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Secondary and tertiary transfer of latent fingermarks using a sticky note – A feasibility study

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ABSTRACT

Latent fingermarks are enhanced in order to be visible and available for comparison to determine source. Once a fingermark has been identified to a source, the activity that led to it being left on a particular surface may need to be determined. It has been previously shown that under certain conditions fingermarks initially deposited onto a surface (the primary transfer) can be transferred on to another substrate through direct contact – secondary transfer. This study investigates the possibility of secondary and subsequent tertiary transfer using sticky notes. To explore secondary transfer, fingermarks were deposited directly onto two different brands of sticky notes, spanning the adhesive and non-adhesive areas, and then placed in direct contact with paper for up to 72 h under a 5 kg weight. For some donors, there was transfer of fingermarks from the sticky note to the paper, with better results for the adhesive areas. The quality of the transferred fingermarks was dependent on initial fingermark quality and the transferred fingermark was a mirror image of the original. The type of paper used as the secondary substrate was also shown to have an effect. Given the adhesive nature of sticky notes tertiary transfer was also investigated and the potential to lift fingermarks from a glass slide and transfer them onto paper or a second glass slide. In the case of transfer to paper, there were only tertiary transferred fingermarks considered to be of useful quality (score 3 or 4) in 6% of samples and a further 33% of samples were detected but provided evidence of contact only (score 1 or 2) (n = 120). For transfer to glass, tertiary transferred samples were of poorer quality with no useful fingermarks and only 3% of samples scoring 1 or 2 (n = 120). The latter was in part due to the deposition of sticky note adhesive traces obscuring the fingermarks. In the case of tertiary transfer, fingermarks on the final tertiary surface were in the correct orientation. This work demonstrates that whilst tertiary transfer of fingermarks is possible under the laboratory conditions used, the likelihood of the effective transfer of a useful and potentially identifiable fingermark is in reality low.

1. Introduction

Latent fingermarks are left when a fingertip comes into contact with a surface (the substrate). A deposit of a complex chemical residue is left in the pattern of the fingertip ridge detail. Latent fingermarks are often invisible or difficult to see and therefore crime scene investigators and forensic examiners use a range of physical and chemical techniques to enhance the ridge detail, making it visible for the purposes of comparison. Determining the source of a latent fingermark i.e. the individual that left it, is an established and accepted process, based on the fact that an established level of fingertip pattern (ridge detail) is regarded as unique to a finger.

Latent fingermark residue consists of natural secretions from predominantly eccrine glands (present on the palmar regions of the hands and fingers) and sebaceous glands (found in varying abundance in different anatomical sites including face and back) [1]. Exogenous substances, such as cosmetics, food, hair and tobacco products, and other contaminants that the fingertips may encounter also contribute to this complex mixture. Once deposited on the surface the chemical composition of the residue changes with time, under the influence of environmental factors such as light, heat, humidity and the substrate itself. As a consequence of the complexity of the composition of latent fingermarks, they vary greatly both between individuals (inter-variability) and over time for the same individual (intra-variability). No two latent fingermarks have exactly the same chemical composition [1,2].

Provided a fingermark is of sufficient quality, following

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enhancement if necessary, it can be identified to a single individual, the source. There may, however, be circumstances in which how or when the fingermark was left on a surface or exhibit is the question – an activity level question [3]. For example, a suspect may not deny that a fingermark at a crime scene is theirs but claim that it was left as a result of legitimate access to the scene on a separate occasion. In this situation the orientation and position of the fingermark on a surface and its age become relevant and may not be consistent with the suspect's explanation. In addition, the surface or exhibit the fingermark has been left on may also be relevant when interpreting what activity led to the fingermarks being deposited particularly if moveable. There is a need for research that can strengthen and develop the interpretation of fingermark evidence [4]. One such area is the secondary transfer of latent fingermarks.

The secondary transfer of trace evidence is the transfer of material from the substrate it was originally deposited on to a second substrate either through direct contact of the two substrates, or via an intermediary (tertiary transfer). Secondary and tertiary transfer could potentially place someone at a crime scene they have never been to [5,6]. In terms of trace evidence, secondary transfer of fibres and DNA have been well-studied, with particular interest in the latter increasing [7–10]. It is well-established that there are many variables which affect the process, making the determination of the probability of secondary transfer occurring in a particular case scenario complex [7,11,12].

There have been case reports of fingermark forgery attempts using secondary transfer of latent fingermarks from one substrate onto another [13,14]. There is, however, very limited research to date on the secondary transfer of latent fingermarks either directly or via an intermediary [15,16]. Beaudoin [15] reported that the secondary transfer of untreated and treated latent fingermarks onto paper via direct contact with a smooth non-porous surface or via a lifter was not detected using ninhydrin. Subsequently in 2018 Jabbal *et al.* [16] showed that latent fingermarks can be transferred through direct contact from a non-porous substrate (glass) to a porous substrate (paper) under specific conditions, namely fresh deposits and the application of contact pressure for at least two hours, and enhanced using 1,2-indandione. Best results were achieved with 5 kg contact weight over a 24 h period. As Beaudoin had previously shown, Jabbal et al. detected no secondary transfer with ninhydrin and attributed this to the lower sensitivity of the reagent compared to 1,2-indandione. Transfer from a porous substrate (paper) was also shown but to a more limited extent. Flanders et al. also demonstrated the transfer of latent fingermarks from one porous substrate to another and noted particular characteristics of the resulting indandione-enhanced transferred fingermarks which could be used as indicators of secondary transfer: a halo effect, fuzzy and/or faint appearance [17].

The transfer of a latent fingermark through direct contact of two substrates, results in a laterally reversed latent fingermark on the second substrate i.e. a mirror image of the original primary fingermark. Consequently, once the enhanced fingermark is identified to an individual it is possible to determine that it was not directly deposited on the exhibit being examined. Jabbal et al. [16] looked at the use of an adhesive fingermark lifter to transfer the latent fingermark from a non-porous substrate to the porous substrate as a way of transferring the fingermark the right way round. They, however, did not successfully develop any clear ridge detail due to interference from traces of adhesive left by the fingermark lifter on the paper.

In addition to providing ridge detail for the purposes of comparison, latent fingermarks can also be a source of DNA (touch DNA) that can be particularly valuable in instances where the ridge detail is insufficient for comparison. It is possible to recover DNA from enhanced fingermarks and the detection of the area on an item that has been touched enables a targeted approach to be used for touch DNA sampling, improving the chances of success [18,19]. Ruprecht et al. [20] showed that fingermarks, initially deposited on the adhesive side of a postage stamp through typical handling that was then stuck down, could transfer onto an envelope under controlled conditions. Within hours of the stamp being stuck onto an envelope, fingermarks could be visualized on the envelope. The quality of the transferred fingermarks improved with time and were deemed of sufficient quality for comparison after two days. Fingermarks of better quality were developed after longer periods of time stuck on the envelope.

The aim of this research study was to determine whether secondary and tertiary transfer of latent fingermarks is possible via an adhesive intermediary to build on previous work [15,16]. Sticky notes were used as a readily available adhesive material and have been identified as a potential transfer intermediary [4]. The conditions under which secondary transfer directly or via an intermediary (tertiary transfer) could occur were explored, including time of contact and substrates used.

2. Materials and methods

2.1. Materials

Zinc chloride (≥98%, Sigma-Aldrich) was obtained from Merck Life Science UK Ltd (Gillingham, Dorset, UK). Ethyl acetate (specified laboratory reagent), glacial acetic acid (analytical grade) and methanol (technical grade) were obtained from Fisher Scientific (Loughborough, UK). 1,2-indandione (99%) was purchased from Scenesafe (Essex, UK). Novec-7100™ (HFE 7100) was purchased from Merck Life Science UK Ltd (Aldrich) and Severn Biotech (3M) Aluminium powder was purchased from Tetra Scene of Crime (Essex, UK).

Table 1 lists the different substrates used in this research study.

2.2. Donors

A pool of 10 donors (assigned codes D1-D10) was used in this study, aged between 20–52 (6 female, 4 male). Five donors were used in each experiment based on donor availability as indicated in Table 2. This study had institutional ethical approval and in accordance with local ethical approval requirements, samples were anonymised and only identifiable by an alphanumerical code to facilitate data analysis.

2.3. Fingermark deposition

Best practice was followed for the collection of natural latent fingermark samples [21,22]. Donors deposited depletion series of two natural fingermarks using normal touch pressure onto each specific substrate. Donors had not washed their hands or used hand sanitiser for at least 30 min and were asked to rub the palms of their hands and fingertips together to evenly distribute skin surface residue prior to deposition. No other pre-deposition preparation was required. The thumb and all fingers except the little finger were used, with a different finger for each sample (sticky note or glass slide). A researcher placed the donors' fingers onto the substrate each time in order to ensure consistency in time and pressure of contact.

Table 1
Porous and non-porous substrates used in Experiments 1–3.

Substrate type	Manufacturer	Details	Supplier
Post-it® Super Sticky Note	3M	Canary yellow Post-it® Super Sticky Notes 76 × 76 mm	Amazon
B&M Sticky Note	B&M	Pastel yellow sticky notes 76 × 90 mm	B&M
White paper	Xerox	A4 white copier paper, 80 gsm	Not known
White card	Navigator	A4 white office card, silky touch, ultra-bright, 160 gsm	Staples
Recycled lined paper	Sainsburys	A4 lined, recycled paper refill pad	Sainsburys
Brown manila envelope	Ryman®	A4 manila envelope	Ryman®
Glass slide	Fisher	Standard microscope slide, uncoated	Fisher

Table 2
Overview of donors and the experiments they were included in.

Donor ID	Sex	Age	Experiments included in		
			Experiment 1	Experiment 2	Experiment 3
D1	F	23	✓	✓	✓
D2	F	40	✓		
D3	M	30	✓		
D4	M	31	✓		
D5	F	24	✓		
D6	M	52			✓
D7	M	28		✓	✓
D8	F	20		✓	✓
D9	F	24		✓	✓
D10	F	20		✓	

2.4. Indandione-zinc enhancement

An indandione-zinc working solution was prepared following the Dstl UK Home Office recommended method [23]. In brief, a zinc chloride stock solution was first prepared by dissolving 0.1 g zinc chloride in 4 mL ethyl acetate and 1 mL acetic acid. Then to prepare the indandione working solution, 0.25 g 1,2-indandione was dissolved in 45 mL ethyl acetate, 45 mL methanol and 10 mL acetic acid. Once the indandione was fully dissolved, 1 mL of the zinc chloride stock solution and 1 L HFE 7100 were added.

Samples were treated by drawing each one through the indandione-zinc working solution in a processing trough. Excess working solution was allowed to drip off the sample before it was placed on laboratory tissue for approximately 5 min or until all solvent had evaporated. Once dried the samples were heated for 10 min in a pre-heated Gallenkamp Fingerprint Development Chamber at 100 °C (± 5 °C) with no humidity.

Indanedione-zinc-enhanced fingermarks were photographed using a Canon EOS 5D digital single lens reflex (DSLR) camera fitted with a 50 mm Canon Compact-macro lens. The camera was positioned on a stand directly above the samples and kept at a fixed height. The camera settings were: ISO 400, f8.0, shutter speed 1/10, automatic focus and Auto White Balance. A Crimelite 4x4 (Foster and Freeman) was used with the green/blue (ex. 500–550 nm) light to illuminate the samples and the viewing filter OG570.

2.5. Aluminium powdering

Aluminium powder was applied using a Zephyr brush, following guidance in the Fingermark Visualisation Manual, until there was sufficient contrast between the fingermark ridge detail and the background when the glass slide was placed on a contrasting (black) fingerprint template board (Tetra Scene of Crime) [24].

Powder-enhanced fingermarks were photographed using a Canon EOS 1300D DSLR camera. The camera was used at a fixed height above the samples which were illuminated by two white LED torches positioned either side at approximately 30 degrees. Camera settings of ISO 200 and f8.0 were used with the shutter speed optimized for each sample.

2.6. Fingermark grading

Fingermarks were scored on the basis of ridge quality and quantity using a form of the Home Office grading scheme (Table 3). Scoring of indandione-zinc-enhanced fingermarks was completed on the day of treatment and after dark-adaptation for 20–30 min, in accordance with best practice guidance [23]. Aluminium powder-enhanced fingermarks were scored up to one week after enhancement.

For evaluation purposes, enhanced fingermarks were categorized as 'useful' i.e. with sufficient ridge detail for potential identification (score of 3 or 4) and 'evidence of contact only' i.e. detected but insufficient ridge detail for potential identification (score of 1 or 2). As previously discussed, detected fingermarks that have insufficient ridge details can indicate a location for swabbing for touch DNA and are therefore still of potential value in an investigation.

Table 3
Home Office enhanced fingermark grading scheme [21].

Score	Description	Fingermark Quality Evaluation
0	No evidence of a fingermark	Not detected
1	Evidence of contact but no ridge detail	Evidence of contact only
2	About $^1/_3$ of ridge details are present	
3	Between $^1/_3$ and $^2/_3$ of ridge details	Useful
4	$^2/_3$ to full ridge details	

2.7. Experiment 1: Secondary transfer of latent fingermarks from sticky notes to a porous substrate (paper)

Natural fingermarks were collected from five donors (D1-D5). Two types of sticky note were used: 3M Post-it® Super Sticky Notes and B&M Sticky Notes (Table 1). For each sample (a sticky note) split depletions of two natural fingermarks were deposited with each fingermark spanning both the adhesive and non-adhesive areas (Fig. 1). Duplicate samples were collected from each donor for each sticky note type. One replicate was stuck down on to white paper (Table 1) within 30 min of collection and the second replicate was stored adhesive side up (i.e. not stuck down) as a control. A 5 kg weight was placed on top of the stuck-down samples (approximately 8 g cm^{-2} contact pressure) and all samples were stored in the dark in a cupboard for 2, 24 or 72 h. A total of 120 fingermarks were deposited: for each of the three time points, 10 stuck down samples and 10 controls were collected for each type of sticky note (two). After the given time had passed, the stuck down sticky notes were separated from their paper and all substrates (sticky notes and paper) were treated with indandione-zinc.

2.8. Experiment 2: Effect of different recipient paper types on the secondary transfer of latent fingermarks from sticky notes

The 3M Post-it® Super Sticky Note was used in this experiment. For each sample (a sticky note), a whole mark depletion series of two natural fingermarks was collected from five donors (D1, D7–10, Table 2) on each of the adhesive area and non-adhesive area using the opposite hand corresponding digit in each case e.g. left forefinger on adhesive and right forefinger on non-adhesive. Fingermarks were placed along the edge of the sticky note so that the area of contact was known and thus where fingermarks were expected to be found following enhancement.

These sticky notes were stuck down onto one of four different paper types (white paper, white card, recycled lined paper, brown manila envelope (Table 1)) within 30 min of being collected and in specific outlined areas such that the expected location of any transferred fingermarks was known. Samples were left stuck down for 2 or 24 h under a 5 kg weight as used in Experiment 1. For each of the two time points, 10 adhesive samples and 10 non-adhesive samples were collected for each type of recipient paper (4), giving a total of 160 fingermarks deposited.

Control samples were also collected whereby donors deposited a depletion of two fingermarks directly onto each type of recipient paper and were subsequently stored for 24 h in the dark. Following the required storage time, the sticky notes were separated from their corresponding paper and all substrates treated with indanedione-zinc.

2.9. Experiment 3: Tertiary transfer of latent fingermarks from a non-porous substrate to a porous or second non-porous substrate using a sticky note

Fig. 2 summarizes the sample processing. A split depletion of two natural fingermarks was deposited onto a glass slide (glass slide 1) by each of five donors (D1, D6–9, Table 2). A sticky note 3M Post-it® Super Sticky Note or B&M Sticky Note, Table 1) was then applied to the glass

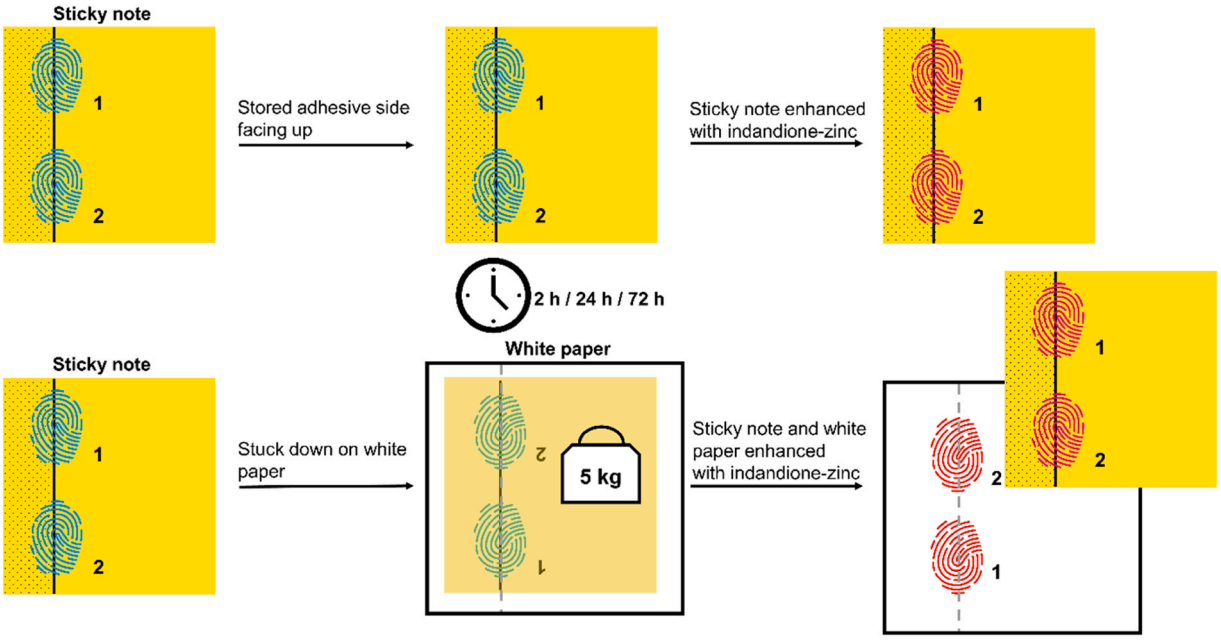

Fig. 1. Overview of sample collection and processing to determine the secondary transfer of latent fingermarks from sticky notes to white paper.

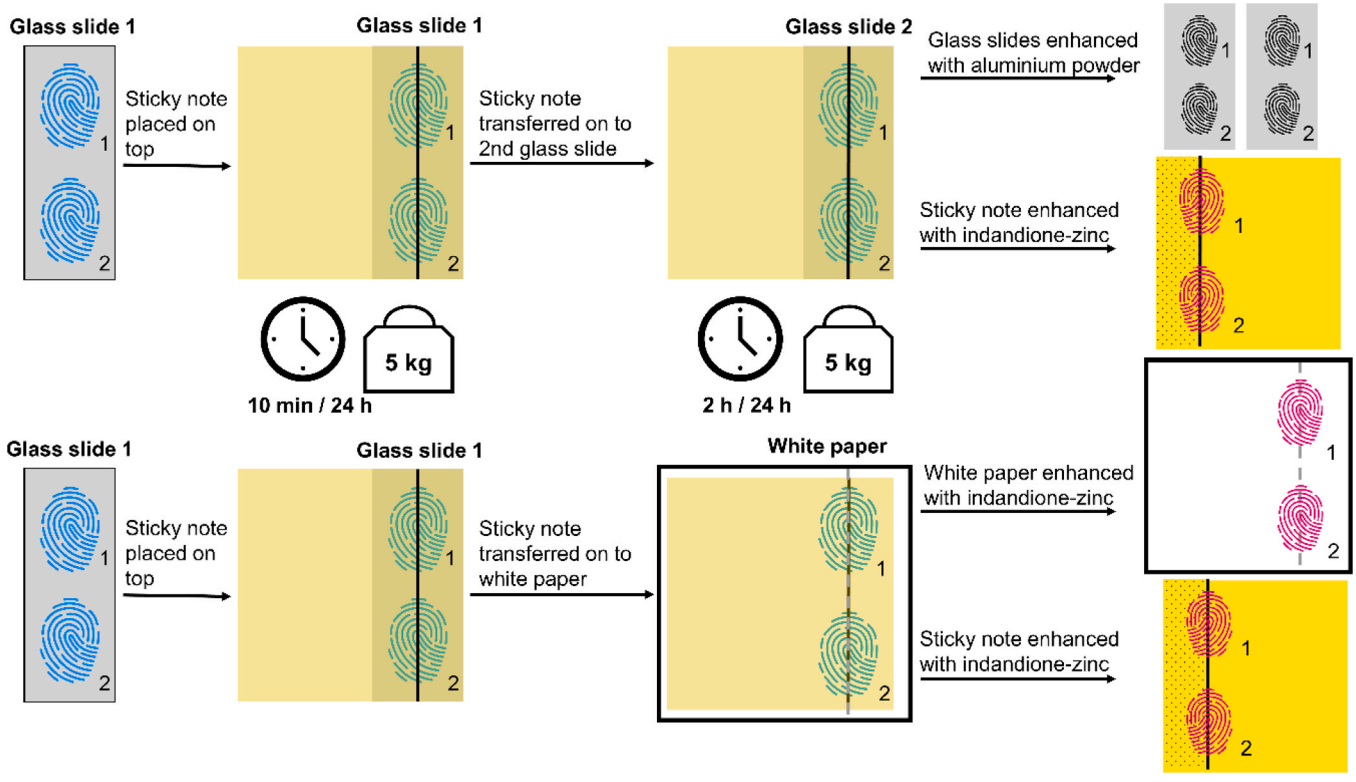

Fig. 2. Overview of sample collection and processing to determine the feasibility of tertiary transfer of latent fingermarks from non-porous (glass) to non-porous or porous (paper) via a sticky note.

slide, within 10 min of fingermark deposition, so that the deposited fingermark spanned the adhesive and non-adhesive areas of the sticky note. After 10 min or 24 h under a 5 kg weight, the sticky notes were removed and stuck down on to white paper (Table 1) or a second glass slide (glass slide 2). In each case, the sticky note was placed in a specific area such that the exact expected location of any transferred fingermarks was known. A 5 kg weight was again placed on top of the stuck-down samples and stored in the dark for 2 or 24 h. After the given time had passed, the sticky notes were separated from their corresponding substrates. All paper and sticky note substrates were treated with indanedione-zinc and all glass slides with aluminium powder.

3. Results and discussion

3.1. Experiment 1: Secondary transfer of latent fingermarks from sticky notes to a porous substrate (paper)

There was no real observable trend when comparing the effect of time the sticky note was in contact with the paper on transferred fingermark quality. Therefore, results for all three contact times (2, 24 and 72 h) have been considered together. Fig. 3 summarizes the results for both sticky note types. Between 37–47% of fingermarks deposited directly onto the adhesive area of the sticky note were graded as useful (score of 3 or 4) compared to 50–73% for the non-adhesive area. Comparing the control samples to the stuck down samples for each sticky note type, contact with the white paper appears to have not been markedly detrimental to the quality of the fingermarks on the sticky note. The lower quality of the fingermarks on the adhesive areas was noticeable in many samples with the fingermarks having a mottled appearance (Fig. 4).

Fig. 4 shows the secondary transferred fingermarks on the white paper for Donor 1 alongside the corresponding initially deposited (primary) fingermarks on the sticky note. Whilst good quality marks overall were enhanced on the sticky note samples, the marks enhanced on the paper to which the sticky notes had been stuck were overall of poorer quality in comparison (Fig. 4(a)) or not present (Fig. 4(b)). Note that the fingermarks on the paper are laterally reversed compared to their corresponding sticky note sample.

Considering all samples for both sticky note types (120 natural fingermarks), there were only two fingermarks transferred onto paper which were scored as useful and these were from the adhesive area of the 3M Post-it® Super Sticky Note (D1 and 24 h (Fig. 4(a)) and D3 and 72 h (not shown)). There were a further 10 fingermarks transferred onto paper using the 3M Post-it® Super Sticky Notes that scored a grade 2 and a further 31 scoring 1 indicating that there had been transfer of fingermark residue and more specifically amino acids that react with indandione-zinc. The majority of transferred fingermarks were from the adhesive area. In the case of the B&M Sticky Notes there were no fingermarks transferred to paper which scored greater than 1 but 21 samples that scored 1.

This experiment demonstrated that whilst secondary transfer can occur, as previously demonstrated [16], the quality of the transferred fingermark was highly variable and generally of poor quality. The quality of the transferred fingermark was of the same or worse quality as the initial latent fingermark on the sticky note itself as expected due to the specificity of indandione-zinc for amino acids in fingermark residue [25]. It also depends on the nature of the initial surface it has been deposited on i.e. type of sticky note and whether it was on the adhesive or non-adhesive area. This is likely due to the ability of the adhesive areas to remove more material from the fingertip during contact and differences in the adhesive material on the two types of sticky note. It is also possible that the indandione-zinc may have reacted to a limited extent with the adhesive, especially if it is an animal protein-based adhesive. The transferred fingermarks did display some of the characteristics identified by Flanders et al., namely a fuzzy and faint appearance [17]. However, these characteristics are also consistent with the appearance of primary fingermarks on the adhesive areas of the sticky note and low amino acid content (inter- and intra-donor variation), so not considered to be unique to secondary transferred fingermarks.

3.2. Experiment 2: Effect of different recipient paper types on the secondary transfer of latent fingermarks from sticky notes

The aim of this experiment was to determine if recipient paper type affects the potential for natural fingermarks deposited onto the adhesive and non-adhesive areas of a sticky note to be transferred to a porous substrate. Four different paper types were used varying in observed quality and porosity.

Fig. 5 shows the results for the transfer of fingermark initially deposited on the adhesive (Fig. 5(a)) and non-adhesive (Fig. 5(b)) areas of the sticky note before being stuck to paper for 24 h with 5 kg contact weight. The quality of the fingermarks on the sticky note are presented (blue bars) alongside the quality of the fingermarks enhanced on the recipient paper (red bars). It should first be noted that fingermarks of reasonable quality (scoring 2 or more) were detected on the recipient paper in at least 50% of samples for the adhesive areas. It is noted that the transfer of fingermarks to white paper was greater in this experiment compared to experiment 1. This is thought to be a consequence of collecting fingermarks on a different day (intra-variability) and using different donors (inter-variability). This highlights the importance of the use of multiple donors on different occasions and that data from different experiments should be compared with caution. Overall poorer quality results were seen for the recycled lined paper and the brown manila envelope (Table 1) following 24 h contact. In the case of the non-adhesive areas, there were no fingermarks transferred to the paper of useful quality (score 3 or 4). However, there was evidence of contact (score 1 or 2) for all samples. Overall poorer results were observed for the 2 h samples (data not included) with less material transferred in all cases.

Fig. 6 illustrates the differences in secondary fingermarks transferred onto the four paper types. In each case the left-hand image is the primary fingermarks of one donor deposited onto the adhesive area of the 3M Post-it® Super Sticky Note. The quality of the primary fingermarks are comparable across the four samples and have a mottled appearance as

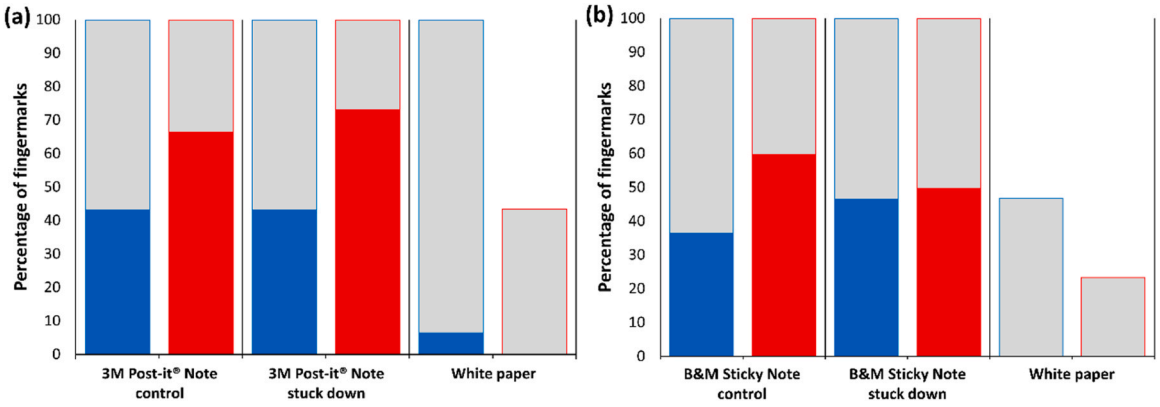

Fig. 3. Percentage of fingermarks on sticky notes and white paper following contact for up to 72 h and corresponding control (not stuck down) sample. (a) 3M Post-it® Super Sticky Note and (b) B&M Sticky Note. Useful fingermarks (score of 3 or 4) deposited on adhesive (blue bars; ■) and non-adhesive (red bars; ■) areas of sticky note. Additional fingermarks detected but only evidence of contact (score of 1 or 2) indicated by grey bars (■). [n = 30 per category]. Scored following the enhanced fingermark grading system in Table 3.

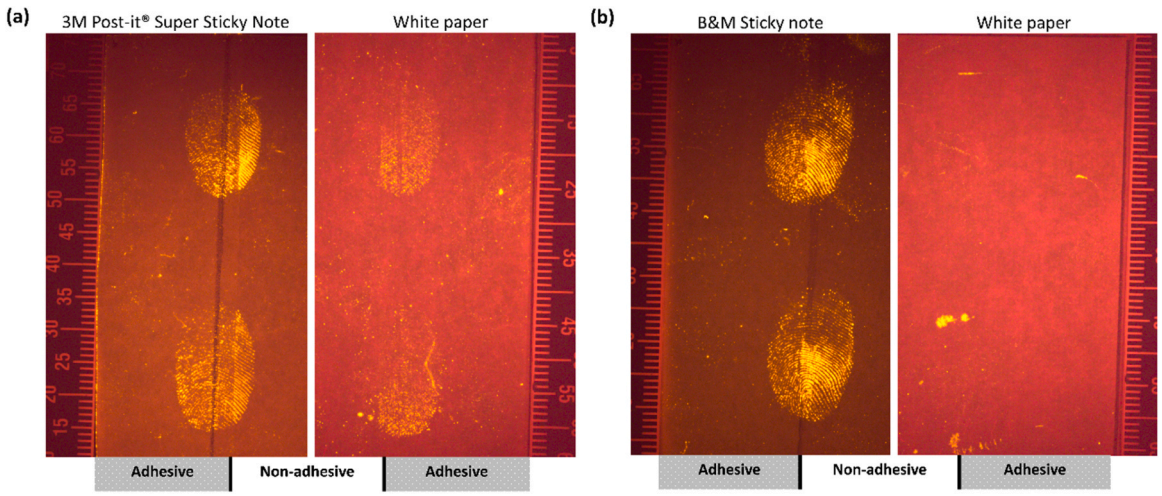

Fig. 4. Donor 1 (D1) samples deposited on (a) 3M Post-it® Super Sticky Note and (b) B&M Sticky Note and the resulting fingermarks transferred onto A4 copier paper following 24 h with 5 kg contact weight. Note that the fingermarks are laterally reversed on the paper compared to the sticky note samples.

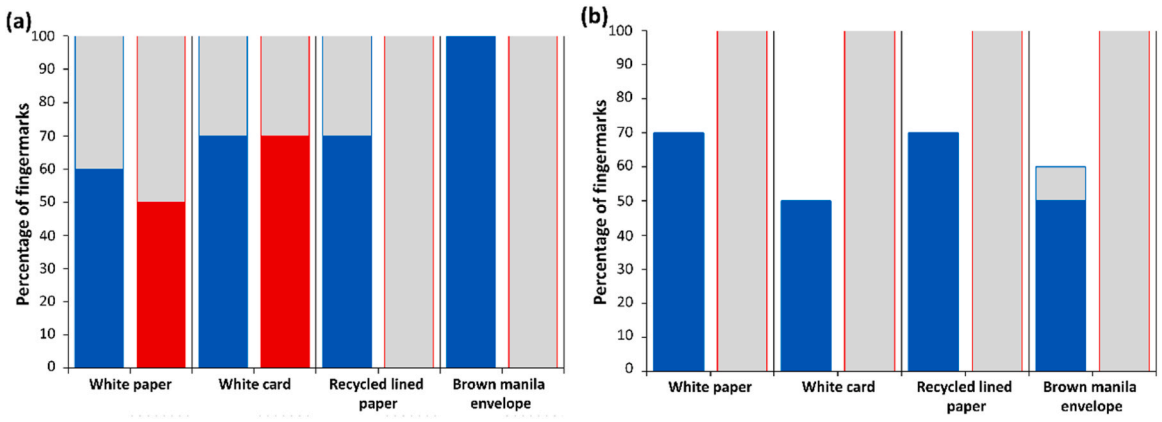

Fig. 5. Number of fingermarks transferred from the (a) adhesive and (b) non-adhesive areas of a 3M Post-it® Super Sticky Note on to different paper types following contact for 24 h under 5 kg weight. Useful fingermarks (score of 3 or 4) on sticky note (blue bars; ■) and corresponding useful fingermarks on paper (red bars; ■). Additional fingermarks detected but only evidence of contact (score of 1 or 2) indicated by grey bars (■). [n = 10 per category]. Scored following the enhanced fingermark grading system in Table 3.

observed in Experiment 1. The variable secondary transfer of material from the sticky note to each of the different paper types is illustrated in the right-hand images. The observed differences are expected to be a consequence of the differences in paper quality. The recycled lined paper (Fig. 6(c)) and brown manila envelope (Fig. 6(d)) were of an observed poorer quality with perceivable differences in porosity. There were also differences in background fluorescence with the recycled lined paper in particular giving high background fluorescence, due to increased staining and/or the inherent properties of the paper itself, that interfered with the ability to clearly view the fingermarks. The background fluorescence was only noticeable on the recycled lined paper and found across the entirety of these samples and therefore not thought to specifically be a consequence of transfer of adhesive from the sticky note to the paper as observed in Jabbal et al. with the adhesive fingermark lifters [16]. The observed variations in transferred fingermark quality are consistent with what is expected in terms of the behaviour of latent fingermarks and more specifically the amino acids within the residue on different types of paper [26,27]. It has been previously reported that latent fingermark residue is absorbed to different extents by different types of paper and this may in this case also affect the ease of secondary transfer of latent fingermark residue from the sticky note [26,27]. The results here indicate that further investigation of the effect of recipient paper type is warranted.

3.3. Experiment 3: Tertiary transfer of latent fingermark from a non-porous substrate to a porous or second non-porous substrate using a sticky note

The aim of this experiment was to determine the potential for natural fingermarks deposited onto a non-porous substrate (glass) to be transferred onto the adhesive and non-adhesive areas of a sticky note and then subsequently transferred onto a porous substrate (paper) or a non-porous substrate (glass). The experiment was designed to assess fingermark quality at each stage i.e. the fingermark deposited on the initial glass slide (primary substrate), the fingermark transferred to the sticky note (the intermediary, secondary substrate) and the fingermark transferred to the paper or second glass slide (tertiary substrate). The effect of time of contact for both the first transfer to the secondary substrate (i.e. time sticky note is stuck to initial glass slide – 10 min or 24 h) and the second transfer to the tertiary substrate (i.e. time sticky note is stuck to paper or second glass slide – 2 h or 24 h) was explored.

Table 4 summarizes the overall results in terms of the quality and quantity of tertiary transferred fingermarks. For the B&M Sticky Notes, the results were comparable for all three sets of transfer contact times for both transfer to paper and glass. In the case of the 3M Post-it® Super Sticky Notes, the quality and quantity of the tertiary transferred fingermarks increased as first and second transfer contact times increased.

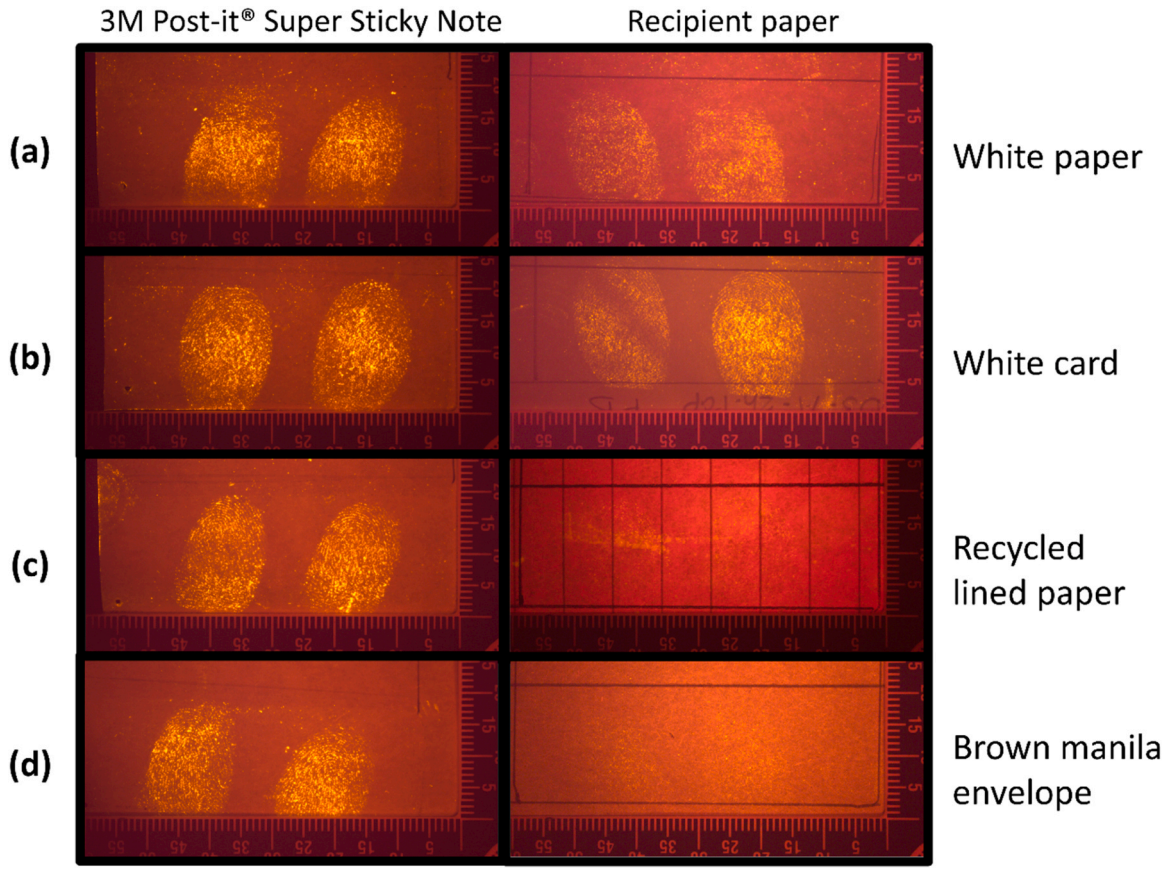

Fig. 6. Comparison of secondary transfer fingermarks from the adhesive area of a 3M Post-it® Super Sticky Note onto different paper types for Donor 7 and 24 h contact under 5 kg weight. Left: primary fingermarks on sticky note. Right: secondary fingermarks on the recipient paper. Note that the fingermarks are laterally reversed on the recipient paper compared to the sticky note samples.

Table 4
Number of enhanced tertiary transferred fingermarks categorized as useful and detected but evidence of contact only.

Sticky note	Contact time		Glass to paper		Glass to glass	
	First transfer	Second transfer	Adhesive (n = 10)	Non-adhesive (n = 10)	Adhesive (n = 10)	Non-adhesive (n = 10)
	10 min	2 h	1[a] (5)[b]	-[c] (-)	- (-)	- (-)
3M Post-it® Super Sticky Note	10 min	24 h	4 (5)	- (1)	- (-)	- (-)
	24 h	24 h	2 (6)	- (1)	- (3)	- (-)
	10 min	2 h	- (7)	- (-)	- (-)	- (-)
B&M Sticky Note	10 min	24 h	- (6)	- (-)	- (-)	- (-)
	24 h	24 h	- (8)	- (-)	- (-)	- (-)
Overall			**7 (37)**[d]	**- (2)**[d]	**- (3)**[d]	**- (-)**[d]

[a] Number of useful fingermarks (score of 3 or 4);
[b] Number of fingermarks detected but only evidence of contact (score of 1 or 2);
[c] No fingermarks observed in this category indicated by "-".
[d] n = 60

The results for 10 min/24 h and 24 h/24 h (contact time for first transfer/contact time for second transfer) conditions will be discussed in detail.

It was observed for the initial glass slides that there was background development with the aluminium powder on the area of the slide which had come into contact with the adhesive area of the sticky note. This was slightly more intense for the 3M Post-it® Super Sticky Notes. It is thought that this was due to traces of the adhesive on the sticky note being left behind on the glass slide when the sticky note was removed [16]. This negatively affected the overall quality of the enhanced fingermarks. A similar phenomenon was observed for the second glass slides which were also in contact with the sticky notes.

Fig. 7(a) summarizes the results for samples where the sticky note was initially applied to the freshly-deposited fingermarks on a glass slide for 10 min and then 24 h stuck down on white paper, the tertiary surface. The initial, primary, fingermarks on the glass slide were variable in quality and were not all of a useful quality (score of 3 or 4). The quality of these primary fingermarks was affected by a number of factors which need to be considered when comparing to the quality of the tertiary transferred fingermarks. The experiment was designed to use natural fingermarks from multiple donors, with no specific pre-deposition activity to artificially load the fingertips with residue. Therefore, variation in fingermark quality was expected [2,21,22]. The application of the sticky note to the primary fingermarks would have lifted some of the deposited residue from the glass slide, reducing the quantity and quality left for subsequent enhancement [28]. Further, as previously noted, the

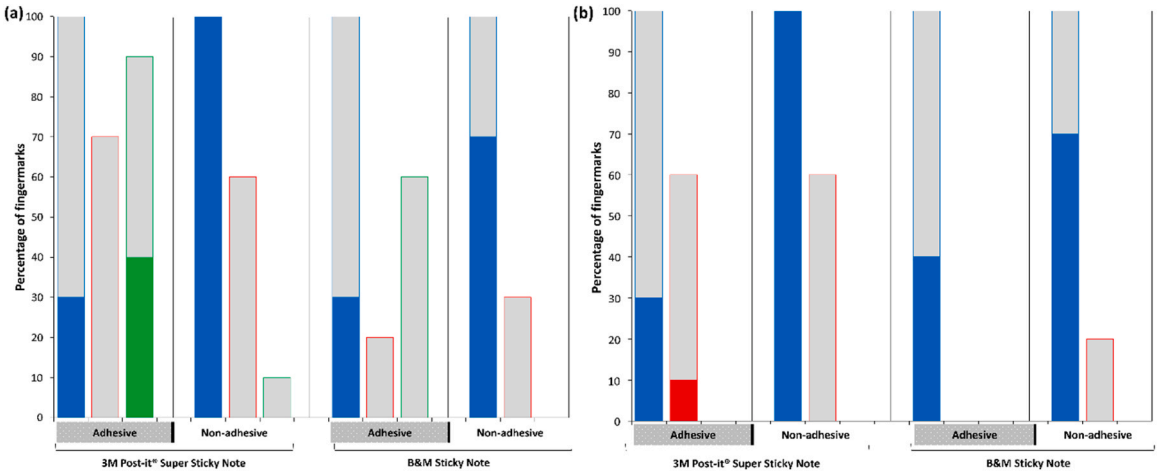

Fig. 7. Number of fingermarks during tertiary transfer from a glass slide to (a) paper and (b) a second glass via a sticky note with contact times of 10 min (between primary and secondary substrates) and 24 h (between secondary and tertiary substrates). Useful fingermarks (score of 3 or 4) on initial glass slide (primary substrate, blue bars, ■); corresponding useful fingermarks on sticky note (secondary substrate, red bars, ■); and useful fingermarks on final substrate (tertiary substrate, green bars, ■). Additional fingermarks detected but only evidence of contact (score of 1 or 2) indicated by grey bars (■). [n = 10 per category]. Scored following the enhanced fingermark grading system in Table 3.

aluminum powder enhanced adhesive traces left on the glass slides, which negatively impacted the clarity of the fingermarks and consequently their score. The results show that tertiary transfer, using a sticky note is possible in some instances, with at least evidence of contact (score ≥1) observed in 40% of the samples (16 out of 40). Of these, four samples were of useful quality (10%, score of 3) and a further two samples scored a 2. With the exception of one sample (which scored 1), tertiary transfer was only seen for the adhesive area of the sticky note. There was a greater number of, and better quality, incidences of tertiary transfer seen for the 3M Post-it® Super Sticky Notes (ten) compared to the B&M Sticky Notes (six) which may be attributed to qualitative and quantitative differences in the adhesive on the two different types of sticky note, as previously noted in experiment 1.

Fig. 7(b) summarizes the results for the tertiary transfer of the fingermarks to a glass slide. There were no detectable marks on the second glass slide i.e. no tertiary transfer. The initial fingermarks on the first glass slide were comparable in quality to those collected in the tertiary transfer to paper (Fig. 7(a)). The fingermarks enhanced on the sticky notes were of much lower quality compared to experiments 1 and 2, but this would be consistent with the marks being lifted onto the sticky note in this case as the secondary substrate, rather than being deposited directly onto them as the primary substrate. It may also be attributable to natural intra- and inter-donor variability in latent fingermark residue composition [2,28,29]. The decreased quality of fingermarks on the sticky note could also be a consequence of being applied to a second non-porous substrate e.g. it may have caused some smudging of the fingermark residue. This would require further exploration to better understand the interactions of the fingermark residue and the different substrates.

With longer periods of contact, 24 h for initial contact of sticky note with first glass slide and 24 h contact between sticky note and tertiary substrate, there were a similar number of incidences of tertiary transfer to paper (17 out of 40) but only two of these were considered to be of useful quality (score of 3 or 4) compared to the shorter contact time (Fig. 8). In the case of tertiary transfer to glass results were better with three marks observed on the second glass slide, although these only scored 1. Fig. 8 summarizes the overall findings.

Figs. 9 and 10 present examples illustrating successful tertiary

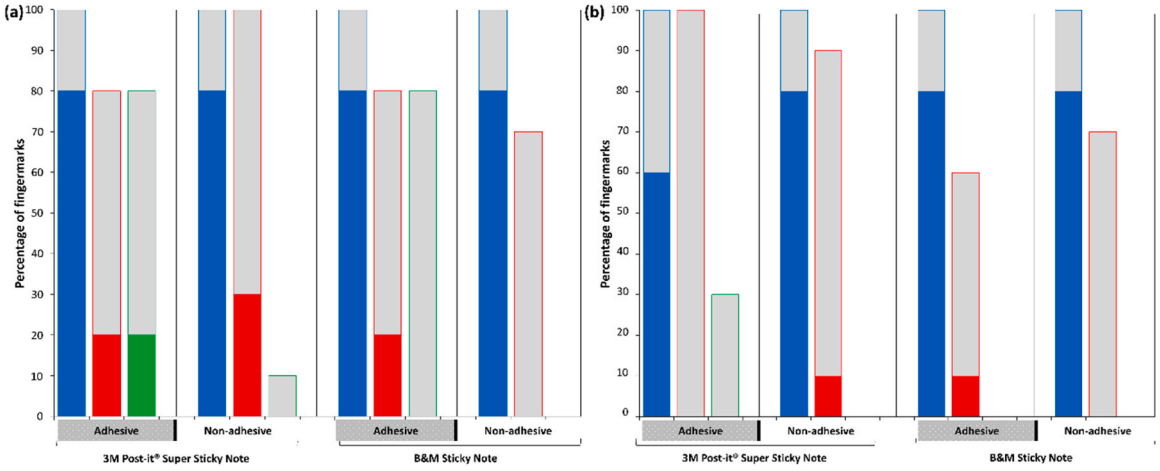

Fig. 8. Number of fingermarks during tertiary transfer from a glass slide to (a) paper and (b) a second glass via a sticky note intermediary with contact times of 24 h (between primary and secondary substrates) and 24 h (between secondary and tertiary substrates). Useful fingermarks (score of 3 or 4) on initial glass slide (primary substrate, blue bars, ■); corresponding useful fingermarks on sticky note (secondary substrate, red bars, ■); and useful fingermarks on final substrate (tertiary substrate, green bars, ■). Additional fingermarks detected but only evidence of contact (score of 1 or 2) indicated by grey bars (■). [n = 10 per category]. Scored following the enhanced fingermark grading system in Table 3.

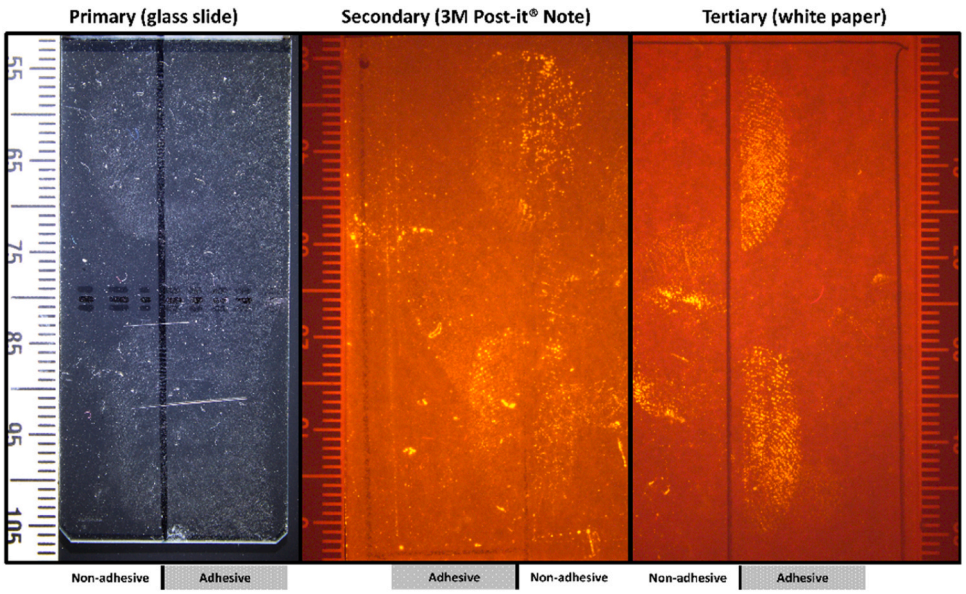

Fig. 9. Enhanced fingermarks at each step of the tertiary transfer for Donor 6 using a 3M Post-it® Super Sticky Note. Sticky note in contact with glass slide for 10 min and then with the white paper for a further 24 h. Note that the fingermarks are laterally reversed on the sticky note compared to the glass slide and white paper samples.

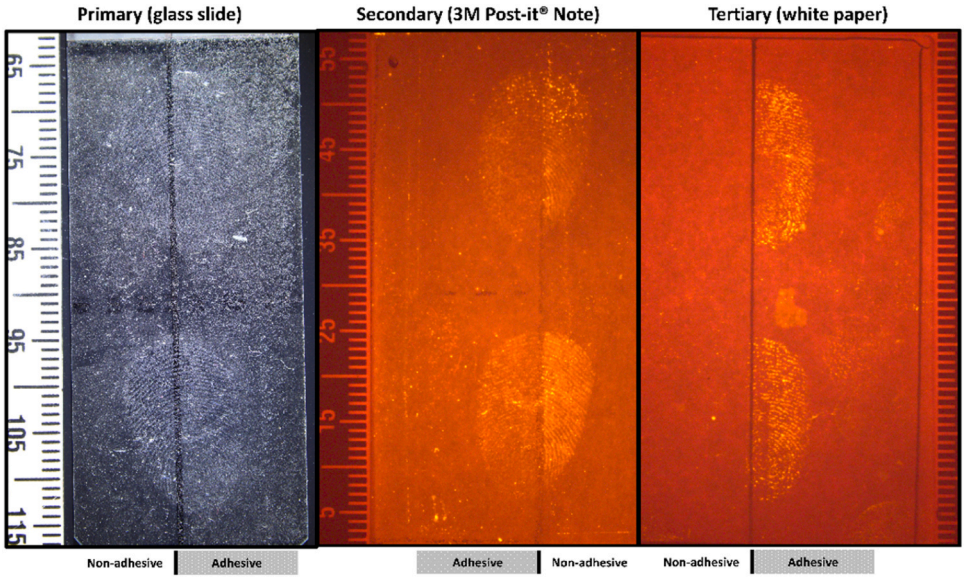

Fig. 10. Enhanced fingermarks at each step of the tertiary transfer for Donor 6 using a 3M Post-it® Super Sticky Note. Sticky note in contact with glass slide for 24 h and then with the paper for further 24 h. Note that the fingermarks are laterally reversed on the sticky note compared to the glass slide and white paper samples.

transfer from a glass slide to paper using 3M Post-it® Super Sticky Notes on the adhesive area only. The fingermarks enhanced on the paper have clear ridge detail and are in the orientation consistent with the source fingertip touching the paper surface directly. As observed in Experiment 1, some of the transferred fingermarks did have a fuzzy appearance with discontinued ridge detail and there was variation in fluorescence intensity. This is most likely due to a reduction in the amount of amino acids in the fingermark residue following each transfer.

Figs. 11 and 12 present examples illustrating successful tertiary transfer from glass slide to a second glass slide using a 3M Post-it® Super Sticky Note on the adhesive area only. The fingermarks enhanced on the second glass slide are not of sufficient quality to be useful but they do indicate contact and could provide useful information, for example to target swabbing for touch DNA. The quality of the fingermarks on the second glass slide are again impacted by the deposition of adhesive material by the sticky note which has been enhanced with the aluminium powder.

Throughout this study, contact time and contact weight were selected based on previous work and to provide favorable conditions for fingermark transfer [16]. A 5 kg contact weight was used in this study which results in a contact pressure of approximately 8 g cm^{-2} once the surface area of contact was accounted for. This aimed to mimic the pressing down of the sticky note onto a surface or, as seen in Jabbal et al., the storage of the sample within a pile of documentation on a desk etc. [16]. Further work would be needed to explore different scenarios aligned with the deliberate use of sticky notes to lift and transfer fingermarks. Furthermore, fresh fingermarks were also used whereby sticky notes and paper substrates were placed in contact within 30 min, or 10 min in the case of Experiment 3, of fingermarks being deposited on the primary substrate. Whilst it is acknowledged that this is not entirely

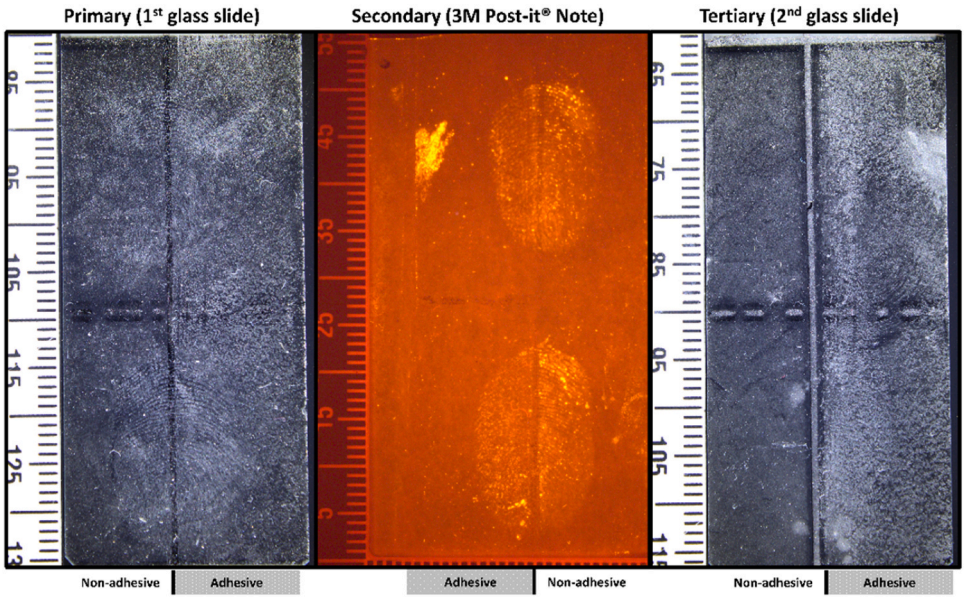

Fig. 11. Enhanced fingermarks at each step of the tertiary transfer for Donor 6 using 3M a Post-it® Super Sticky Note. Sticky note in contact with first glass slide for 24 h and then with the second glass slide for a further 24 h. Note that the fingermarks are laterally reversed on the sticky note compared to both glass slides.

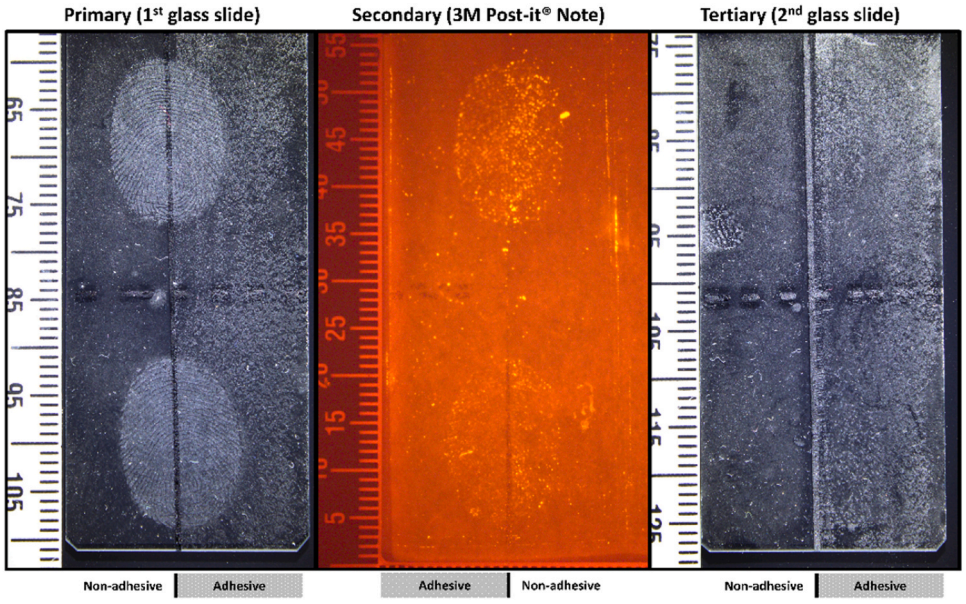

Fig. 12. Enhanced fingermarks at each step of the tertiary transfer for Donor 8 using a 3M Post-it® Super Sticky Note. Sticky note in contact with first glass slide for 24 h and then with the second glass slide for a further 24 h. Note that the fingermarks are laterally reversed on the sticky note compared to both glass slides.

representative of casework, fresh fingermarks were chosen to provide a best-case scenario in terms of quantity and quality of latent fingermark residue available for transfer. This was particularly important in the case of tertiary transfer where the quantity of residue available would decline with each transfer step. The use of more realistic latent fingermarks that are representative of casework is needed in further work to fully understand the likelihood of observing secondary and tertiary transfer.

4. Conclusions

It has been demonstrated in this study that fresh natural latent fingermarks deposited on sticky notes can transfer to paper under certain laboratory conditions (5 kg contact weight and up to 72 h contact time). The quality of the transferred mark is dependent on the initial quality of the fingermark and the recipient paper type. There was greater transfer observed for fingermarks deposited on the adhesive area of the sticky note compared to non-adhesive. This scenario is representative of someone using a sticky note, removing it from its pad, touching either or both the adhesive and non-adhesive areas and then placing it down on to another surface, albeit paper or something else.

Tertiary transfer of fresh natural latent fingermarks has also been demonstrated. It has been shown that it is possible to transfer a latent fingermark initially deposited on glass to paper or a second glass surface using a sticky note. The quality of the enhanced transferred fingermark on the tertiary surface depends on the initial fingermark quality, sticky note type and duration of contact, as well as the tertiary substrate type. The tertiary fingermark is of the same orientation as the original primary fingermark and from observation it may therefore be challenging to

differentiate whether a fingermark is a primary or tertiary deposit. As observed here, sticky notes can in some cases, e.g. on glass slides, leave behind traces of adhesive which are subsequently enhanced with powder and provide an indication that the surface may have been in contact with an adhesive material. Tertiary transferred fingermarks did display some characteristics previously reported for secondary transferred fingermarks [17].

This feasibility study builds on previous work focusing on secondary transfer. Whilst secondary and tertiary transfer were not seen for all samples, it has been shown that both mechanisms can occur when conditions are favorable. In the case of tertiary transfer, this was only on a relatively small number of occasions (49 out of 240 samples) and under specific 'ideal' laboratory conditions including freshly deposited latent fingermarks. Further only a small fraction of the tertiary transferred fingermarks were considered to be of useful quality and only scored a 3 (7 out of 240 samples). Therefore the likelihood of effective transfer of a useful and potentially identifiable fingermark through tertiary transfer using a sticky note is in reality low. Further work using older fingermarks is needed to fully establish the potential of tertiary transfer in realistic case scenarios. This work does, however, highlight the need to consider the handling and storage of exhibits, particularly those of an adhesive nature and the potential to transfer fingermarks whilst processing exhibits e.g. treating the adhesive and non-adhesive surfaces of tapes in sequence. Furthermore, this is not limited to adhesive surfaces and the potential transfer of latent fingermarks from one non-adhesive surface to another e.g. folded plastic wrapping or sheets of paper remains an area that also deserves exploration.

Ethics

Collection and processing of fingermarks for this study were approved by the Northumbria University ethics committee, reference number 41767. All donors read, understood and signed consent forms prior to participating.

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CRediT authorship contribution statement

Croxton Ruth: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing, Funding acquisition. **Mavroudi Dimitra Maria:** Conceptualization, Investigation, Methodology, Writing – review & editing. **Lonsdale Suzanne:** Investigation, Methodology, Writing – review & editing. **Allenby Brett:** Investigation. **Pepper Lucy:** Investigation. **Ashmore Sarah:** Investigation. **Gillott Jasmin:** Investigation.

Declaration of Competing Interest

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

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