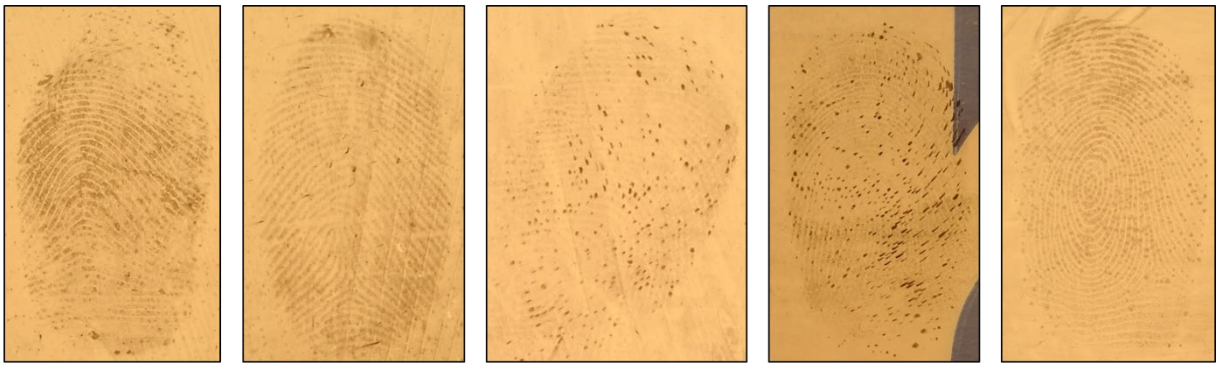


Figure 52. An example of fingermarks for participants 02, 03, 05, 07 and 09 with improved development quality.

It was interpreted that the improvement in development for the above participants may not only be as a result of inter and intra person variation but, may also but a result of other variables controlled within this study for example, the substrates and ageing periods. The effect these variables had on the quality of fingermarks will be discussed further in 4.3.2 and 4.3.3.

The 5 participants with fingermarks graded on average above 10, frequently displayed developed fingermarks with continuous ridge detail; as illustrated in Figure 53. The continuous ridge detail for these participants was the strongest indication that the quantity and distribution of residue impacted the quality of development. It was thought that the participants who deposited fingermarks that developed with continuous ridge detail secreted a larger quantity of sweat and/or, perhaps collected more contaminants. It was anticipated that the larger the quantity of sweat present on the friction ridges, the further the residue would spread resulting in a more even distribution of eccrine constituents across the friction ridges. Problematically, as described in 4.1.2 the quantity of residue deposited was not analysed however, from the visual analysis it was logical to think that there was a more even distribution of interacting constituents being deposited for these participants, than those who gave discontinuous ridge detail.

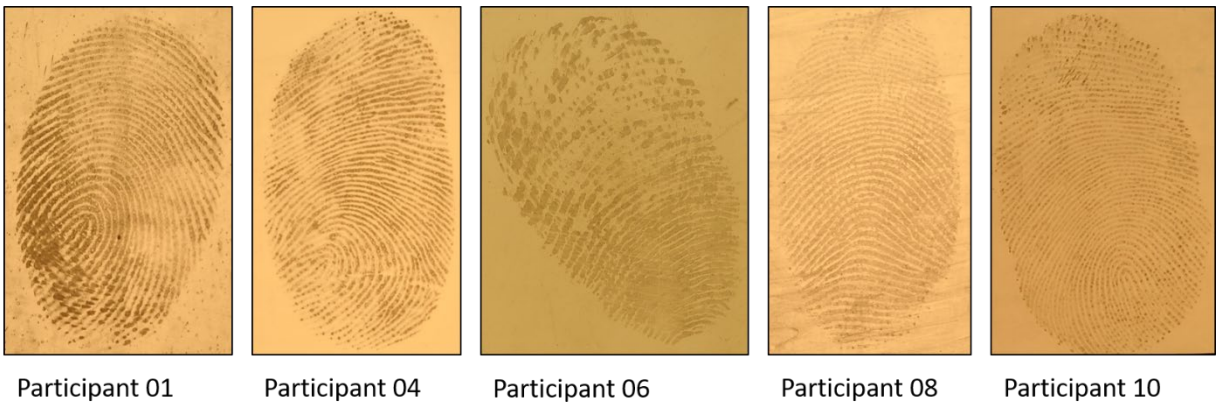


Figure 53. An example of developed fingermarks from the participants who, on average scored above 10.

Overall, the quality of development observed as a possible result of inter and intra person variation demonstrated that iron oxide WPS is successfully able to develop fingermarks from a range of participants. During this study, only 4 out of the 10 participants had a modal grade of 0, with all other participants achieving modal values of 8 or above. This could suggest that iron oxide WPS has a reasonably high rate of development success as, 60% of the participants showed development on the majority of occasions. However, this original knowledge also reinforces the need for sequential processing, as there is still the potential for fingermarks to be missed as a result of no development with iron oxide WPS, if the fingermark does not contain the interacting properties.

The difference between participants demonstrates that without purposefully selecting good, average and poor donors, a range of donor quality was still obtained due to natural variation. Literature recommends donors of varying abilities, poor, average and good or, light, medium and heavy should be obtained for phase 2 studies (IFRG, 2014; Sears *et al*., 2012). Although this method is widely recommended and very often used in fingermark research, it was not used for this study as, it was deemed vital to obtain original knowledge on how iron oxide WPS developed latent fingermark representative of operational marks was key. The decision not to select participants based on the quality of their fingermarks was justified by the intra person variability found in the pilot study (4.1.3). These results indicated that participant quality can vary from day to day, making it challenging to select participants that would be consistently good, average or poor. The variation found in participant quality both inter and intra personally from this study and the pilot study, suggest that the methods frequently published (IFRG, 2014; Sears *et al.,* 2012), and used in fingermark research may not always have the desired effect in controlling the variables. Very little research has been carried out in to the effectiveness or necessity of these methods. Throughout this study and the pilot study the methods used, and variables controlled were very stringent and yet, there was still a vast amount of variation observed in the quality of development between participants. The findings from the study suggest that the recommended processes may not always be useful and, subsequently highlights that more research on fingermark research methods is necessary.

A difference between male and female participants was apparent from the visual analysis of the developed fingermarks. Four of the 5 male participants in this study deposited fingermarks which were on average, graded above 10 giving higher quality development than 4 of the female participants (section 3.3.1, Figure 34). The visual differences were supported by the results of the statistical analysis, showing a significant difference between male and female fingermark grades with a medium effect size (3.3.1). These results indicated that there may be one or more characteristics in a latent fingermark which differs between male and female participants; leading to the difference in development quality. As mentioned in 4.1.1, the only female participant to achieve an average grade above 10, was the only participant of a different race. This may have been an influencing factor on that female participant achieving higher grades however, due to the limited sample of participants from a range of races, this conclusion could not be further investigated.

Previous research gives conflicting conclusions on whether sex can affect the composition of a fingermark (Cadd *et al.*, 2015; Frick, Fritz and Lewis, 2016). Some studies reported that a difference in composition between male and female fingermarks can be detected but very often have either a small sample size such as, Huynh *et al.* (2015) where just 6 participants were used or, show no statistically significant difference (Croxton *et al.,* 2010; Fritz *et al.*, 2013). For those studies which tested slightly larger samples (20 participants), conflicting results were found, perhaps due to the method of analysis (De Puit *et al.*, 2013; Asano, 2002). Penn *et al.* (2007) reported that a difference could be detected between male and female samples analysed in their study however the results were multivariate; meaning that no one compound or set of compounds were found to be different between the two sexes on every occasion. Very few large-scale studies have been conducted in this area of research, so it is a necessity to the improvement of fingermark research for the cause of differences between male and female fingermarks to be explored further. As this study had a relatively small sample size to analyse the difference between male and female participants, it was conceivable that the difference observed was due to the sample size; for a more robust result, further work would need to be undertaken.

As literature suggests that there are limited differences in the chemical composition of fingermarks between male and female participants, it was considered that a physical difference the fingermark composition may impact on the variation observed. Multiple pieces of literature testing a variety of nationalities, all found females to have higher ridge density/narrower ridges than male participants (Gutiérrez-Redomero *et al.*, 2013; Soanboon, Nanakorn and Kutanan, 2016; Acree, 1999; Krishan, Kanchan and Ngangom, 2013). Additionally, Nagesh, Bathwal and Ashoka (2011) found that on average, female participants had a higher number of pores per centimeter along the friction ridges however, this proved to not be a statistically significant difference. It could be perceived that under these circumstances, female participants may be able to produce better ridge continuity with iron oxide WPS, than the male participants however, this was not evident. Therefore, it was thought that the quantity of sweat had a large impact on the quality of development.

As with the pilot study, a depletion series was used in this study to investigate the sensitivity of iron oxide WPS with a larger sample size. It was anticipated that the quality of development and sensitivity of the development technique was to do with the quantity of residue present prior to deposition and perhaps, force applied to surface on deposition. It was interpreted that the participants who were graded on average below 10, produced a lower quantity of residue than the participants who were graded on average above 10. Figure 54 illustrates the 1st, 5th and 10th fingermarks in a depletion series for a participant who, on average, was graded below 10 and, Figure 55 shows the same for a participant who, on average, was graded above 10. From the quality of development displayed in Figure 54 it is evident that the quantity of residue diminished on each consecutive touch, resulting in decreasing fingermark quality and consequently fingermark grade. Positively, these results demonstrate iron oxide WPS's sensitivity as it was able to develop marks of a diminished quality for a participant whose modal grade was 0. Adversely, Figure 55 illustrates that fingermark residue does not diminish on each consecutive touch for all participants. For those participants who were graded on average above 10, it was thought that they deposited larger quantities of residue, aiding in the ability to deposit fingermarks with unwavering quality overall multiple depletions. The fingermarks in Figure 55 were all graded 18, demonstrating the consistency in quality over 10 depletions.

Figure 54. Left to right; The 1st, 5th and 10th fingermarks in a depletion series for a participant whose average grade was below 10.

Figure 55. Left to right; The 1st, 5th and 10th fingermarks in a depletion series for a participant whose average grade was above 10.

This contribution to knowledge demonstrates the sensitivity of iron oxide WPS when the interacting characteristics of a fingermark are present; justifying the recommendation for its use in the Fingermark Visualisation Manual (Centre for Applied Science and Technology, 2014). None the less, it must still be emphasised that the selective nature of iron oxide WPS means that it would be beneficial for it to remain in the sequential development processing chart alongside other, less selective techniques. As discussed in 4.1.4 it is likely that fingermarks of varying quantities will be found at crime scenes and on items of evidence.

To investigate the distribution of sweat as an influencing factor on the quality of development, a small study was carried out. The distal portion of each participant's index finger was wetted with a 20 µL drop of deionised water. The droplet of water was rubbed between the two index fingers until dry. Each participant then deposited a depletion series of 10 consecutive fingermarks with each of the two fingers, as described in (2.3.6) with controls being taken from a non-wetted finger. The same method as in section 2.3.6 was used to age and develop the marks.

From visual analysis, it appeared that the addition of water/moisture to the friction ridges aided in the distribution of interacting secretions along the ridges, resulting in a more 'complete' developed fingermark for all participants, especially those who usually had discontinuous ridge detail. The results observed aided in corroborating the knowledge that the distribution of interacting constituents prior to development have an impact on iron oxide WPS's ability to provide good quality development of a fingermark. Again, these results suggest that iron oxide WPS is very selective in the interacting characteristics it requires to develop a latent fingermark.

For this study, deposition was not controlled; this decision came as a result from observations made during the pilot study. The deposition method was controlled in the pilot study yet, as described in 4.1.1, inter person variation was still apparent; suggesting that variation between participants would still occur whether the force at which a finger touches the substrate was controlled or not. Therefore, as it appeared that controlling the deposition did not eliminate variation and as the purpose of a phase 2 study is to observe the development technique with samples representative of operational work, it was decided that deposition would not be controlled. Problematically, during deposition, some participants were observed using excessive force when depositing their fingermarks. This resulted in some fingermarks displaying little or no ridge detail, scoring low in criteria 2 of the grading system. Figure 56 demonstrates developed fingermarks from participant 08 who often had a heavy deposition. Participant 08 repeatedly deposited fingermarks that developed in this way, distorting the ridge detail. It was interpreted that these characteristics were due to deposition pressure and

not as a result of a fingermark characteristic as the same participant was able to deposit fingermarks with the same fingers which displayed excellent ridge detail.

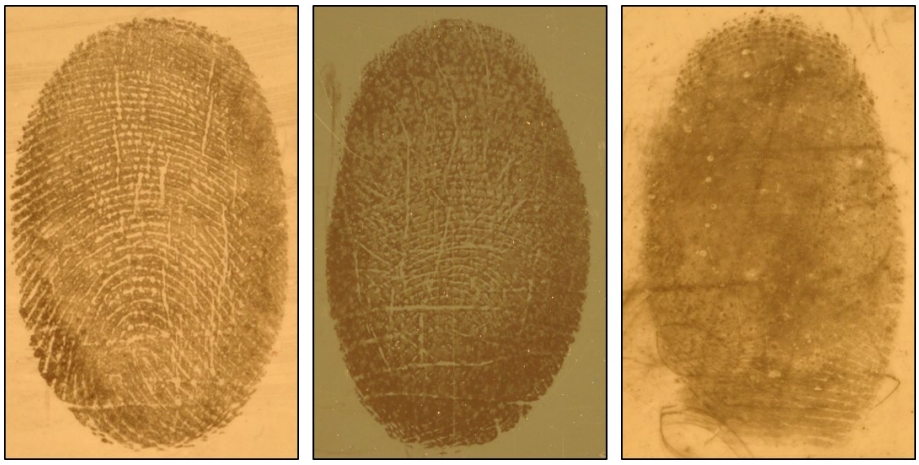


Figure 56. An illustration of consistent excessive force applied during deposition by an individual participant.

Many grading systems used in fingermark research tend to grade fingermarks based on the ability to identify the developed mark (Sears *et a*l., 2012; Maslanka, 2016; Castello, Frances, Verdu, 2013; IFRG, 2014). Using grading systems such as these, fingermarks similar to those in Figure 35 would have been graded poorly due to limited or no identifiable ridge detail. Grading systems such as those, tend to inadvertently assess a developed fingermark on the quality of the deposited mark not necessarily the quality of the development technique; this can skew the impression of the abilities of a development technique as, if a fingermark has been poorly deposited, identifiable ridge detail will never be visible regardless of the technique applied. For this reason, it was deemed important to grade the developed fingermarks in this study on more factors than simply if a fingermark was identifiable or not, as the aim of this study was to investigate what causes the selective deposition of iron oxide WPS, not if it can produce an identifiable fingermark on every occasion. The grading system used for this study (as described in 2.3.5) allowed different qualities of a developed fingermark to be analysed, meaning that marks such as those in Figure 56 were still significant to the study regardless of whether there was sufficient ridge detail. Fingermarks such as the right-side mark in Figure 56 indicated that

the deposited mark had insufficient ridge detail for identification, perhaps due to the method of deposition (criterion 2 and 3). Yet, it indicated that there were characteristics present that iron oxide WPS had an affinity to (criterion 4) and, that those characteristics were distributed over the entirety of the distal portion of the finger upon deposition (criterion 1). This was vital to the study as it indicated the characteristic(s) causing the selective deposition was present and that iron oxide WPS was sensitive enough to develop marks of an otherwise 'poor quality'.

Although the grading system chosen appeared to work effectively in aiding the analysis of what may influence the quality of development, there were on some occasions, concern for its effectiveness. On some occasions (for example) fingermarks were being graded 12 and were of a quality that could be identified, yet poor contrast brought the grade down. Whereas, some fingermarks were also being graded a 12 yet were not identifiable but were being graded equally, due to higher contrast grades. However, due to the ability of being able to assess the individual criterion achieving the total grades, it was deemed beneficial as it was possible to establish which criterion were contributing to the overall grade of each fingermark. It was advantageous to this study, as interpreting the basic understanding of what was causing the selective deposition was more possible with the type of grading system.

The findings from this study were essential to create the fundamental understanding of what causes the selective deposition of iron oxide WPS or, what may influence the quality of development; hence the decision for the aforementioned grading system. Problematically, as literature suggests, most forms of grading are subjective; thus, the conclusion drawn from results, in particular statistical analysis, has the potential for being misinformed (Fritz *et al.,* 2015). To ensure that all fingermarks were being graded to a consistent standard, one full set of 30 developed fingermarks on each substrate were chosen at random and graded for a second time. The results of the original grades and re-graded fingermarks can be found in appendix 1. This repeat was carried out 6 months after the initial grading took place. Additionally, the grader of the fingermarks took part in a grading proficiency test as detailed and designed by Fieldhouse and Gwinnett (2016).

Due to the deposition method being uncontrolled, a slight limitation that was observed during this study was participant dexterity. Some participants struggled to deposit fingermarks in the desired format with all 10 digits. Figure 57 illustrates the expected surface area compared to a fingermark deposited by a participant who was not able to deposit the full desired area of fingermark. All 10 fingers were used for deposition due to how many marks were required, yet some participants struggled to get the whole distal portion of their thumb or little finger flat to the surface.

Figure 57. Illustrates the area of fingermark (graded 12 out of 20) deposited compared to the area of fingermark that was expected.

This observation particularly affected the grade of a fingermark for criterion 1; the expected area of a whole fingermark. Where participants did not deposit a 'whole' fingermark as a result of the angle of deposition, they were being graded lower than participants who did deposit a more complete area of fingermark. The lower grade made it appear that those participants had less of the desirable/interacting characteristics in their fingermark depositions, whereas in fact, they were simply not depositing a complete fingermark. It is commonly understood that not all fingermarks recovered from a crime scene or items of evidence will be perfectly 'whole' with sufficient ridge detail for identification. Fingermarks such as the one illustrated in Figure 57 were unintentionally, representative of fingermarks that may be encountered in operational work. The presence of the interacting characteristics was evident by the quality of the mark that had developed on the surface, positively, these results demonstrate that,

providing the participant has the interacting characteristic present, iron oxide WPS is sensitive enough to develop partial marks. Problematically, therefore, the results also suggest that perhaps the grading system used was not the most appropriate for assessing the quality of development.

Further, to the findings from the pilot study (4.1), the inter person variation between all 10 participants observed in the phase 2 study, contributed to the knowledge that iron oxide WPS has a very selective nature in the characteristics it requires to develop a fingermark. The selective nature of iron oxide WPS suggests that some participants have an abundance of the characteristics that the iron oxide particles have an affinity for, which other participants did not or, have in a lesser quantity. Operationally, this means that iron oxide WPS is not guaranteed to develop all fingermarks, potentially resulting in evidence being unnoticed if it is used an independent development technique. The novel findings from this study corroborate the recommendations to use iron oxide WPS as a sequential process alongside other development techniques.

4.3.2. Substrate effect on quality of development.

The aim of this part of the study was to investigate the effect substrate type may have on the quality of fingermark development with iron oxide WPS. This is an original contribution to knowledge as, no other study has observed the quality of development with iron oxide WPS for a range of fingermark compositions on multiple substrates to this extent.

As literature suggests, the substrates chosen in a phase 2 trial should be representative of surfaces that may be encountered in operational work in instances where the development technique may be applied (IFRG, 2014; Sears *et al.*, 2012). As iron oxide WPS is an aqueous development process, it is suggested for use on non-porous and semi-porous substrates (Centre for Applied Science and Technology, 2014). Again, due to its aqueous nature, iron oxide WPS is also recommended for application on items that are or have been wetted (Centre for Applied Science and Technology, 2014). This gives iron oxide WPS the potential to be a widely used development technique for items recovered from outdoor crimes scenes which

may have been exposed to rain water and, items of evidence recovered from water sources. Due to the WPS's potential, the substrates used in this study were selected for their common uses and likelihood of being encountered at crime scenes both indoor and outdoor and, items of evidence.

Table 28 gives examples of some of the applications for each substrate used in this study.

Table 28. An example of scenarios where the substrates used in this study may be encountered at a scene of crime.

Substrate	Indoor crime scenes	Outdoor crime scenes	Items of evidence
PVC	Flooring, kitchen fittings	Building fixtures such as pipe work	Credit cards, 'cling film', children's toys
uPVC	Window and door fittings		-
ABS	Vehicle components (glove compartments, door panels), shower components (shower heads)	Vehicle components (bumpers)	Mobile phone/tablet casing, computer key boards, luggage, children's toys
PE sheet (High density)	Swimming pool installation, occasionally chairs and tables	Water crafts, water/drainage pipes, storage sheds	Plastic bottles
PE bag (High density)	-	-	Retail 'carrier' bags, occasionally food storage bags
Glass	Windows (buildings/vehicles)		Mobile phone/tablet screens, drinks bottles and glasses
Painted metal	Kitchen appliances	Vehicles	Casing for mobile phones/tablets

When observing the developed fingermark grades over the various substrates on the box and whisker chart (Figure 40, in 3.3.2), PE bag, ABS and uPVC gave the highest median values and highest upper quartile grades. This initially indicated that these substrates may have a characteristic that the latent fingermarks and/or iron oxide WPS had an affinity to, resulting in

better quality development than the other substrates. Similarly to intra person variation, there was a large range of grades achieved for each substrate, illustrated by the box and whisker chart (Figure 40 in 3.3.2). It was interpreted that the range of fingermark grades on all substrates indicated that the substrate type may not have had a substantial impact on the quality of development. The overlap in fingermark grades achieved, when comparing substrates indicated that it was possible for fingermarks on some substrates to achieve grades as high or as low as on other substrates; showing no distinct difference between some.

The results shown in Figure 41 (3.3.2), suggested that the substrate type could not guarantee good quality (above 10) fingermarks for every participant; the difference in the fingermark grades appeared to be relative to the quality of each participant, not necessarily the substrate the fingermarks were deposited on. Although the overall quality of fingermarks appeared to be dependent on the quality of participant, it was apparent that (in general) PE bag, ABS, uPVC and PE sheet enabled the highest quality development for all 10 of the participants. PVC tended not to produce the same quality as the other plastic substrates, however this was not a consistent observation for all participants. The order of substrates per participant, based on the highest fingermark grade achieved was not consistent between participants (Figure 41 (3.3.2). The only consistent pattern observed, was painted metal achieving the lowest fingermark grade for all 10 participants. From this inconsistency, it was interpreted that even if the substrate type had an effect on the quality of development, it was also largely dependent on the characteristics of the fingermark present on the surface.

The statistical analysis (3.3.2.1) showed that the only substrate to have significant differences with large effect sizes was painted metal; the substrate that obtained the lowest median fingermark grade (Figure 40, 3.3.2). The large effect sizes were seen when painted metal was tested against ABS, PE bag and uPVC; the substrates that obtained the highest median fingermark grade. As detailed in 3.3.2.1, all of the other substrates had some significant differences when tested against other substrates but either with small or medium effect sizes. It was interpreted that the differences in fingermark grades and subsequent quality of developed fingermarks, as a result of the difference in substrates could be an influence from either a chemical or physical characteristic of the substrates.

It was thought that the fingermarks on painted metal may have been of a lower quality due to the characteristics of the substrate and how it interacts with fingermark residue. Literature suggests that fingermark residue can chemically interact with some substrates. Bond (2008 a and b), found that it was possible for metal to corrode due to the salts/chloride present in fingermark residue.

Problematically, painted metal was the only substrate that was obtained from an operational environment. The samples were taken from a used car bonnet, which had been exposed to unmonitored outside weather conditions and, cleaning processes and products. During development, this substrate retained iron oxide particles on the surface in areas surrounding the fingermarks, resulting in background staining. Therefore, the participants who (as previously described), perhaps deposit less residue frequently resulting in poor contrast, were often not as visible on painted metal. Whereas, those participants who (as previously described), perhaps deposit a larger quantity of residue resulting in good contrast, were clearly visible on painted metal, even where background staining was evident. Figure 58 gives an example of a fingermark that was hardly visible due to back ground staining and, a fingermark that was clearly visible even with background staining. It was thought that the heavy background staining on the painted metal was a result of contaminants that had remained on the surface even after the cleaning process. The results of this study imply that for future studies, consideration should be made on how substrates are obtained; it would be recommended that all samples used in the same phase of a study are new/unused or, operational/weathered samples.

Figure 58. Left to right; fingermarks developed on painted metal showing poor contrast due to background staining and excellent contrast over the background staining.

Additionally to the painted metal samples displaying background staining, the PVC and uPVC samples also encountered background staining. Figure 59 illustrate the background staining frequently observed on uPVC (top) and PVC (bottom). Unlike the painted metal samples, both PVC and uPVC were new, unused and washed prior to fingermark deposition (2.2.2), so it was thought that any background staining should not be from contaminants like those on painted metal. Both PVC and uPVC had a protective film covering the surface when purchased; this was removed prior to the washing process. The background staining, particularly that on the uPVC samples appeared to form striation patterns that seemed to correspond with the manner in which the protective film was removed; similar to the way that JLar fingerprint lifting tape becomes distorted if it is not pulled from the roll in a smooth motion. It was initially thought that the pattern may be due to the protective film leaving behind adhesive residue on the surface prior to the cleaning process. However, after testing this theory by removing the film in a different manner, the striations still appeared (post development) in a similar format to the original samples. It was thought that the storage environment and length of time the film remains on the surface of the plastic, post manufacturing, prior to its end use, effected the amount of background staining. All samples produced for this study were created in a laboratory environment, using new substrates (except for painted metal as previously

described). Verbal communications with crime scene investigators suggest that WPS's develop fingermarks on uPVC with reasonably little background staining so, it was thought that weathering the substrates over time may reduce the effect of the protective film.

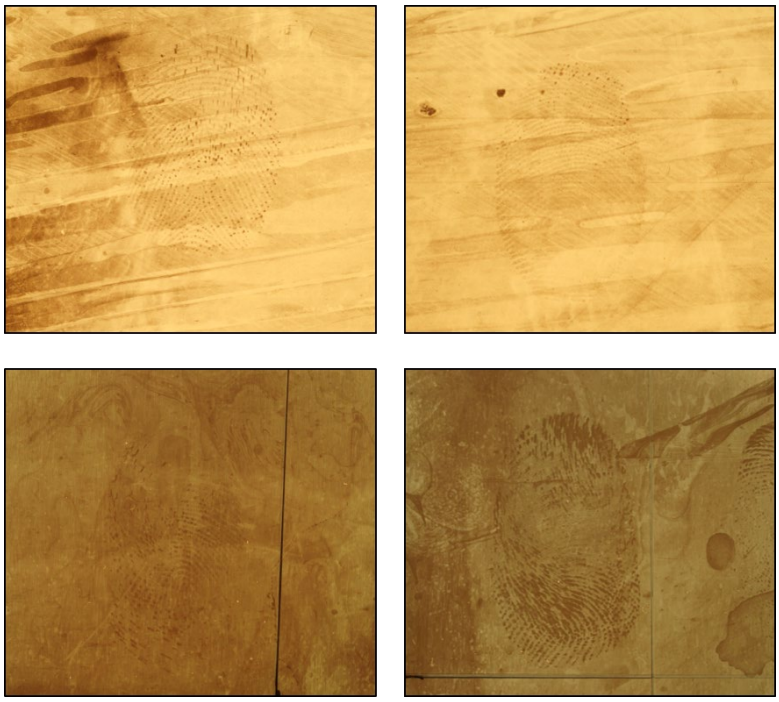


Figure 59. An example of the background staining frequently observed on uPVC (top) and, PVC (bottom).

Alternatively, it was also thought that the background staining on uPVC and PVC could be an effect from a physical characteristic of the plastic. It is possible that the way the plastics are produced, leaves a physical distortion/pattern in the topography of the surface, which then has an effect on the selective deposition of iron oxide particles. Jones, Downham and Sears (2009) carried out a study investigating the effect surface topography may have on the quality of development of latent fingermarks when developed with iron oxide WPS. The study analysed natural fingermarks from 2 participants on uPVC, PE and, formica. The results from this study showed that the quality of development on PE was not affected by any major topographical variations in the substrate. However, on the same substrate, minor topographical changes in the direction of striations affected development and resulted in

background staining. The quality of development on uPVC showed that again, major topographical variations such as 'pits' did not affect development quality but, linear marks could cause some disruption in development. The study by Jones, Downham and Sears (2009) was a small study (two participants) but, overall proposes that the surface type can have a small effect on the quality of development with iron oxide WPS.

Jones, Downham and Sears (2009) found that major topographical characteristics did not appear to affect the interaction of iron oxide WPS; the findings from this study would appear to suggest the same. The statistical analysis from this study showed that there was a difference between the fingermark grades from the PE bag and PE sheet but only with a small effect size. (Field, 2018; Gray and Kinnear, 2012) suggest that a significant difference with a small effect size is negligible in the impact that difference has. As the two substrates were made from the same plastic, but with different physical characteristics, it was thought that perhaps physical properties do not have a major impact on the interaction with iron oxide WPS. It was anticipated that the quality of interaction may be more effected by the chemical characteristics of the substrates.

It was also considered that the difference in quality of developed fingermarks may be a result of chemical interactions between the iron oxide particles and substrates. Additives such as stabilisers, plasticisers, colourants and, fillers are often introduced into plastics before being processed into an object. For example, titanium dioxide particles are often added to plastics to give a white colouring. It has been reported that particles found within fingermark development techniques, such as the carbon particles in carbon based WPS, can interact with the titanium dioxide particles giving development of a fingermark and background staining (Bacon *et al.*, 2013). This may have been a similar instance with the background staining observed on some of the substrates in this study, particularly the white coloured uPVC. If a chemical interaction such as this was occurring, it is plausible that it occurred on all substrates and the quality of fingermark development was depended on the chemicals present in each substrate. This may indicate why 4 of the plastics, ABS, PE bag, PE sheet and uPVC tended to show better development (higher fingermark grades) than glass, PVC and painted metal. It may

be that ABS, PE bag, PE sheet and uPVC have similar chemical properties, resulting in similar development qualities, generally better than the remaining substrates.

In this study, glass gave some of the lowest fingermark grades (3.3.2), jointly with PVC. The generally poor-quality results from the glass samples were similar to those obtained in the pilot study. Between the two studies there was a slight variation in the glass samples used; in the pilot study glass microscope slides were used whereas, in this study glass window panes were used. It was considered that as the two types of glass have different purposes, they may have had slightly different chemical and physical characteristics however, both types of glass generally showed poor quality development. This suggested (like PE bag and PE sheet), if there were any differences in the two types of glass (chemically or physically), the differences did not have a major impact on the interaction with iron oxide WPS; it suggests that the fundamental characteristics of glass, had the overarching effect on the quality of development.

As the quality of fingermarks on glass from both studies were poor compared other substrates, it may suggest that the recommendations of using glass as the initial substrate for a phase one study on non-porous surfaces should be reconsidered. As described in 4.1.4, literature often suggests that glass should be used as the primary substrate when researching a new or relatively unknown development techniques as, it is a commonly encountered non-porous surface, generally with a uniform appearance so the visual appearance of a background does not interfere with the assessment of the quality of development (IFRG, 2014, Sears *et al,* 2012). However, the results from the phase 1 and phase 2 studies discussed in this report suggest that this widely accepted method in fingermark research should perhaps be reviewed. As previously described, glass gave fairly poor results with iron oxide WPS overall so, especially in the pilot study, perhaps gave a false impression of iron oxide WPS's ability to develop latent fingermarks. Whereas, fingermarks developed with iron oxide WPS on different substrates showed significantly better quality development. Therefore, perhaps consideration should be made earlier on in fingermark research as to which substrate is used for phase 1 studies. In this instance it may have been more beneficial to use a plastic such as ABS, uPVC or PE for the phase 1 study. The fact that an alternative substrate was not considered for the pilot study

indicates why it is imperative to ensure further studies, such as phase two and operational trials are exercised, as phase 1 studies may lead to false-negative findings.

Although varying qualities of development were observed over the seven different substrates, no substrate gave such significant background staining or poor development for all participants that no fingermarks were visible at all; as with 4.2.3, it was clear that some substrates enabled better quality development than others, but all surfaces showed development. For operational purposes as a result of this study, it could be recommended that WPS works with a better quality on plastic substrates (in particular those that were tested in this study) over glass or painted metal. It could be recommended that alternative development techniques are applied on glass and painted metal to ensure that the most fingermarks possible are recovered. However, iron oxide WPS should not be entirely dismissed as a development technique for these substrates as both still enabled good quality development for some participants. These findings suggest that perhaps iron oxide WPS as a sequential treatment would ensure the most successful development and recovery of fingermarks.

The knowledge generated from this study, in particular the statistical analysis (3.3.2.1), suggests that the quality of development can vary between substrates however, the chemical and physical interactions taking place were not investigated. Additional research similar to Jones, Downham and Sears (2009) topographical study could be carried out to investigate the physical interactions and, to enhance the foundation of knowledge that this study has created.

It was deemed imperative to start with phase 1 and phase 2 studies, gradually introducing and monitoring different variables to build the fundamental understanding of what may cause the selective deposition of iron oxide WPS, as so little was unknown about this development technique prior to this study. Throughout this study all samples were kept dry prior to development to build an initial foundation of knowledge observing the quality of development of latent fingermarks, on different substrates without the added influencing factor of wetting the substrates. Literature suggests that the addition of water can affect the persistence of fingermarks and subsequent quality of development (Goldstone, Francis and Gardner, 2015; Trapecar, 2012). Therefore, the addition of wet or wetted samples in this study would have

hindered ability to build a fundamental understanding of iron oxide WPS, as it would have been unclear whether the quality of development was affected by the fingermark composition, the substrate type, ageing period or addition of water. This study is an original contribution to knowledge as it gives an understanding of the quality of development of latent fingermarks using iron oxide WPS on a variety of dry substrates.

In addition, it was also considered that a large number of items which may be treated with WPS's could be dry. The sequential treatment chart in the Fingermark Visualisation Manual (Centre for Applied Science and Technology, 2014) recommends the use of WPS as an alternative technique to superglue fuming. There is no suggestion on which technique to use preferentially over the other; each technique is reported to have its benefits and should be considered dependent upon the scenario surrounding the item to be processed for fingermarks; a benefit of WPS's is the ability to apply the technique to wetted items. However, as this is only a benefit of the technique and not a sole use recommendation, the sequential development chart implies that WPS can also be used on dry items. Furthermore, WPS can be a very messy technique upon application and as a result, has limitations to its application at crime scenes. Therefore, it may not always be appropriate to use the technique at a crime scene but, in some instances WPS may be deemed to be the most appropriate technique to use on an item of evidence due to it being wet or wetted. If this is the case and a wet item of evidence is packaged, transported and stored before being treated with WPS, the item may have dried in transit, again, confirming the need to understand the quality of development of iron oxide WPS on dry samples. Currently there is no significant information on what causes the selective deposition of iron oxide WPS and the quality of developed fingermarks on dry substrates. If this knowledge continued to remain minimal, practitioners may be reluctant to use the technique as it would be unclear whether the technique is able to develop fingermarks on dry items of evidence; this study goes a significant way to filling that gap in knowledge.

It has been reported that WPS is capable of developing fingermarks from contaminated items from fire scenes (Gardner, Cordingley and Francis, 2016) or, drugs paraphernalia (Centre for Applied Science and Technology, 2014) again, these are likely to be dry.

4.3.3. The effect of ageing on the quality of developed fingermarks.

As discussed in 4.1.4, the statistical results for the pilot study indicated that ageing fingermarks short term (up to 1 week) did not appear to have an impact on the quality of development when using iron oxide WPS. Literature detailing recommendations for fingermark research methods suggest, to analyse the quality of a development technique over different ageing periods, a broader range of times should be used (IFRG, 2014; Sears *et al.,* 2012; Kent, 2010). Taking the pilot study results and fingermark research recommendations into consideration, it was decided that the ageing time periods for the phase 2 study would be, within 24 hours, 2 weeks and, 4 weeks. A study of the quality of fingermarks developed with iron oxide WPS over these time periods has not been conducted prior to this; resulting in an original contribution to knowledge.

Visual analysis seemed to suggest that there was an improvement in fingermark quality over time. However, the statistical analysis results in 3.3.3 indicated that although there was a significant difference between the fingermark grades from 24 hours to 2 and, 24 hours to 4 weeks however, with only a small effect size. There was no difference between the fingermark grades for 2 weeks and 4 weeks. This result inferred that perhaps the age of a fingermark (up to 4 weeks) does not have a larger impact on the quality of development. Figure 60 illustrates the 1st deposition fingermarks on glass for 1 participant over the three time periods. It can be seen that there was no significant change in the quality of development, suggesting that perhaps the characteristic(s) that iron oxide WPS has an affinity to, does not change vastly from initial deposition up to 4 weeks old.

Figure 60. An example of a participant's 1st depletion on glass; (left to right) developed after 24 hours, 2 weeks, 4 weeks.

It is thought that there are two stages to the composition of fingermark residue; the initial composition immediately following deposition and, the aged composition which may change over different lengths of time. Various studies suggest that time affects the composition of fingermark residue although usually, with varying results (Girod *et al.,* 2015; Archer *et al.*, 2005; Dikshitulu *et al.,* 1986). It was anticipated that if iron oxide WPS was affected by the changes in fingermark composition, the quality of development would have changed more significantly over the three time periods.

Mong (1999 (cited in Cadd *et al.,* 2015)) suggests that the loss of water content through ageing may hinder chemical development techniques as the changes in fingermark can decrease the surface area available for development. It could be suggested that this may be a cause of the poor ridge continuity observed for some participants in this study. However, if this were true, it was anticipated that the discontinuous ridge detail would be apparent across all participants. The continuous ridge detail observed for some participants even up to 4 weeks old, may indicate that the interaction taking place is not a chemical reaction.

From these results it was interpreted that the characteristic(s) that iron oxide WPS had an affinity to, appeared to not alter vastly from deposition to 4 weeks. As it has been reported that eccrine residue is the most affected by time due to the evaporation of water, the results

would perhaps indicate that it is not just eccrine residue that iron oxide WPS has an affinity to. Similarly to 4.1.4, the effective development of aged fingermarks means that, operationally, iron oxide WPS could be recommended for use on fingermarks up to 4 weeks; with the potential for even older fingermarks however, this was not tested. Problematically, the age of a fingermark is almost always unknown however, the knowledge generated from this study gives a reasonable indication that iron oxide has the potential for developing reasonably old fingermarks.

Chapter 5. Conclusion and Further Work

5.1. Conclusion

The aim of this research project was to investigate the factors that influence the quality of development of latent fingermarks when visualised using iron oxide WPS, to create a basic and fundamental understanding of the development technique, which had previously been unknown.

The aim was successfully accomplished by achieving the objectives. It was determined that iron oxide WPS was able to develop eccrine rich, sebaceous rich and natural fingermarks but with varying qualities (objective 1). The novel results indicated that iron oxide WPS may have an affinity to constituents found in eccrine residue but, most effectively when able to persist on the substrate with the addition of fatty lipids and/or contaminants. Improvements in the quality of development also appeared to be as a result of the quantity and distribution of residue.

It was established that there was very little consistency in quality of developed fingermarks between participants (inter personally), when developed with iron oxide WPS (4.1.1 and 4.3.1). The results suggested that the variation in participant quality appeared to have the largest impact on the quality of development, indicating that iron oxide WPS is very selective in the characteristic(s) it has an affinity to. Again, it was interpreted that the quantity and distribution of the fingermark residue may largely influence the development quality (objective 2). The consistency in quality of developed fingermarks within each participant (intra personally) also showed the selective nature of the development technique (objective 3). Both of these objectives created new knowledge as, a study on the quality of fingermark development with iron oxide WPS has not been investigated prior to this. From the new knowledge generated, it was recommended that, as a result of the inconsistency in development both inter and intra personally, iron oxide WPS should be considered as a sequential development technique rather than an independent technique.

A further original contribution to knowledge was established as it was found that substrate type could influence the quality of fingermark development with iron oxide WPS (objective 4). The results indicated that plastics, in particular ABS, uPVC and PE facilitated good quality development of both participant fingermarks and, fingermarks spiked with individual constituents found in eccrine residue. Painted metal, PVC and glass tended to result in a poorer quality of development. These results indicated that there was perhaps a chemical or physical property of the substrates that either the fingermark residue or, iron oxide WPS interacted with but to differing extents. The results from this study suggested that there was an interaction taking place between the fingermark residue and substrate, the substrate and iron oxide WPS or fingermark residue and iron oxide WPS. As previously discussed in 4.2.3, it was deemed logical to think that all three interactions were causing inconsistencies in the selective deposition of iron oxide WPS. The inconsistencies observed within this part of the study further demonstrate the selective nature of iron oxide WPS. For operational purposes, as a result of this study, it was recommended that iron oxide WPS could, if necessary, be considered as an independent development technique on ABS, uPVC and PE however, on the remaining substrates, it should be considered as part of a sequential process.

It was determined that the age of latent fingermarks did not particularly affect the quality of fingermark development for fingermarks up to 4 weeks old (objective 5). Analysis indicated that for the phase 1 study analysing short term time periods and, the phase 2 study analysing longer time periods, there were no substantial differences in the quality of development; the fingermark quality did not appear to improve or deteriorate. Operationally this means that iron oxide WPS has the potential for a wide application as it is able to successfully develop fingermarks from, within 24 hours to, as old as 4 weeks.

It was established that the development quality between iron oxide wet powder suspension and individual constituents found in eccrine residue varied depending on the method used (objective 6). It appeared that when the constituents were able to persist on the substrate during the development technique, all of the constituents analysed developed, indicating multiple causes of selective deposition; but (again) with varying qualities. This suggested that there may be many components of a fingermark that iron oxide has an affinity to and causes

the selective deposition of the particles. This new knowledge was particularly important for the recommendations of iron oxide WPS in operational work. It inferred that many of the most commonly encountered and most abundant constituents found in eccrine residue were able to cause the selective deposition of iron oxide WPS. Further to objectives 2 and 3, the findings from objective 6 suggested that the quantity and distribution of residue may have the largest impact on the cause and quality of development as it was evident that multiple constituents were able to develop successfully.

Combining the findings from all objectives, it was anticipated that there were multiple factors affecting the cause and quality of deposition. These interactions were believed to be between the surface and iron oxide WPS, the surface and fingermark residue and, iron oxide WPS and fingermark residue. It was thought that this large number of factors affecting the selective deposition of iron oxide WPS was the cause of the inconsistency in the quality of development. This original contribution to knowledge illustrates that iron oxide WPS is exceedingly selective in the characteristic(s) it has an affinity to, which may cause potential problems operationally.

This study contributed original knowledge to the field of fingermark development using iron oxide WPS as it vastly contributed to the otherwise unknown basic and fundamental understanding of what may be causing the selective deposition of iron oxide WPS, through the application of phase 1 and phase 2 studies. Pseudo-operational and operational trials were not carried out for this research project as the technique is already in use operationally. Following this study, phase 3 and 4 trials should be considered for further work now that this study has formed the basic knowledge of the development technique that was previously unknown.

5.2. Further work

Suggestions for further work were mentioned throughout this report but have been summarised here.

Pseudo-operational and full operational trials as outlined in Sears *et al.* (2012) and, IFRG (2014) should be carried out, to finish the investigative sequence (phase 1, phase 2, pseudo-operational and full operational) that is recommended for new development techniques or, development processes where relatively little is known about the technique. Due to the variation in the quality of development on 'clinical' lab samples (found in this study), it could be recommended that a combination of pseudo-operational trials detailed by both IFRG (2014) and Sears *et al.* (2012) are carried out. The pseudo-operational trials recommended by IFRG (2014) would entail planting known fingermarks on used/weathered substrate samples, representative of case work. Additional pseudo-operational trials where samples of used/weathered substrates are obtained, containing unknown fingermarks of unknown origins should also be considered, as recommended by Sears *et al.* (2012). Both pseudo-operational trials would require all fingermarks to be developed by iron oxide WPS and analysed in a manner similar to this study. Full operational trials could be carried out following the pseudo-operational trials to test the effectiveness of iron oxide WPS in operational case work, in comparison to the development techniques that are currently used preferentially.

Further investigations into how iron oxide WPS fits as a sequential process could be considered to ensure that iron oxide WPS is being used operationally to its optimum potential and, if appropriate, to encourage use of the development technique. The Fingermark Visualisation Manual (Centre for Applied Science and Technology, 2014) states that WPS's could be used sequentially after dry powders and, before Basic Violet 3. The sequential processing chart states that this is the 'most effective' process route however, no substantial research has been carried out in this area. Therefore, it could be suggested that there may be an alternative sequence of development processes which include iron oxide WPS, that is more successful in the visualisation of latent fingermarks. Studies similar to phase 2, pseudo-operational and, full operational trials, using a range of development techniques recommended for non-porous and

semi-porous substrates should be carried out to investigate the optimum development sequence utilising iron oxide WPS.

Further analysis on the chemical and physical interactions causing the selective deposition of iron oxide WPS is vital, to establish the interaction that is taking place between the iron oxide particles, latent fingermark residue and the substrates the fingermarks are on. Jones, Downham and Sears (2009) carried out an introductory study on how surface topography could affect the selective deposition of the iron oxide particles. This study generated important new knowledge, indicating that the method was suitable for purpose. Therefore, the method from this study could be repeated, with the adaptation of applying it to a phase 2 study (like the work carried out in this study) or, to pseudo-operational trials. This would investigate how topography may impact the quality of development, taking in to account a wider variety of variables, on a larger scale. Atherton (2013) started to investigate the correlation between the quality of fingermark development, using iron oxide WPS and, the chemicals present/quantity of chemicals in fingermark residue. This investigation should be furthered now that this study has provided a foundation of knowledge on the factors that affect the quality of development with iron oxide WPS. Gas Chromatography Mass Spectrometry (GC-MS) may be considered for this investigation as Atherton (2013) found it to be a suitable method; alternative methods that may be considered are Scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDX) or, Infrared Microscopy/Fourier-Transform Infrared Spectroscopy.

Although the main aim of this study was to establish factors that affect the development of latent fingermarks when using iron oxide WPS to visualise the fingermarks, it became apparent that the most current, suggestions of fingermark research methodologies need reviewing. From this study it is recommended that a thorough investigation into the reproducibility and consistency of fingermark research methods is carried out.

Chapter 6. References

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Appendices

Appendix 1

Below are the re-graded fingermarks used to demonstrate consistency in the grading technique used. Thirty fingermarks from each of the 7 substrates were randomly chosen for re-grading. Therefore, the 'time period' and repeat number have not been noted as it was deemed irrelevant to the 'blind' re-grading process. Tables 59 – 65 show the original grade for each fingermark in black (the first number) and, the re-graded values in green (the second number).

ABS	Participant 01	Participant 02	Participant 03	Participant 04	Participant 05	Participant 06	Participant 07	Participant 08	Participant 09	Participant 10
Deposition 1st	16 16	10 10	18 19	19 18	13 13	16 16	7 7	18 18	17 17	18 18
Deposition 5th	15 15	13 13	10 10	19 19	14 14	15 15	11 11	18 18	14 14	17 18
Deposition 10th	15 15	13 12	10 10	19 19	12 12	13 14	13 13	15 15	15 15	16 16

Figure 61. The original and re-graded fingermark grades on ABS.

PE Sheet	Participant 01	Participant 02	Participant 03	Participant 04	Participant 05	Participant 06	Participant 07	Participant 08	Participant 09	Participant 10
Deposition 1	16 16	13 13	9 9	19 19	6 6	11 10	8 8	18 18	5 5	13 13
Deposition 2	15 15	13 13	12 11	19 19	5 5	10 10	10 10	17 17	4 4	15 15
Deposition 3	14 14	13 13	9 9	19 19	4 4	13 12	12 12	17 17	5 4	15 15

Figure 62. The original and re-graded fingermark grades on PE sheet.

PE Bag	Participant 01	Participant 02	Participant 03	Participant 04	Participant 05	Participant 06	Participant 07	Participant 08	Participant 09	Participant 10
Deposition 1	17 17	11 11	7 6	19 19	5 5	17 16	14 14	17 17	17 17	16 16
Deposition 2	18 18	4 4	4 4	19 19	5 5	15 15	7 7	16 16	9 9	13 13
Deposition 3	17 17	7 7	7 7	17 17	5 5	16 17	5 5	12 12	6 6	10 10

Figure 63. The original and re-graded fingermark grades on PE sheet.

Glass	Participant 01	Participant 02	Participant 03	Participant 04	Participant 05	Participant 06	Participant 07	Participant 08	Participant 09	Participant 10
Deposition 1	14 15	4 4	4 4	17 17	2 2	10 10	0 0	12 12	2 2	6 6
Deposition 2	15 15	9 9	8 8	16 16	2 2	8 8	0 0	13 13	0 0	15 15
Deposition 3	12 12	2 2	0 0	15 15	2 2	7 8	0 0	10 10	0 0	11 11

Figure 64. The original and re-graded fingermark grades on Glass.

PVC	Participant 01	Participant 02	Participant 03	Participant 04	Participant 05	Participant 06	Participant 07	Participant 08	Participant 09	Participant 10
Deposition 1	12 12	7 7	5 5	11 11	0 0	13 13	4 4	12 12	14 14	15 15
Deposition 2	15 15	8 8	6 6	15 15	0 0	13 13	0 0	16 16	4 4	13 13
Deposition 3	10 10	7 7	0 0	13 13	0 0	5 6	0 0	11 11	0 0	15 15

Figure 65. The original and re-graded fingermark grades on PVC.

uPVC	Participant 01	Participant 02	Participant 03	Participant 04	Participant 05	Participant 06	Participant 07	Participant 08	Participant 09	Participant 10
Deposition 1	12 12	10 10	15 15	17 18	14 14	12 14	8 8	17 17	14 14	8 8
Deposition 2	12 12	8 8	12 12	19 18	14 14	13 14	10 10	11 11	7 7	9 9
Deposition 3	12 12	8 8	13 13	19 18	13 13	15 15	10 10	10 10	0 0	9 9

Figure 66. The original and re-graded fingermark grades on uPVC.

Painted metal	Participant 01	Participant 02	Participant 03	Participant 04	Participant 05	Participant 06	Participant 07	Participant 08	Participant 09	Participant 10
Deposition 1	15 15	0 0	0 0	18 18	0 0	12 10	0 0	19 19	14 14	19 19
Deposition 2	13 13	0 0	0 0	14 14	0 0	13 12	0 0	20 20	0 0	18 18
Deposition 3	11 11	0 0	0 0	16 16	0 0	10 9	0 0	19 19	0 0	17 17

Figure 67. The original and re-graded fingermark grades on painted metal.