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ORIGINAL ARTICLE

# Determination of latent fingerprint degradation patterns—a real fieldwork study

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**Abstract** For over a century, law enforcement agencies, forensic laboratories, and penal courts worldwide have used fingerprint impressions as reliable and conclusive evidence to identify perpetrators of criminal activity. Although fingerprint identification has been repeatedly proven as one of the most robust and definite forensic techniques, a measure of the rate at which latent fingerprints degrade over time has not been established effectively. Ideally, criminal investigators should be able not only to place any given individual at a crime scene but also be able to date the moment any latent fingerprints were deposited at the location. The present report aims to determine particular visual patterns of degradation of latent fingerprints exposed to certain monitored laboratory conditions simulating those in the field. Factors considered include temperature, relative humidity, air currents, composition of fingerprint depositions (sebaceous and eccrine), various exposures to daylight (direct, penumbra, and darkness), and type of physical substrate (glass and plastic) over a period of 6 months. The study employs a titanium dioxide-based powder as developer. Our results indicate that, contrary to common belief, certain latent fingerprints exposed to direct sunlight indoors degrade similarly to those in the dark where environmental conditions are more constant. While all sebaceous latent fingerprints on glass are still useful for identification after 6 months, diverse results are obtained with impressions on plastic; these demonstrate a much higher and faster degree of decay, making identification difficult or impossible, especially for eccrine depositions.

**Keywords** Fingerprint · Degradation · Pattern · Powder developer

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## Introduction

One of the greatest challenges facing forensic scientists today is determining the specific time at which a latent fingerprint was deposited and doing so with a proven methodology that will find acceptance in courts of law. When powder developers are used for visualization, this is even more difficult. There are two primary reasons for this: the numerous factors involved during deposition/preservation of latent fingerprints and the absence of standardized protocols that could be applied in analysis, despite several attempts at research conducted on this issue [1]. While there are no doubts about the universal acceptance of fingerprints for personal identification, determining the instant at which the impression was deposited is crucial, especially in situations where a suspect has had previous or subsequent legitimate access to a crime scene. In many instances, defense attorneys have been able to successfully invalidate otherwise solid fingerprint evidence by questioning the time at which an impression was left at the scene.

To shed some light on this complex and challenging issue, the authors of this study developed a practical experiment based on a real-world case. In the early morning of 9 May 2011, a restaurant in the city of Esplugues de Llobregat, Barcelona, was burglarized. Among other targets were a slot machine located on the premises which was forced open and its containers of coins emptied. Approximately 5 h after the crime, forensic experts of the Catalonia Police Force—Mossos d'Esquadra—successfully developed one latent fingerprint located on a polystyrene (plastic) container used for coin collection inside the machine. The impression was developed by "dusting" with a commonly used titanium dioxide-based powder. A suspect was identified and subsequently interviewed. This individual, a Caucasian male in his 30s, provided investigators with the alibi that he worked for the slot machine company, that he had collected the deposited coins 6 months prior to the burglary, and accordingly, had had legitimate access to the machine's inner components. Forensic specialists were unable to determine the time at which the latent fingerprint was deposited, so no charges could be filed.

There was a 6-month interval between the actual crime and the date the suspect stated he last accessed the inner components of the machine. The authors of this study designed an experiment to determine how latent fingerprints visually degrade over time, taking into account the potential environmental conditions that the questioned fingerprint in this scenario may have been exposed to during that time period. The visual analyses were conducted on powder-developed latent fingerprints that had been exposed, prior to "dusting," to certain environmental conditions. Adhesion of powder reagent was used as an indirect qualitative method of evaluating latent fingerprint visual degradation over time. Using the test results as indicators, the authors then estimated the approximate date the suspect's fingerprint could actually have been deposited at the crime scene, and whether the suspect's 6-month alibi could therefore be reasonably questioned.

## Using fingerprints as forensic evidence

Latent fingerprints, also referred to in this report as latent fingermarks, are depositions of friction ridge skin and are the result of the deposition of naturally secreted substances from skin glands (see below) [2–5]. Usually, latent fingermarks remain where they have been placed until they are obliterated by some physical or chemical action. The durability or lifespan of a latent fingerprint is the length of time during which it can be processed or developed to a point where it can still be reliably correlated to its donor.

Although physical evidence, such as latent fingermarks, undoubtedly determines an individual's presence at any crime scene, it is far more difficult to date the instant of latent fingerprint deposition beyond indirect observational signs, mostly based on the individual expertise of the investigator. For example, forensic experts in the field commonly use indirect visual indicators such as powder adhesion, ridge continuity, and grease diffusion, among others, to gauge the approximate "freshness" of a latent fingerprint. However, with no formal guidelines or protocols, conclusions can be inaccurate and/or imprecise with little probative value in a court of law. Crime scene investigators also have to consider any potential contamination of the scene due to intentional or unintentional fingerprint depositions left by unrelated persons.

## Factors that determine the degradation of latent fingerprints

Despite all the technological advances in fingerprint science, no relevant studies have been conducted to estimate general or particular observational patterns of latent fingermark degradation based on visual analyses of powder-developed depositions. This is due largely to the number of variables involved and the combination of circumstances that influence the progression of latent fingerprint deterioration. In order to determine the suitability of latent fingerprint examination techniques, four general factors should be considered:

1. Donor (depositor);
2. Substrate (receiving surface);
3. Donor/substrate physical and chemical interactions;
4. Environmental conditions.

Donor conditions include rate of sweat, amount and composition of secretions, age, health status, mental stress, race, and gender, among others. The substrate should be evaluated for its temperature and physical and chemical properties. Surface characteristics include dryness, adhesive property, size, shape, smoothness, type of material, cleanliness, and porosity. In relation to the interaction between donor and substrate, the following should be considered: pressure produced at the time of deposition, angle and length of contact, physical and chemical reactions with the specific surface, and type of foreign contaminants present such as dust, grease, and blood [6, 7]. Environmental conditions include, among others, temperature, insolation, i.e., intensity and duration of direct and indirect exposures to natural light, air currents, and relative humidity. Given the above, investigators would expect that latent fingermarks would evolve differently on distinct substrate types depending on the particular combination of several of these diverse factors.

## Composition of latent fingerprints and mechanical developer of choice

Latent fingerprints are composed of the natural secretions of glands in the skin. These are the sudoriferous (eccrine and apocrine) and sebaceous glands [1, 8]. Eccrine gland secretions, i.e., "sweaty" impressions are from fingers, hands, and feet. Apocrine glands are associated with hair follicles of the armpits and pubic area, and their contents usually mix with sebaceous products. Sebaceous secretions, i.e., "greasy" impressions are not present on the friction ridge surfaces of the hands and feet. However, sebum is usually found on the hands as a result of touching other parts of the body, such as the face, head, or arms [7, 9].

For non-porous surfaces in situ at crime scenes, powdering is still considered as the primary physical detection procedure; it is the most cost effective and easy-to-use and is available to most police departments and forensic laboratories despite its lower sensitivity compared with chemical developers [10]. In the powdering process, the crime scene investigator "dusts" with a powder reagent, and the particles of the developer adhere to residues left by friction ridge skin in contrast with the colored background surface [10].

## Objectives of the study

Attempting to replicate all the real-world environmental conditions in which forensic scientists encounter friction ridge depositions is impossible. However, the authors of the present study designed an experiment that includes several of the most common factors, as well as certain specific situations correlated to the field case.

In the experiment, researchers employed both types of fingerprint secretions, eccrine and sebaceous, from a single donor. Polystyrene[1] was used as a sample substrate to simulate the field condition, and glass was used for reference as an ideal surface for preservation and development. Although both substrates were non-porous, the authors chose to compare these two materials owing to their unique physical and chemical characteristics, for example, their density and permeability [11]. Insolation or solar radiation, temperature, and relative humidity were monitored for each experimental indoor and outdoor condition. A white-colored titanium dioxide-based powder was utilized as developer after latent fingerprints were exposed to defined experimental climate conditions. This reagent is regularly employed for the visualization of latent fingerprints on dark non-porous surfaces by attaching to the moisture and oily components contained in the deposition [1, 7, 10, 12].

Research was performed over a 6-month period with the following specific objectives:

1. Identify and describe any visual differences in the degradation patterns of latent fingermarks subject to certain controlled and/or monitored indoor conditions that most closely replicate those in the field case after being visualized with powder developer.
2. Select the necessary criteria to establish the aging chronology of a single donor's latent fingerprints.
3. Determine the effect of each selected environmental factor under analysis.
4. Define any particular patterns of latent fingerprint degradation based on observational indicators.
5. Estimate the approximate age of latent fingerprints from the field by extrapolation of experimental results.

There are standard observational or qualitative indicators of latent fingerprint degradation as they occur during the aging process. These physical parameters were utilized as indirect signs of latent fingerprint deterioration, in contrast to direct analytical methods, such as chemical analysis of the components of sweat [7, 8, 13]. The indicators that investigators considered were:

- Diffusion of fingerprint secretions on the substrate
- Loss of adhesive property of ridges to the powder reagent
- Narrowing of the fingerprint ridges
- Loss of continuity along the fingerprint ridges
- Increasing width of furrows
- Decreasing number of identifiable macroscopic dactyloscopical elements (minutiae) [14].

Although the entire surface of each developed deposition was accurately analyzed for the parameters described, the specific area of choice for minutiae examination was exclusively the core region of the fingerprint since it has shown to be the most reliable, i.e., minutiae are easily and frequently imprinted with lower skin distortions and better quality [15]. The authors recorded the number of minutiae as the most objective analytical parameter, data that have been included under the broader term "visual quality of latent fingerprints" together with the other factors considered.

It should be noted that this report is the first part and basis of a more extensive and in-depth experiment which would consider other factors that may influence the rate of degradation of latent fingerprints; these include differences in donor age, race, gender, health conditions, physical substrates, etc. Ideally, further exploration in this area could provide a new approach to a complex and unresolved issue of great relevance to criminal investigators and courts of law.

# Materials and methods

## Sample preparation

Two non-porous materials, glass and polystyrene, were used as deposition surfaces. These were accurately washed with 70 % ethanol, followed by distilled water in order to remove any likely interfering materials. A single fingerprint donor, a 33-year-old Caucasian male, was used for all impressions of both sebaceous and eccrine secretion types. For sebaceous-rich latent fingerprint samples, the donor's hand was not washed for at least 1 h prior to deposition. Before each

[1] It should be noted that polystyrene here refers to hard plastic, not the foamed product, i.e., styrofoam.

imprinting, the donor's fingers were allowed to recharge by rubbing across an oily region of the face, such as nose or forehead. Eccrine-rich latent fingerprint samples were prepared by allowing the donor's clean hands to become sweaty from exercise and/or rubbing the fingers on sweaty surfaces of arms or dorsal sides of the hands. To minimize the natural variation of pressure and angle application, the donor's hand was guided by another investigator throughout the imprinting process, placing the fingers with constant, firm pressure parallel to the surface for 1 s. The donor deposited two latent fingerprints (middle and ring finger) of the right hand onto glass, i.e., regular microscope slides, and three latent fingerprints (index, middle, and ring finger) of the same hand onto polystyrene, once for each of the three distinct light exposure indoor sites according to three experimental daylight exposure conditions. The experiment was conducted in an access-controlled laboratory of 6 $m^2$ with no air conditioning or active air currents, i.e., a closed environment. Latent fingerprint categories by indoor location consisted of the following: (1) direct exposure to sunlight ("LIGHT" group) through a double-glazed glass window (CLIMALIT® SGG STADIP ®); (2) indirect exposure (penumbra) at 1.5 m from the window ("MEDIUM" group); and (3) absolute darkness in a confined dark-walled containment in the same area ("DARK" group).

A total of 30 single depositions were prepared for each of the 11 collection time periods: 18 impressions on polystyrene (nine each, eccrine and sebaceous) and 12 impressions on glass (six each), except for collection time 0 when six impressions were deposited on polystyrene (three each); and four on glass (two each) totaling 310 single latent fingermarks deposited on the same morning (collection time 0). These samples were placed horizontally in the respective three indoor locations previously described and suspended 3 to 5 mm from the support surfaces to minimize any heat transfer that could potentially distort the progression of deterioration. The baseline quality of impressions was visually assessed at the time of deposition using a magnifying glass against the light.

## Environmental conditions

Investigators classified environmental factors as variable, fixed, and constant. Variable factors included temperature (°C), relative humidity (RH%), exposure time to daylight (hours), and intensity of natural light (lux) between July and September. These were non-controlled but monitored by the authors. Fixed characteristics were air currents, substrate types (glass and polystyrene), sample location (designated as "LIGHT", "MEDIUM," and "DARK"), and type of latent fingerprint with regard to its secretion type (eccrine and sebaceous). These were the subjective factors established by the investigators and the basis of the experiment. Constant factors included donor, pressure applied to the substrate and its angle, duration of deposition, powder developer, and discrete frequency of latent fingerprint development over time. These did not vary throughout the experiment and were the same for all sites and collection periods. As referenced above, outdoor environmental parameters measured were temperature (Temp), RH%, and insolation. They were recorded next to the window and designated as "EXTERIOR" group.

Variable factors were regularly recorded in the restricted access area to document any undesired environmental disturbances and ultimately, to determine their effect on latent fingerprint degradation. Temp and RH% were measured regularly at different random day times using a standard digital thermometer and hygrometer. Intensity of natural light was measured five discrete times over a period of 24 h, between September and December, using a portable digital lightmeter (Chauvin-Arnoux®) in *lux* units, quantifying solar radiation at an angle parallel to that of sample surfaces and inferred for the totality of days. Data for July and August had to be extrapolated from the measured values obtained. Air currents were minimized by restricting any access to the experiment area. Ultraviolet (UV) light absorption data through the double-glazed window were obtained from the SGG STADIP specifications manual.

To provide correlations between laboratory results and data in the field case, Temp and RH% were recorded on three occasions inside a slot machine of the same brand and model as the original. These data, referenced as "INSIDE" group, were collected on separate days with all machine doors closed allowing the device to function non-stop for 30 min and for 24 h prior to measurement. In addition, data were recorded from the machine functioning for 1 week, disconnecting it every night to simulate original field conditions. These environmental conditions were as close as possible but may not be exactly analogous to those inside the original machine, as it was destroyed during the burglary and no original data could be recovered. The original machine was not exposed to direct light at any time and was unplugged every night as reported by its owner.

Statistical tests, paired *t* tests, and ANOVA were performed using IBM-SPSS® Statistics 20.0 computer software. The analyses involved paired values and group comparisons for each of the environmental factors analyzed, i.e., Temp, RH%, and insolation data, between locations, i.e., EXTERIOR, LIGHT, MEDIUM, DARK, and INSIDE, in order to characterize them statistically at a 95 % confidence interval of the difference (CI).

## Latent fingerprint collection and development

Latent fingerprints were successively developed over a period of 6 months at 11 discrete collection times, selected randomly from the pool of sample sets between the months of July and December. Starting on the same day of deposition (collection time 0), ten additional developing times were established at days 7, 14, 21, 28, 49, 70, 91, 112, 140, and 170. Fresh titanium dioxide mixture was applied to all latent impressions throughout the experiment. A total of 310 individual fingermarks were developed by the same investigator with an unused fiberglass brush (Sirchie®): 124 on glass and 186 on polystyrene. Powder reagent was carefully applied to avoid over-powdering, and excess material was wiped off with a squirrel hair brush (B.V.D.A. INTERNATIONAL B.V) to minimize background staining. At each interval, samples were photographed under constant laboratory artificial lighting (Philips® GENIE 11 W) using a digital camera[2].

### Image standardization and qualitative analyses

In order to study in detail the visual quality of each powder-developed latent fingermark at the appointed interval without additional degradation or compromising factors, the respective photographic image was analyzed. Each fingerprint image was scaled 1:1 and color enhanced adjusting grayscale levels (black/white contrasts) to a standardized white background using photograph-editing computer software. Visual image analyses of samples and comparisons considered several latent fingerprint features, including powder adherence, ridge width, continuity and contour definition of ridges, diffusion of powder reagent, distance between ridges/valleys, number of identifiable minutiae, and global visual degradation over the 24-week period. These visual parameters were independently evaluated by two forensic scientists to determine the degree of degradation and the subsequent identification of latent fingerprints. The evaluation was blind, i.e., the analysts were not informed of the collection period of the sample. In order to calculate the number of minutia, a 1 $cm^2$ area from the core region was delimited. Then, two random counts were performed on the best preserved latent fingerprint ($n$=124) from each location and substrate type. The average minutiae count and STD for collection period 0 (day 0), collection period 5 (day 49), and collection period 10 (day 170) were plotted as representative of each condition (Table 1).

Each powder-developed latent fingerprint ($n$=310) was subjectively assigned a score based on visual quality as seen in the respective digital image (Table 1):

- Samples designated with + + +, + +, and + could be easily identified by the investigator and presented each one of the selected visual parameters at the highest degree of quality.
- Samples designated with - displayed lower quality of some visual parameters and were hardly identifiable.
- Samples designated with - - and - - - presented few or none of the visual parameters considered, and identification was not possible.

Although all powder-developed latent fingerprint images were examined and particular deterioration patterns drawn by comparing the same fingers per factor, only the images of best visual quality were shown in the summary table due to space constraints (Table 2). These were representative images for each specific pattern of degradation per collection periods 0, 5, and 10, plotted by location, surface type, fingerprint nature, and environmental factor.

## Results and discussion

Analyses were performed to objectively determine any statistical difference between each light exposure location for the factors considered (Table 3). After evaluating the degree of visual latent fingerprint degradation in the laboratory, investigators could conclude which environmental factor(s) may have been the most influential per site. Ideally, the results could be extrapolated to the field case and provide a closer realistic estimate of the time at which the questioned latent fingerprint was deposited. The naturally occurring environmental factors were not manipulated at any time by the researchers, avoiding any biased or artificially altered effects on the results. The aim was to simulate, as close as possible, the natural variability of environmental conditions in the field.

### Temperature, relative humidity, air currents, and insolation at each location

The range of Temp at EXTERIOR (E), LIGHT (L), MEDIUM (M), and DARK (D) locations was accurately determined: E presented the widest range of measured values, i.e., highest variability, while D values were the most constant of all sites (Fig. 1 and Table 3). Statistical tests indicated that range of Temp among locations was significantly different ($p<0.05$). The standard deviation (STD) and mean temperature values per location (Table 4) were also noted (see Electronic Supplementary Material, ESM).

The range variability of RH% per site is summarized in Table 3 (see ESM for further details). Statistical tests indicated that the only not significant differences were observed between L–M ($p$=0.429) and L–D ($p$=0.063) (Fig. 2 and Table 3). These results could be explained either because L and M have very similar average RH% values or because the wide range of RH% of the L sample group would include the values of M and D. Although analyses

[2] ISO 100, f/3.4, 1/60 s shutter speed

**Table 1** Summary of latent fingerprint visual quality and number of minutiae at three different collection times after continuous exposure to environmental factors

| | | Surface type | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Glass | | | Polystyrene | | | |
| | | Collection day | | | Collection day | | | |
| | | 0 | 49 | 170 | 0 | 49 | 170 | |
| Latent fingerprint type | Greasy | + + +(37±1)** | + + +(32±1) | + + +(25±1) | + + +(35±1) | + +(23±4) | -(9±4) | Light |
| | | + + +(37±1) | + + +(33±2) | + +(17±4) | + + +(35±1) | +(22±4) | -(6±2) | Medium |
| | | + + +(37±1) | + + +(33±2) | + + +(31±2) | + + +(35±1) | + +(21±1) | + +(20±4) | Dark |
| | Sweaty | + +(15±3) | + +(24±2) | +(15±1) | + + +(34±2) | -(5±1) | - - -(0±0) | Light |
| | | + +(15±3) | +(21±3) | +(17±2) | + + +(34±2) | - [a](7±0) | - - -(0±0) | Medium |
| | | + +(15±3) | + +(27±3) | - -(0±1) | + + +(34±2) | - -(3±2) | - - -(0±0) | Dark |
| | | | | | | | | Light exposure site |

(+ + +, + +, +)=identification; (-)=hardly identifiable; (- -, - - -)=no identification

[a] Sample corresponds to collection period 7 (day91)

** Indicates average number of minutiae and STD

determined there were no significant differences among the ranges of these groups, investigators focused on the ranges' amplitude per location rather than comparisons between paired individual values. Then, again, RH% was determined to be the most constant at D throughout the experiment (Table 4).

No specific studies were performed with regard to the effect of active air currents in the evaporation of water content of samples. Investigators considered this effect negligible because samples were kept in a closed, relatively warm and humid room at all times[3], except when data readings were obtained and latent fingerprints collected. Under these environmental conditions, the evaporation rate was assumed to be constant [16]. However, investigators did not discard this factor if any differences in sample degradation were observed.

Insolation values were calculated based on intensity and duration of natural light exposure. For each successive latent fingerprint development period, solar radiation values were estimated and summed up successively, as accumulative insolation: overall accumulated solar radiation values at E, L, M, and D as shown in Fig. 3 (see ESM for further details). Statistical tests indicated that the accumulated radiation and each sample's insolation per period at every location were significantly different ($p<0.05$) from any other (Fig. 3). According to the CLIMALIT® SGG STADIP® manufacturer, more than 95 % of the UV light irradiated by the sun was being absorbed by the double-glazed window, so this component of solar radiation was not further studied.

Time span of exposure to direct interior sunlight (DE) and to indirect daylight (IL) were also recorded to assess the variability of this factor during the experiment and then extrapolated for the remaining days (see ESM for further details). As expected, both direct and indirect exposures to natural light decreased over time. These data were used to calculate accumulative solar radiation values for each discrete collection period. Temp and RH% ranges inside the slot machine of reference are summarized in Table 4.

## Patterns of degradation and climate-influencing factors on sebaceous and eccrine latent fingerprints

### *Sebaceous latent fingerprints*

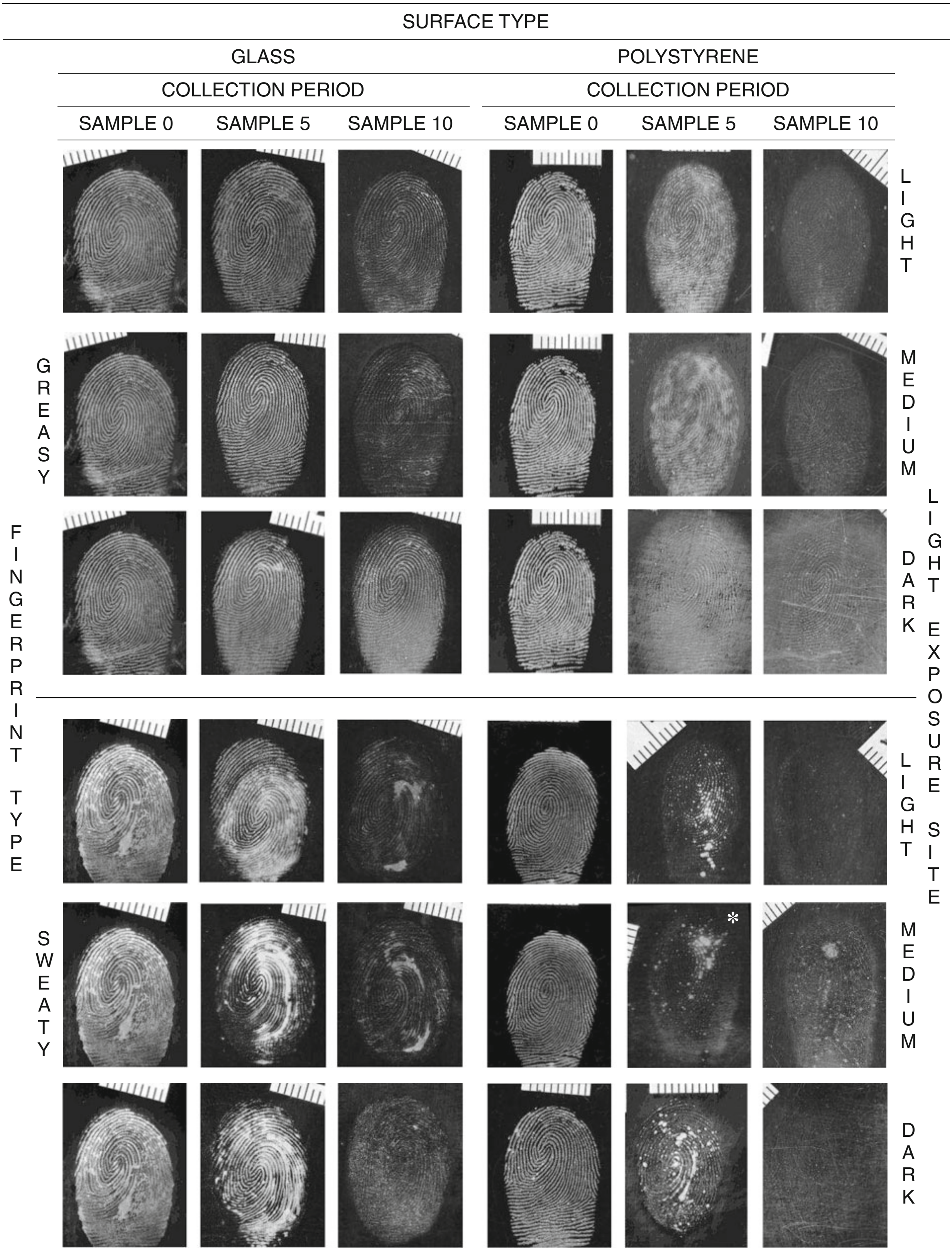
To best describe the particularity of the aging process, investigators divided results into three categories, as described below.

1. Progression of latent fingerprints on glass and polystyrene over time

*Glass substrate* No major visual differences were observed between the initial impressions and the nine subsequent collection periods of sebaceous latent depositions powder-developed on glass (up to 5 months) for any of the light exposure sites. Powder adhesion was slightly better for samples preserved in the dark, coupled with slightly increased powder diffusion between ridges, which may have been caused by powder reagent sticking to smearing grease in this particular condition. Contour ridge definition, thickness and continuity of ridges, and number of identifiable minutiae were analogous for all samples, presenting altogether a remarkably high-color contrast with the background (Table 2). Unexpectedly, all latent fingerprints on glass from every location were visually very similar in quality once dusted,

[3] Range Temp=17 to 35 °C, range RH%=27 to 71 %

**Table 2** Depiction of representative powder-developed samples by surface, location, and latent fingerprint type over time (image scale 1:1.25)




Sample 0 = day 0; sample 5 = day 49; sample 10 = day 170

[a] This sample was from period 7 (91 days of natural interior light exposure)

**Table 3** Statistical significance and range reduction between light exposure locations

| | | Environmental factor | | | | | |
|---|---|---|---|---|---|---|---|
| | | Temperature (°C) | | Relative humidity (%) | | Accumulative Insolation (lux) | |
| | | Paired *t* test (sign.) | % range reduction between locations | Paired *t* test (sign.) | % range reduction between locations | Paired *t* test (sign.) | % range reduction between locations |
| Light exposure site | Light–medium | 0.000 | 36.4 | 0.429 | 52.3 | 0.002 | 99.4 |
| | Light–dark | 0.000 | 42.6 | 0.063 | 68.2 | 0.002 | 100 |
| | Light–exterior | 0.000 | 21.8 | 0.000 | 39.7 | 0.002 | 80.2 |
| | Medium–dark | 0.000 | 9.8 | 0.002 | 33.3 | 0.001 | 100 |
| | Medium–exterior | 0.000 | 50.2 | 0.000 | 71.2 | 0.002 | 99.9 |
| | Dark–exterior | 0.000 | 55.1 | 0.000 | 80.8 | 0.002 | 100 |

implying that depositions aged very much alike and were perfectly identifiable after 5 months. Investigators had assumed that degradation, especially in light vs. dark conditions, would be very different. As it turned out, this was not the case. For example, the minutiae count for the same finger deposition at collection period 9 for L ($n$=30±1) and M ($n$=32±3) were similar enough to their respective initial values to support the idea that degradation was not apparent or occurring. However, for depositions at D ($n$=17±3), the quantity of minutiae observed decreased approximately 50 % compared with the initial count, yet this reduction did not prevent good sample identification. This decreased quantity of minutiae was not detected for the final collection period 10; we surmise that the lower number of macroscopic elements observed in period 9 was due to the particular quality of the deposition and not the product of the "natural" progressive degradation of the sample.

*Polystyrene substrate* The quality of latent fingerprints on polystyrene showed much more difference and variability for the same time periods. A halo of powder reagent, possibly due to grease diffusion, appeared in most developed samples after the first week, especially noticeable on those preserved in the dark. Over time, this effect became more pronounced, with larger extension of the halo around the developed depositions, again in the dark. Samples exposed to direct interior sunlight showed the least prominent halos, ridges became thinner, and lighter color contrasts with the background were observed, in comparison to impressions in the dark. At M, developed latent fingerprints shared similar visual features with those at L and D (Table 2). Although still potentially identifiable, degradation of all depositions progressed over time and was obvious for all cases. This visual deterioration was also observed as a decrease in the number of minutiae detected at collection period 9 for M ($n$=20±3) and D ($n$=18±4). The number of minutiae at L ($n$=29±4) was relatively unchanged compared with the initial deposited samples. However, after one more month, i.e., collection period 10, latent fingerprints at L and M presented a significant decrease in minutiae count and overall worse visual quality.

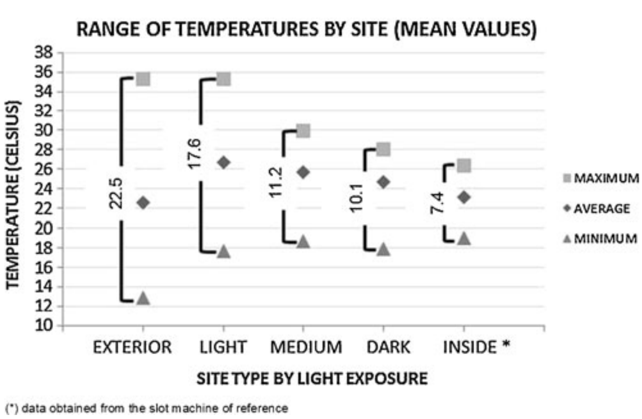



**Fig. 1** Range of temperatures by site

2. Description of the final powder-developed latent fingerprints on glass and polystyrene

*Glass substrate* At the end of the experiment, collection period 10 (6 months), sebaceous depositions on glass exposed to direct natural light degraded similarly to samples in the dark. At L, developed impressions presented no or little diffusion of powder reagent, i.e., grease, and displayed thicker ridges. They showed lower powder adherence compared to impressions in complete darkness, and accordingly, less color contrast with the background. At M, samples presented similar visual features to those at L but with thinner ridges. All powder-developed depositions on glass were useful for visual identification. Unexpectedly, according to the parameters examined, greasy developed latent fingerprints at L and D were equivalent in quality to samples at M, presenting the highest degree of visual deterioration (Table 2). As mentioned, investigators had expected samples at L to be far more degraded than those at D. The

**Table 4** Summary of STD, range, and mean values by factor and light exposure location

| | | Environmental factor | | | | | |
|---|---|---|---|---|---|---|---|
| | | Temperature (°C) | | | Relative humidity (%) | | |
| | | STD (95 % CI) | Range values | Mean values | STD (95 % CI) | Range values | Mean values |
| Light exposure site | Exterior | 4.7 | 22.5 | 22.6 | 17.1 | 73 | 65.7 |
| | Light | 4.2 | 17.6 | 26.7 | 9.5 | 44 | 47.3 |
| | Medium | 2.6 | 11.2 | 25.7 | 3.8 | 21 | 48.0 |
| | Dark | 2.3 | 10.1 | 24.8 | 2.2 | 14 | 49.3 |
| | Inside[a] | 2.5 | 7.4 | 23.2 | 8.2 | 22 | 36.5 |

[a] These data correspond to the slot machine of reference

number of identifiable minutiae slightly decreased over time, except for samples at M where macroscopic dactyloscopical elements were reduced 55 %. Nonetheless, this reduction did not affect the visual qualification of the respective depositions once the remaining observational parameters were considered (Table 1).

*Polystyrene substrate* More diverse results were obtained with those powder-developed depositions on polystyrene. Samples presented a higher degree of powder diffusion, probably of grease, for all; a prominent halo of powder reagent was observed for impressions at D, a feature not detected for samples on glass, including a much lower color contrast with the background. Impressions at L and M presented loss of ridge continuity, lower powder adherence, and thinner ridges. This made visual identification more challenging (Table 2). In this case, visual degradation in the final collection period was different for each substrate type and exposure site, and generally worse than powder-developed latent fingerprints on glass. Samples at D presented higher powder adherence and a much higher degree of powder diffusion than depositions in the other locations. In this condition, dusted latent fingerprints were still identifiable at the end of the experiment. Developed impressions at M appeared to age similarly to samples exposed to direct natural light, except for the presence of the halo, which presented the lowest visual quality throughout. Minutiae count decreased very significantly (75 – 80 %) for depositions at L and M but not for D (30 %) (Table 1). In this case, more stable conditions in the dark were a key factor in better powder development of depositions.

It is worth mentioning that the overall "quality of latent fingerprints" shown in Table 1 does not necessarily correlate with the number of identified minutiae, basically due to the other physical parameters considered for the qualification of samples. Therefore, depositions with the same or similar count of minutiae may display a different value of visual quality.

3. Influence of experimental factors in the durability of latent fingerprints

*Glass substrate* Environmental factors for latent fingerprints developed on glass seemed not to result in any remarkable visual differences among samples (Table 2). In this situation, higher solar radiation and wider range variability of RH% did not influence the overall permanence or final visual identification of depositions. Accordingly, these factors may have played little role in the degradation of latent fingermarks, including the UV component of light filtered through the window glass. The absence of major

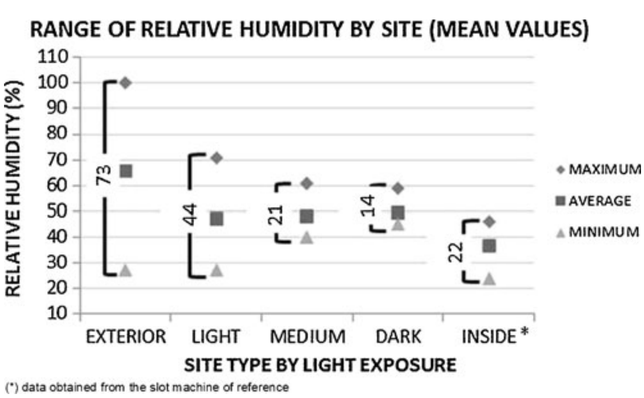



**Fig. 2** Range of relative humidity by site

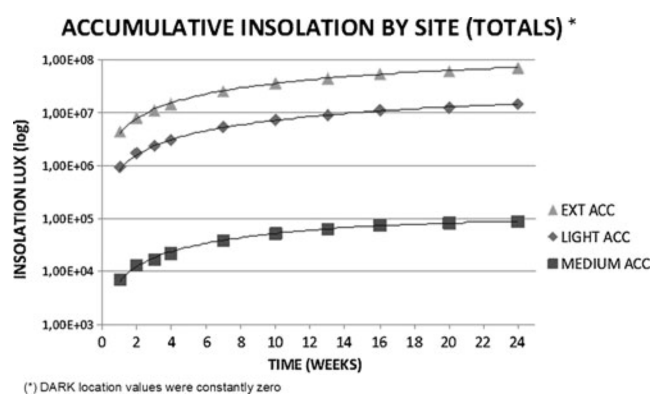



**Fig. 3** Accumulative insolation by site over time

visual differences between samples at L and M could be explained by the fact that the damaging oxidative effect of UV light was being reduced significantly [17]; the glass of the window protected samples from potentially more severe degradation that might have occurred if otherwise exposed to direct sunlight outdoors. Temperature was the least variable of factors in range percentage and cannot be discarded as an influencing factor on degradation since no visual differences could be observed among developed samples. Apparently, solar radiation appeared to fix or desiccate samples on glass, making samples easier to visualize rather than degrading them. Depositions exposed to direct natural light were slightly better preserved than those in penumbra, and their visual quality was similar to those in the dark. Powder adhesion to "desiccated" latent fingerprints could be explained either because the powder developer attached to the remnant moisture of the impression due to the source of water vapor from the air and/or because the reagent bound to chemical components of the grease other than water [1]. This "fixing" effect was not observed for latent depositions aged and successively developed on polystyrene substrate.

*Polystyrene substrate* On polystyrene, the narrower ranges of Temp and RH% in the dark, i.e., more constant climate values, improved the preservation and subsequent visualization of samples (Table 2). Of the factors studied, insolation, with the highest range reduction between sites in percentage (100 %), were the least influencing of factors for the durability of latent fingerprints. This is because a narrower range variability of Temp and RH% affected the samples similarly to those under the effect of much higher insolation, as seen, for example, between depositions at L and M (Table 3). Differences in the nature of substrate materials also play a role in the diverse performance of latent fingerprints between glass and polystyrene. For example, the presence of a halo in those samples developed on polystyrene, and their generally poorer visual quality under the same environmental conditions as compared to those on glass demonstrates a very clear difference in latent fingerprint durability based on substrate.

In summary, powder development and potential identification of sebaceous latent fingerprints were more easily achieved on glass surfaces than on polystyrene. For example, thicker and better continuity of ridges, higher color contrast, and more minutiae were observed for depositions on glass, corroborating previous studies [1, 3]. This difference was observed in all three light exposure situations analyzed, where samples were all easily identifiable, and with only slight visual differences. In this instance, the effect of solar radiation, i.e., possible fixation of secreted sweat components, would counteract the degradation effects induced by greater ranges of Temp and RH%. By the end of the experiment, it appeared that visual quality was generally better in conditions of darkness with more constant Temp and RH% on polystyrene surfaces as compared to those with full exposure to light. In this particular case, exposure to solar radiation would favor the preservation of samples to a certain extent, but at the final collection period, this effect was reduced and had finally a negative influence.

*Eccrine latent fingerprints*

As with the previous section, results were organized in three areas.

1. Progression of latent fingerprints on glass and plastic over time

*Glass substrate* Again, no major visual differences were observed between the initial depositions and the nine subsequent collection periods of eccrine latent fingerprints powder-developed on glass (up to 5 months) for all exposure sites. Powder adherence slightly decreased for all depositions over time, as well as width and continuity of ridges and number of identifiable minutiae. Visual differences were observed only toward the last collection periods as minor thinning of ridges (Table 2) and a reduced number of macroscopic elements, especially for depositions at M and D. Latent fingerprints from every location evolved similarly and could still be potentially correlated to the donor after 5 months. However, eccrine samples were not as contrasted or clear as sebaceous depositions. For instance, the minutiae count at collection period 9 was 20±2 at L, 12±3 at M, and 9±3 at D. It was further noted that depositions at D appeared to be visually degrading at a faster rate than at other locations, although samples were still identifiable.

*Polystyrene substrate* The quality of eccrine latent fingerprints on polystyrene was different for each location (Table 2). Generally, no pronounced halo of powder reagent was observed for any of the samples, although impressions at M and D occasionally presented some degree of powder diffusion, which could be attributed to particular deposition or climate conditions of the sample. Over time, ridge continuity for all latent fingerprints was compromised—ridges became thinner, and they showed a lighter color contrast with the background. This was especially noticeable after collection period 7 (13 weeks). Although potentially identifiable for depositions at L and M, visual degradation became very obvious over time. Samples preserved at D were hardly identifiable and presented the greatest visual degradation of all, as indicated by the loss of powder adherence, greater ridge discontinuity, lower minutiae count, and thinning of ridges. In this particular case, impressions at M evolved overall like latent fingerprints exposed to direct interior sunlight. The number of minutiae at collection period 9 (5 months) was 15±4 at L, 5±3 at M, and 4±3 at D. Although M and D presented the lowest count of minutiae, L and M more closely resembled each other visually.

2. Description of the final powder-developed latent fingerprints on glass and polystyrene

*Glass substrate* At the final collection period 10, powder-developed eccrine latent fingerprints on glass at L and M were, unexpectedly, still potentially identifiable, unlike those at D, where minutiae were not sufficient in number and quality for identification. Loss of powder adherence and considerable discontinuities and thinning of ridges (Table 2) were observed. Samples preserved at M degraded similarly to those at L but were much better in quality than those at D. In this case, the absence of direct solar radiation and more constant environmental conditions did not apparently improve the development of latent fingerprints over time. Qualitative differences of dusted depositions between non-confined (L and M) and confined group samples (D) could not be attributed to the effect of air currents because impressions at D became more degraded than those at L and M. The number of minutiae decreased very significantly for samples at D (100 % reduction) dropping to zero at collection period 10 (Table 1). However, reduction for samples at L and M was equivalent and enough in number for proper visual identification.[4]

*Polystyrene substrate* By collection period 10, powder-developed latent fingerprints on polystyrene were not useful for identification for any of the locations, although samples at L visually degraded at a slower rate than those at M and D and were potentially identifiable for a longer period of time (up to 5 months). The least damaged depositions when visualized with powder reagent were impressions at M, where some random ridges could still be observed, although insufficient for a positive identification. All samples deposited and developed on polystyrene were completely obliterated by the end of the experiment. Compared with sebaceous latent fingerprints, the degree of powder diffusion was minimal (Table 2), and the number of minutiae was zero for all light exposure conditions (Table 1).

3. Influence of experimental factors in the durability of latent fingerprints

*Glass substrate* In terms of environmental factors, higher solar radiation resulted again in better powder development of latent fingerprints on glass in comparison with those on polystyrene. This was especially noticeable by the final collection period. Additionally, smaller ranges of Temp and RH%, i.e., more constant conditions, in the dark did not result in a significantly better visual quality of developed depositions; on the contrary, contour ridge definition decreased, and fewer minutiae were progressively identifiable over time (Table 3). The previously noted principles of UV light filtering through the double-glazed window apply in this case as well.

*Polystyrene substrate* On polystyrene, insolation and more constant Temp and RH% did not contribute to better long-term preservation and visualization of powder-developed latent fingerprints because all impressions were finally obliterated (Table 2). Solar radiation did not degrade samples significantly in comparison with direct light-deprived latent fingerprints of the same periods (Table 1).

To sum up, glass was again a better substrate for eccrine latent fingerprint powder development and identification than polystyrene. For example, eccrine depositions on polystyrene were compromised earlier as observed at collection period 5, where impressions on polystyrene were difficult or impossible to visually identify in comparison with samples on glass. Direct solar radiation did not significantly increase the rate of latent fingerprint degradation when compared to the other light exposure locations. And finally, more stable Temp and RH% did not improve the visual quality nor did they extend the lifespan of eccrine latent fingerprints in the laboratory.

## Extrapolation of experiment results to the real-world case study

Investigators attempted to correlate the experiment results to the original field case by comparing the most similar laboratory environment data with the field-case environment and applying the relevant latent fingerprint degradation pattern.

Laboratory and crime scene powder-developed latent fingerprints were compared based on insolation data, substrate type, secretion nature, variability of Temp and RH% ranges, and their statistical STD. The aim was to categorize the original latent fingermark (left by the suspect at unknown deposition time) into the specific pattern identified in the experiment (Table 4) with which it would have the highest physical resemblance. Accordingly, based on climate data calculations, the questioned deposition[5] would have aged similarly to impressions preserved at M[6] or at D[7] on polystyrene substrate. Then, qualitative, or visual,

[4] The quality of the initial depositions for this specific condition was not as good as the other impressions, hence the initial low number ($n$=15±3) of minutiae count (Table 1).

[5] Range RH%=22 %; range Temp °C=7.4 °C; $RH_{STD}$=8.2; $Temp_{STD}$=2.5; $RH\%_{MEAN}$=36.5 %; $Temp_{MEAN}$=23.2 °C

[6] Range RH%=21 %; range Temp °C=11.2 °C; $RH_{STD}$=3.8; $Temp_{STD}$=2.6; $RH\%_{MEAN}$=48 %; $Temp_{MEAN}$=25.7 °C

[7] Range RH%=14 %; range Temp °C=10.1 °C; $RH_{STD}$=2.2; $Temp_{STD}$=2.3; $RH\%_{MEAN}$=49.3 %; $Temp_{MEAN}$=24.8 °C

comparisons between powder-developed latent fingerprints from M and D and the questioned impression were performed. Common visual parameters between the groups included high continuity and contour definition of ridges, high-color contrast with background, absence of powder diffusion, and nonexistence of a halo. Assuming that an eccrine-rich latent fingermark was recovered from an inner plastic component of the original slot machine, we could reasonably infer that the questioned latent fingerprint may have been deposited earlier than 6 months, bringing into question the initial statement made by the suspect. The preliminary data presented herein would allow investigators to estimate, with reservations, that the suspect's latent fingerprint might be between 0 and 3 months old.

While not accurate to the day or week, we are nonetheless given a much more powerful tool with which to return to the suspect's alibi and scrutinize it with a higher level of certainty. Further conclusive, detailed and extensive data need to be obtained to finally confirm or deny the results described. These will be the subject of future studies.

### Limitations of the present study

The authors note that at this early stage, certain limitations exist in this approach to drawing conclusions and extrapolating experimental results to the field. Some of these limitations have been noted throughout the manuscript, and can be grouped as pre-deposition, deposition, and post-deposition [1, 18]:

Pre-deposition limitations comprise variability in the composition of fingerprint secretions among donors (inter-variability) and with the same donor (intra-variability) [19], including different age, gender, race, pathologies, and toxics present, as well as physical parameters such as erosion of fingerprint ridges, etc. Regarding inter-person variability, the objective of the present report was focused on analyses of the particular patterns of visual degradation of a single individual's eccrine and sebaceous latent fingerprints developed with powder reagent under specific conditions over time; any analyses incorporating a larger population sample would be outside the scope of this study. In terms of intra-person variability, investigators minimized this factor by depositing all experimental samples within a time frame of 4 h.

Deposition limitations include, among others, the substrate, shape, smoothness, cleanliness, contaminants, and temperature, as well as the pressure and the angle applied, and the duration of contact between the donor and the substrate. A multitude of substrate types exist that could have been analyzed, but our research focused mainly on two types of non-porous surfaces, suggested by the conditions in the field case. The exact same types of deposition surfaces were used throughout the experiment.

Finally, post-deposition conditions are factors that affect the quality of latent fingerprints after being imprinted. Examples of these parameters are climate factors such as relative humidity, temperature, winds, and insolation, which were accounted for in the experiment design. Research was conducted indoors as this condition closely replicated the field case. In addition, outdoor factors could be more numerous, variable, and uncontrollable, complicating or inhibiting the collection of any conclusive results. These uncontrollable factors could be, for example, rain, strong winds, pollution, etc., which would heavily interfere with the progression of latent fingerprint deterioration and add difficulty in interpreting results. While analysis of latent fingerprint degradation in outdoor conditions is an equally important question, it falls outside the domain of this specific case study. The amount of developing reagent applied, powdering technique, brush types, daytime of development, photography conditions, and personal expertise of the investigator are important factors that could influence the final outcome of latent fingerprint detection and quality. The effect of these factors was minimized by using a single investigator with extensive experience in latent fingerprint powder development and photography. When interpreting individual sample degradation, investigators evaluated observational signs of deterioration as indirect measurement of latent fingerprint aging process, as opposed to chemical or molecular analyses which may not be easily available in the field for crime scene investigators. For example, Raman spectroscopy is a sensitive technique currently in use for the visualization and analyses of latent fingerprints based on their chemical composition [20].

Physical appearance of powder-developed latent fingermarks remains one of the central tools that experts in the field have available to differentiate "fresh" from "old"; the extent to which the circumstances described above impact the degradation of latent fingerprints and their subsequent powder development will be the subject of future research by our laboratory.

## Conclusions

The main objective of the study was to determine particular patterns of degradation of latent fingerprints over time subject to certain monitored experimental conditions. The experiment corroborates some previously published data related to latent fingerprint degradation, for example, that better preservation occurs on glass substrates rather than plastic and that greasy samples are potentially identifiable for longer periods of time than sweaty specimens [3].

However, this study noted some new and previously unexpected results:

1. Insolation through a double-glazed window does not necessarily have a significant visual impact on latent fingerprint degradation compared to samples preserved in the dark. This unexpected result could be explained because secretions deposited indoors exposed to direct interior natural light are possibly "fixed" on the substrate, adhering their chemical components to the material and maintaining some of the properties to which powder reagents can attach. Alternatively, however, a possible explanation for this outcome is that the powdering technique used is not sensitive enough to detect minor visual differences between these two environmental conditions.
2. Evolution of each group of deposited samples (eccrine/sebaceous) is remarkably different depending on the substrate (glass/polystyrene), even under the same environmental conditions (Table 1). Generally, greasy or sebaceous samples were shown to be more durable and resilient after 6 months than sweaty or eccrine depositions, making their visual identification easier when using powder developers. It is interesting to note that latent fingerprints in penumbra evolved similarly to those exposed to direct sunlight, implying that direct natural light exposure indoors may not be as significant for latent fingerprint degradation as expected; quite the opposite, it has been demonstrated to be beneficial in certain cases.
3. Environmental factors reveal a distinct effect on the development of latent fingermarks in the laboratory depending on the substrate deposited, as seen for the same type of finger secretion in the same location. In some other cases, the climate factors analyzed apparently have little or no differential effects on samples in different locations, as for deposited sebaceous impressions on glass. Therefore, it is believed that a balance of the unique combination of factors in each specific condition contributes to the successful development and identification of latent fingerprints. Then, the same exact factors combined differently result in a very different outcome; accordingly, the combination of factors should be carefully considered when dealing with latent fingerprints. This is quite significant if (1) latent fingerprints need to be preserved for extended periods of time in the laboratory before development and (2) there is the need to determine approximate deposition times of questioned latent fingerprints using powder developers, without the requirement of expensive equipment or advanced technical expertise that may not be available at the field location or that may be excessively time consuming for the criminal case under study.

It appears that greater solar radiation does not necessarily imply a higher degree of latent fingerprint degradation indoors or add difficulties in the powder development of depositions. On the contrary, in some cases, incidence of solar radiation in the laboratory aided the preservation of samples, while locations deprived of natural light and with more constant environmental conditions showed no increase in the lifespan or quality of powder-developed latent fingerprints for successful visual identification. Therefore, in order to preserve fingerprint samples, experts should consider the possibility that solar radiation may be the least damaging of environmental factors and that more constant Temp and RH% are not always beneficial for optimal preservation.

As for the extrapolation of laboratory results to the field case, the authors believe that the experiment shows encouraging preliminary results that demonstrate the possibility of dating powder-developed latent fingerprints using portable and inexpensive equipment that can be useful for field experts. Further analyses are needed for these initial conclusions to yield evidence acceptable for use in courts of law. In reference to the original field case, as of the present time, no formal charges have been brought against the suspect.

The conclusions and hypotheses described herein are not definitive and provide only the first suggestions for future research. Our intention is not to universalize any of the conclusions but rather to explore new methods for the characterization of latent fingerprint degradation patterns. We believe that continued research in the area of latent fingerprint evolution and the effect of combined environmental factors may offer tremendous value for law enforcement agencies by providing fast, powerful, and reliable crime-fighting tools.

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