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To glove or not to glove? Investigations into the potential contamination from handling of paper-based cultural heritage through forensic fingerprinting approaches

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ABSTRACT

The handling of cultural heritage objects has become a highly debated topic in the last decade. The work and outcomes described in this paper are aimed to provide objective data to assist in making appropriate decisions as to whether or not wearing gloves is appropriate in a given situation. The forensic fingermark development techniques of 1,2-indandione and single metal deposition II were used to investigate the efficacy of handwashing and glove use to improve the information available when deciding whether to use gloves when handling paper objects. It was found that fingermarks did not permeate through polymer glove types but could through cotton gloves. It was also shown that the amounts of observable fingermark residues were greater 5 min after handwashing than if handwashing had not occurred, undermining previous arguments for not wearing gloves if hands could be washed before object handling.

1. Introduction

There is significant debate concerning the wearing of gloves while handling paper-based cultural heritage objects within museums, archives, and conservation laboratories. Baker and Silverman's 2005 paper "Misperceptions about White Gloves" [1], has led to widespread reviews of handling procedures in such organisations. Arguments presented by Baker and Silverman against the use of gloves included concerns around the loss of tactile response of users when handling fragile documents and some evidence that cotton gloves are not sufficient to protect against sweat permeation when handling objects [1]. They also note that paper objects will have already been handled significantly by bare human hands before their collection. Baker and Silverman [1] concluded that simple handwashing with soap and water before handling paper-based collections provides adequate protection against soiling, without dulling the valuable sense of touch [1]. Changes in some cultural heritage institutions' recommended handling practices resulting from these arguments [2–8] include the use of handwashing rather than glove use when handling paper artifacts, and to a lesser extent the introduction of antibacterial gels. Despite the significant anecdotal evidence among collection staff that handwashing is sufficient to reduce visible grime on objects, no published scientific evidence exists to support their conclusion that handling paper artifacts with washed hands leaves minimal non-damaging contamination. In Baker and Silverman's [1] own words, "Given the widespread belief that routine handling of paper with bare hands chemically damages it, it is telling that our research uncovered no scientific evidence supporting this notion." However, absence of evidence is not evidence of absence, and an exploration of any potential impacts is warranted to support science-based collection handling guidelines.

The research presented here seeks to address the unproven assumption that clean hands do not contaminate objects in a meaningful way. The purpose of this research is to inform the debate on glove-wearing and glove alternatives so that conservators and curators can make an informed decision on their handling practices. The approach adopts a forensic mindset and employs forensic methods to assess whether ungloved contact with cleaned hands leave detectable traces on porous materials like paper. If fingermark deposition from clean hands

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can be established for paper artifact surrogates, an understanding of fingermark composition could then inform decisions on whether cumulative damage to the object is possible from these fingermark residues. Initially, however, Baker and Silverman's supporting statements - that the composition of fingermarks are predominantly water and that gloves do not offer protection from sweat permeation - can be questioned based on current forensic literature.

1.1. Fingermark composition

Baker and Silverman [1] state that fingermarks left by ungloved hands are composed mainly of water, which would be harmless if deposited on a paper substrate. They support this conclusion by misinterpreting Hurley [9], who states, "It (eccrine sweat) is composed of 99.0–99.5% water … " [1,9]. Kent (2016) dispels the myth that fingerprints are purely sweat, explaining that the residue on fingertips is far more complex and more closely approximates 20% water [10]. Moreover, due to human behaviors involving their hands: such as eating, unconscious grooming, and working; it does not follow that the components of a fingermark deposited on a surface are equivalent to sweat as these behaviors are likely to transfer other contaminates to hands [11].

There is a significant body of forensic related research exploring the chemistry of latent fingermarks that demonstrates their complex and variable composition. Research into the chemical nature of fingermarks has predominantly been driven by the need to understand the fundamental science behind fingermark detection methods [12,13]. As Houck and Smith [14] stated, cultural heritage chemistry is very similar to forensic science; in both mindset and approach. In this case, a significant and relevant body of forensic research can be used to help inform the former group.

Fingermark residue is composed of water-soluble and insoluble materials that roughly equate to eccrine and sebaceous secretions, respectively. However, this does not include external sources of hand contamination such as food and cosmetics. Eccrine glands are distributed over the entire body and are the only glands found on the fingertips [15,16]. Eccrine secretion comprises primarily salts and amino acids, with ratios of these components varying between people due to health, diet, and the individual's body matrix [15]. The sebaceous component consists mainly of sebum, a complex mixture of many molecular species such as wax esters, cholesterol, and squalene. These glands are located on most of the body, but not the hands and feet [17]. The presence of lipid components in fingermarks is a consequence of touching areas such as the face and hair during everyday activities [18,19]. Dorakumbura et al. [20] showed that fingermarks on non-porous surfaces are likely to exist as a complex emulsion. Further information on fingermark composition and analysis can be found in Girod et al. [11] and Frick et al. [13].

Discussing the question of glove use in handling culturally significant objects Kent [10] summarized "the amount of water in eccrine sweat is modified by evaporation and re-absorption" and that "most latent fingerprints contain additional sebaceous material" [10]. Based on their calculations and the published forensic literature regarding fingermark chemistry, Kent concluded that damage could be caused to irreplaceable artifacts by the "no gloves" policy as it has been previously shown that fingermarks may become visible if aged at 40–60 °C for six weeks [21,22]. While it is unlikely that paper objects will be stored under these circumstances, higher temperatures increase the aging of paper and fingermarks, and similar results would be expected to happen at lower temperatures over an extended period. Keisar et al. [23] found empirically that the water content of fresh fingermarks varied between 20 and 70% for different donors [23]. Moreover, the impregnation of fingermarks into paper surfaces has previously been demonstrated by Almog et al. [24] where it was shown that the amino acid content of latent fingermarks could diffuse into a paper surface to a depth between 40 and 60 μm. Latent fingermarks can also be very long-lived on paper documents. A recent study has demonstrated the detection of historic latent fingermarks on paper documents using the amino acid-sensitive reagent 1,2-indandione/zinc (IND) [25]. Fingermarks with forensically useful ridge detail were detected on a range of paper documents up to 90 years after deposition.

1.2. The protective roles of gloves

Personal safety should be the artifact handler's initial consideration; gloves have a role in protecting the wearer against the harmful effects of whatever they are handling. Hazards such as pigments containing mercury and arsenic, formaldehyde in anatomical specimens, and lead in sculptures are a few reasons why glove-wearing should be considered for protection when handling cultural objects [26]. For example, in a recent library investigation, four books bound in green painted covers in the collections of the University Library of Southern Denmark and the Library of Congress in Washington were found to be painted with a mixture of yellow orpiment (As_2S_3) and indigo. The researchers used industrial hygiene methods to assess the risk from handling and concluded that polymer gloves and a respirator must be worn to protect the user [26].

Baker and Silverman raise a valid point that cotton gloves are a potential vector for dirt transfer [1]. However, this is true of any glove when handling several objects consecutively. Although not noted by Baker and Silverman, this also occurs with bare hands, as demonstrated recently by Boseley et al. [27]. It was shown that simple handling of coins is enough to contaminate hands to allow transfer of metals from the coins to another surface. The concern of transfer-by-touch can be addressed by using a fresh pair of disposable gloves for different surfaces – already standard practice during the forensic examination of crime-scene exhibits sensitive to cross-contamination. This is another point in favor of disposoable nitrile over cotton gloves. In principle, cross-item contamination without gloves could ostensibly be avoided by cleaning the hands between every object touched, although this would require ready access to a handwashing station.

A recently identified concern for art conservators relates to the failure rates of disposable gloves [7]. However, all accessible medical and laboratory gloves must have an AQL (acceptable quality level) rating. This quality control rating relates to pinhead-sized holes in the gloves, and the lower the rating, the smaller the chances gloves have of containing defects in a given batch. An AQL of 2.5 (the standard rating for medical and laboratory gloves) allows only 25 failures for every 1000 gloves produced [28]. While the word failure sounds dramatic, it should be considered that this is a very low rate, and these failures would most likely not be important when dry handling cultural objects.

1.3. Previous handling studies

Considering the complexity of latent fingermark composition as discussed above, one must consider whether gloves offer an effective strategy for preventing fingermark residues being left on paper.

In a forensic context Willinski [29] determined that latex gloves were permeable to fingermark materials after 20 min, creating smudged glove marks on non-porous surfaces. In the case of cotton gloves, 60 min were required until permeation occurred. The recommendation from this study was for forensic scientists and examiners to double glove, first with cotton gloves, followed by a pair of latex gloves over the top. It is recognized that this approach would only exacerbate the loss of tactile sensation in art handling. This issue has not been revisited in the forensic literature for some time, despite changes to manufacturing processes and the introduction of nitrile gloves [30,31] that are a more effective chemical barrier compared to latex, which is why they are now the standard in most laboratories [32].

More recently, in a cultural heritage context, McKay [33] investigated the detection of fingermarks on paper surfaces using ninhydrin, an amino acid-sensitive fingermark detection technique [33]. McKay found that fingermarks could be detected from breakthrough with cotton gloves, but not nitrile gloves. McKay also showed that with accelerated aging for five days at 50 °C, fingermarks caused localized discoloration of the paper.

1.4. Aims

This investigation used forensic fingermark detection techniques to assess whether handwashing is sufficient to prevent fingermark contamination on paper handled bare handed. The possible permeation of fingermark residues through gloves was also explored, as was the alternative use of antibacterial gels, especially relevant in the present pandemic environment. Fingermark detection was carried out using the amino acid-sensitive reagent IND [34] as a proxy for the water-soluble components of fingermarks and the recently introduced technique single metal deposition II (SMDII) for the components of the sebaceous fraction [35].

2. Methods and materials

Six donors were recruited for each portion of this study. An effort was made to diversify age and biological sex; no identifying details of the donors were recorded on any samples taken.

2.1. Fingermark detection methods

IND is an amino acid-sensitive reagent for latent fingermarks on paper surfaces that is recognized for its sensitivity. IND is applied by briefly dipping a sample in a bath of acidified 1,2-indandione and zinc chloride solution. After the solvents have evaporated off the sample, it is then heated at 160 °C for 30 s. Once developed the IND-amino acid reaction product produces a characteristic pink stain that is luminescent when viewed under a blue-green light (505 nm) with an orange filter (Fig. 1a). IND reacts with the amino acids to form an analog of Ruheman's purple, while the zinc solution improves the fluorescence and stabilization of the fluorescent compound [36]. This approach allows for a more sensitive contrast over other detection methods [37]. In the study by McKay ninhydrin was used; IND was used as an alternative in this study as it is a more sensitive technique. Ninhydrin has been shown to fail to detect 24% of marks, whereas the false-negative rate of IND is only 1% [38]. The IND treatment is currently widely used for forensic purposes in multiple jurisdictions [25].

SMDII is a recently introduced alternative fingermark development technique that uses gold nanoparticles to visualize fingermarks on porous surfaces and produces a dark-colored stain (Fig. 1b). It can be used to detect latent fingermarks on wetted paper surfaces, and as such has been used in this paper as a proxy for the non-water soluble components of latent fingermark deposits. The choice of SMDII was made over other methods such as physical developer (silver nitrate) due to its reliability [35]. SMDII involves the deposition of gold nanoparticles from a colloidal gold solution onto the fingerprint's surface; this is followed by further enhancing the fingermark with an additional gold reduction step.

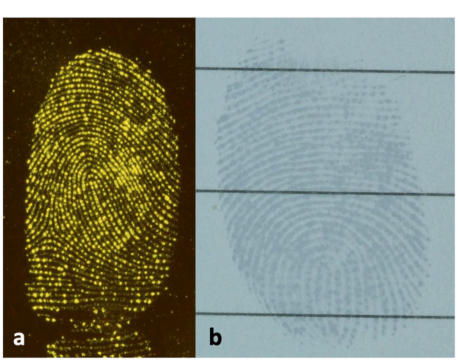

Fig. 1. A typical example of an (a) IND fingermark under blue light with an orange filter (b) SMDII developed fingermark. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Where fingermarks of both IND and SMDII were collected, a technique of split prints was used. A split print is when the center fingermark is split down the center of two different surfaces during collection (Fig. 2). A split print is used to reduce potential intra-donor variability [39]. Full details on the use and development of IND and SMDII can be found in the supplementary information.

The presence of other luminescent materials in the donors' fingermarks was ruled out by examining the fingermarks before development under a variable wavelength light source (Polilight PL500). The examination was performed under the same conditions used for viewing IND, at 505 nm with an orange filter.

2.1.1. Choices of paper

Fingermarks in this study were developed on copy paper with IND, and with SMDII when depostited on NU:World stone paper. Copy paper was chosen as it is easily accessible, and a single ream would be suitable to cover the entire project, so changes in a batch could not affect the outcomes. SMDII yields a more reliable development when used with the calcium carbonate-based paper surface typical of stone paper [35]. Although these two paper substrates do not accurately reflect all historic paper surfaces, they are representative of modern collections and thus present reasonable surfaces for testing.

2.2. Effects of handwashing on fingermark deposition

Donors washed their hands using a moisturizer free liquid hand soap and dried them using paper towels. Fingermarks were collected immediately after washing and at 5, 10, 15, 30, and 60 min elapsed periods. These fingermarks were then developed a day later using IND and SMDII. As a control for the handwashing experiment, fingermarks were collected before washing.

2.3. Effect of gloves on fingermark deposition

Donors' ungloved fingermarks were initially collected on white copy paper to ensure that their deposited fingermarks were measurable with the selected development techniques. Donors then wore a glove on one hand, while the other hand was left ungloved as a control. Twelve different gloves (see Supplementary Information Table 1) commonly available in Australia were investigated, including three material types - nitrile, cotton, and vinyl - for each experiment. Gloves were purchased from a range of locations, laboratory suppliers to hardware stores, to cover the potential manufacturing quality ranges. In all cases, the gloves used were listed as powder-free by the manufacturer, a common stipulation for conservation settings as the powder can contaminate or stick to objects. Only one brand of vinyl gloves was tested as this type of glove tends to be poor fitting and would not likely be suitable for conservation

Fig. 2. Schematic diagram illustrating a split print over two types of paper.

use. Latex gloves were not used as the risk of donors being allergic to the rubber component was considered too high.

2.3.1. Permeation of fingermark residue through gloves

Six donors wore a glove on one hand for up to 2 h with their arm slightly extended and avoiding touching any objects or themselves. This procedure prevented contamination of the outer glove surface. Every 15 min, each donor pressed the middle three fingers from their gloved hand against white copy paper for 3 s. The donors were asked to use a consistent medium pressure for each sample. The fingermarks left from the gloved fingers were developed using IND. SMDII was not considered as a developer at this stage as the fingermarks collected should be predominantly amino acid based as glands do not produce sebum on the hands. In all cases, as a control, the ungloved hand was simultaneously used to produce reference fingermarks on paper to ensure the donors' marks were consistently detectable.

2.3.2. Contamination and transfer of fingermark residues from common touch surfaces

Donors were asked to touch different surfaces while wearing a glove, and glove marks were immediately collected in the manner described above and subsequently developed with IND. SMDII was again not used as IND was deemed sufficient to identify transfer.

Donors were also asked to open a door handle while wearing gloves to simulate a common touch surface that might contaminate gloves if handled. In this experiment, only the Ansell® "Touch'n tuff" nitrile glove and a cotton glove were tested. The door handle used is the main access point to the office area for the laboratory, and the experiment was performed towards the end of the working day, after it had been handled multiple times by other staff and students.

To investigate the effects of sebum on fingermark deposition of gloved hands on paper, donors were also asked in a separate experiment to touch their face and hair with clean gloves as they might commonly do, e.g., running fingers through hair, as this is habitual human behavior. All donors touched both their faces and their hair. These glove marks were collected as above and developed with IND.

2.4. Effects of antibacterial gels on fingermark residue

To assess the effect of transfer of hand sanitizer, and to gauge if hand-sanitizers are a reasonable alternative to handwashing, donors were asked to use three different antibacterial gels available in Australia: Aqium® antibacterial hand sanitizer, Dettol® instant hand sanitizer original, and Dettol® instant hand sanitizer moisturizing. These were selected by purchasing the most sold products from local pharmacies. Both the Aqium® and Dettol® moisturizing version contain added moisturizers in their formulations, whereas the Dettol® original, does not. Donors tested these antibacterial gels on different days to avoid contamination between the different gels. The donors were asked to apply the gels to their hands according to the product instructions: "Apply 1–2 pumps to palm, spread and rub over back of hands and fingertips, allow hands to air dry" (Aqium®) and "Squeeze 1.2 tsp amount in your palm then briskly rub hands together until dry" (Dettol®). Fingermarks were collected on paper before the antibacterial gel was applied and also 5 min after application to allow for complete air drying of the gel solvent.

3. Results and discussion

3.1. Handwashing

Fingermarks were collected before and after handwashing at intervals within an hour. These fingermarks were developed with both SMDII and IND. Fingermarks were still detected even after handwashing and were seen for all 6 donors. A representative set of developed fingermarks is presented as Fig. 3. In this study a more strongly colored fingermark image is being taken as an indication as a higher quantity of fingermark residue having been deposited. Five minutes after handwashing, the deposits of fingermark residue are higher for all donors than the fingermarks deposited before handwashing and it continues to increase until the 30 min mark. The levels of developed prints only return to the initial values around the 1 h mark. This pattern was observed for both SMD and IND developed fingermarks. This change in the level of fingermark deposition is likely due to the skin attempting to return to its natural moisture levels. This is similar to handwashing pH studies where the pH of hands and nails begin to return to normal after 20–90 min [40, 41]. The higher-level deposit in the present study is most likely due to the over-production of skin secretions in this equilibration process, part of the skin barrier response to handwashing. This is the first time that this response to handwashing has been demonstrated in fingerprint detection research. To achieve low levels of contact deposition, handlers of paper objects would need to rewash their hands at unacceptably frequent intervals, and no amount of handwashing appears to protect objects from contamination transmitted through contact with bare hands.

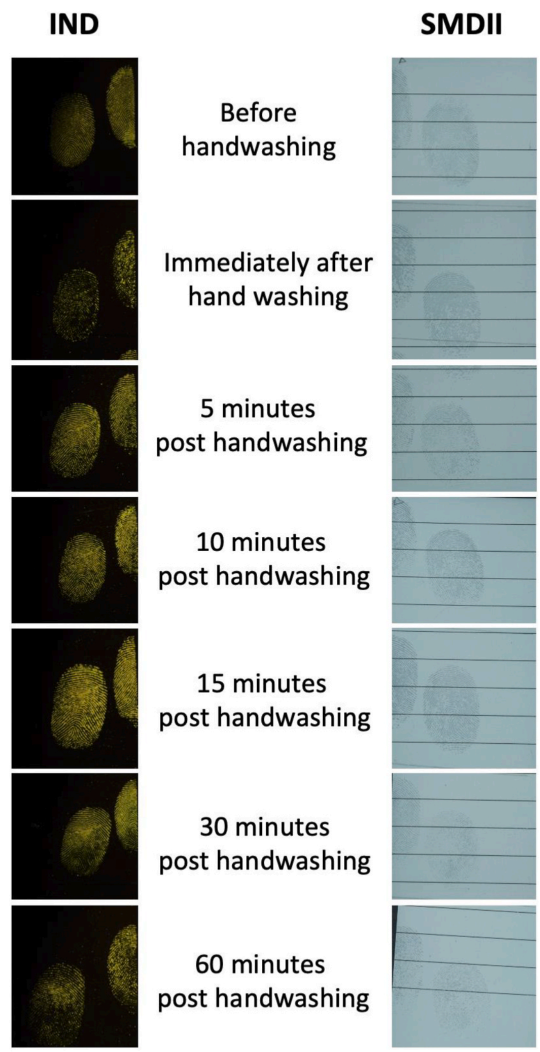

Fig. 3. Fingermarks collected as split prints post handwashing. Developed with IND (left) and SMDII (right).

3.2. Use of gloves

Donors were initially asked to wear a glove for up to 2 h and not touch surfaces with their gloved hand. However, due to skin irritation caused by wearing synthetic gloves (nitrile and vinyl) for such long periods without removing them, only fingermarks deposited up to 1 h were collected. The most likely cause of this irritation is due to perspiration and a lack of ventilation inside the glove [42]. The irritation was not experienced with cotton gloves, as the woven nature of the glove allows for air movement and wicking of perspiration away from the skin surface.

In the case of synthetic gloves, no fingermark components were detected. In the case of cotton gloves, one donor of the six left a faint smudge at the 1 h mark (Fig. 4). The smudge was not identifiable as a fingermark but was in the expected area of the fingermarks to develop. All donors left detectable fingermarks with their ungloved hand. This shows that synthetic gloves perform slightly better in preventing the breakthrough of fingermarks. It is significant that there is very little to no transfer of fingermark residue through gloves when worn appropriately.

In the case of the nitrile gloves for all donors, a glove print was collected on paper after touching the door handle (Fig. 5). However, the cotton glove did not create a developable print even after touching the contaminated door handle. This experiment was also repeated with donors touching their hair and face wearing gloves, and the same results were seen with nitrile and cotton gloves. The touching of faces and hair is considered a normal behavioral habit and commonly occurs even while wearing gloves. In the case addressed by Johnston et al. [43], a mean of 2.6 hand-to-face contacts were made per hour by laboratory workers wearing gloves. It is important to note that even if clean nitrile gloves are put on by a user, contamination can still be picked up from hair and face touching and transferred to other objects. Overall this shows that no matter which type of gloves are chosen, incorrect glove hygiene when handling of objects will not prevent fingermark contamination of surfaces; cotton gloves will allow for breakthrough and nitrile gloves will allow contamination transfer.

3.3. Antibacterial gels

Antibacterial gels have become a common alternative to handwashing in archival reading rooms and are also pervasive in the pandemic environment in which these experiments were conducted. Donors were asked to use three types of antibacterial gel and deposit a fingermark (Fig. 6). Very little change is seen between the natural fingermark and the fingermark after using the Dettol® Original sanitizer (Fig. 6c). However, a noticeable increase in the developed fingermark deposit was observed after using the moisturizer version of Aqium® (b) and Dettol® (d). The common factor between these two antibacterial gels is the added moisturizers in the product formulas, which are amino acid based and most likely reacted with the IND. This shows that simple product use, such as antibacterial gels that are assumed to evaporate, can have transfer effects and contribute to fingermark residues. Similar results were seen by Chadwick et al. [44] when they investigated if fingermark development methods are affected by hand sanitizers. More recently, the Library of Congress [45] showed that hand sanitizer, when artificially aged, discolored a paper surface.

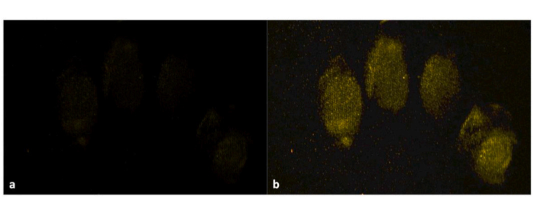

Fig. 4. Faint development of fingermark secretions through a cotton glove (a) unaltered image (b) image with brightness increased by 75%.

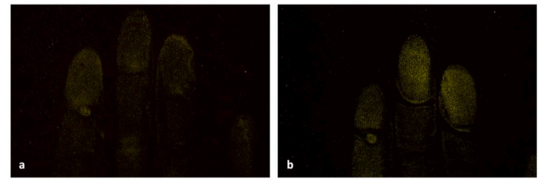

Fig. 5. Glovemark developed with IND (a) from touching door handle (lb) from touching forehead.

3.4. Interpretation

By applying forensic fingermark detection techniques to assess the effect of handwashing, we have shown that soap and water do not prevent the transfer of fingermarks to paper surfaces. These fingermarks are known to contain significant amounts of non-volatile materials, both organic and inorganic. Previous studies have shown that fingermarks penetrate into paper surfaces, persist over long periods, and can darken paper when artificially aged. We have also shown that excretion residues are not entirely removed from fingers even immediately after handwashing. Importantly, those deposits initially increase after handwashing – achieving their highest level approximately 15–30 min after washing – before eventually returning to normal levels. The depositional changes are most likely due to the skin over-producing secretions to make up for those lost in the washing process [40,41].

Therefore arguments equating handwashing with ordinary soap and water to skin "cleanliness," while appearing to follow good judgment, are in fact contrary to observable evidence provided by this study [1]. These results demonstrate that handwashing may not be sufficient to remove fingermark contaminants from the hands if the goal is to prevent contamination of paper surfaces and to reduce the risk of alteration of handled objects.

As shown by Kent and contrary to claims by Baker and Silverman, fingermarks are not composed of sweat nor are they 99–99.5% water, but instead contain a more complex combination of lipids, salts, and amino acids. It should be noted that the detection techniques used in this study target the organic components of latent fingermarks. Recent work has also demonstrated that inorganic components from cosmetics may also be present [27]. Fingermarks have been shown to become visible brown marks after being aged at relatively low temperatures, and McKay's artificial aging experiments on paper surrogates confirms this [33]. Further research needs to be conducted into the interactions of fingermarks and paper; however, we know that fingermarks are persistent and can be detected on 90 year-old documents [25]. As this research proves that fingermarks on paper-based documents, books, and artworks cannot be prevented with simple handwashing, archives and cultural institutions should reconsider their object handling guidelines in light of this evidence.

4. Conclusions

The current study has shown that while wearing polymer gloves (nitrile and vinyl), no transfer of fingermark residues is experienced through a glove even after an hour of wear. Clean cotton gloves were found to have some evidence of permeability after an hour, but they proved more resistant to the transfer of contamination from common touch surfaces. While gloves are not infallible and do result in a loss of tactile sensation, selection of well-fitting gloves meeting relevant quality standards can mitigate these issues.

Considering that handwashing is not sufficient to protect objects from contamination, alternatives utilized in the field such as the use of gloves or antibacterial gels has also been studied. Results of this work show that antibacterial gels do not reduce the levels of fingermark deposits and may in fact increase them if a moisturizing component is present. Antibacterial gels work on the premise of killing germs rather

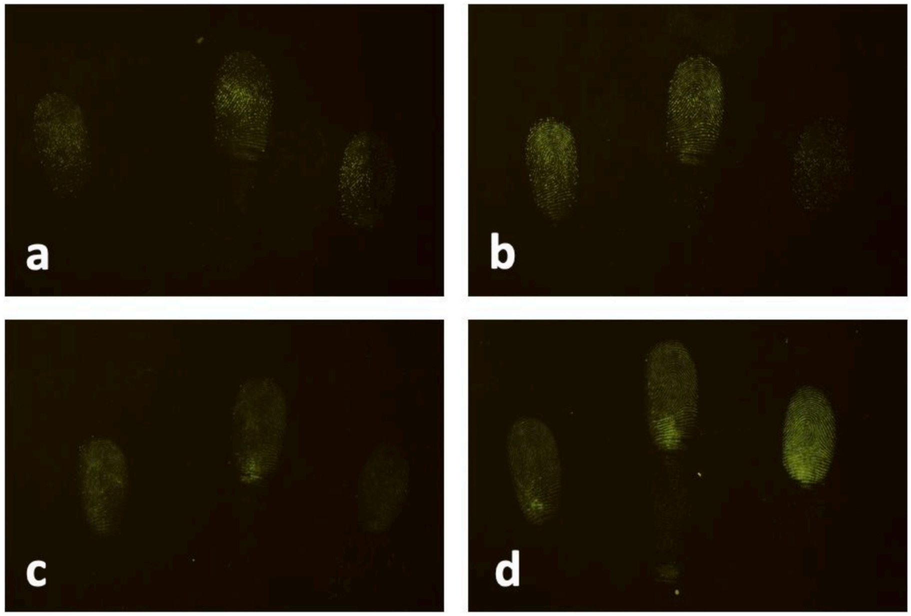

Fig. 6. Fingermarks from a single donor using antibacterial gels (a) natural fingermark (b) Aqium® antibacterial hand sanitizer (c) Dettol® instant hand sanitizer original (d) Dettol® instant hand sanitizer moisturizing.

than removing dirt and oils as would be expected when washing hands with soap and water and would not remove exogenous contamination.

With glove-wearing comes the glove wearer's responsibility not to contaminate the surface of the glove. If the glove wearer should touch their face or other contaminated surfaces, they will pick up fingermark resides or other contaminants on the outside of the glove. Poor glove-wearing technique is not an inherent fault of gloves themselves and can be overcome with appropriate education and could be mitigated by frequent re-gloving. It should be considered that this study only addresses the contamination of gloves from touching items and surfaces – not from issues relating to the state of the gloves "as new," and this needs to be examined in future work.

Ultimately it is up to the conservator to use this work to make an educated decision on the best way to handle objects knowing that handwashing is not sufficient to remove fingermark contamination and that synthetic and cotton gloves have both benefits and disadvantages in reducing contamination.

Practical aspects of this research were conducted before the emergence of COVID-19 and its subsequent declaration as a "public health emergency of international concern" by the World Health Organization in January 2020. Changes in community behaviors such as the frequency of handwashing, use of antibacterial gels, and cleaning of common touch surfaces are expected to have occurred. The authors recommend following local health authorities' instructions and insist this research does not constitute medical advice.

Disclaimer

As Guest Editor of the Special Issue and an Editorial Board Member of FSI Synergy respectively, Greg Smith and Simon Lewis had no involvement in the peer review of this manuscript. Peer review was handled by the FSI Synergy Editorial team.

CRediT authorship contribution statement

Karin J. van der Pal: Conceptualization, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Rachel S. Popelka-Filcoff:** Supervision, Writing – review & editing. **Gregory D. Smith:** Supervision, Writing – review & editing. **Wilhelm van Bronswijk:** Supervision, Writing – review & editing. **Simon W. Lewis:** Conceptualization, Project administration, Supervision, Writing – review & editing.

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fsisyn.2021.100160.

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