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Investigating the Developmental Capacity of Latent Fingerprints Exposed to Cold Weather Conditions: An Experimental Study

Soğuk Hava Koşullarına Maruz Kalan Latent Parmak İzlerinin Gelişim Kapasitesinin Araştırılması: Deneysel Bir Çalışma

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ABSTRACT Objective: Fingerprints are one of the oldest and most common types of forensic evidence linking the crime scene to the criminal and play an important role in identification due to their unique pattern sequences. The multifaceted examination of fingerprint evidence obtained at crime scenes allows the preservation of evidence structure in forensic science applications and its re-analysis in forensic trials. However, the effectiveness of fingerprint development methods varies significantly depending on the characteristics of the surface used and environmental conditions, especially temperature and time. This study aims to investigate the development capacity of fingerprints on porous and non-porous surfaces under low-temperature conditions (-160°C, -80°C, -20°C and 0°C). **Material and Methods:** Using cyanoacrylate vapor and ninhydrin methods, 800 fingerprint samples from 10 donors were evaluated at different temperatures and durations (1 day, 1 week, 1 month, 2 months, and 3 months). Statistical analyses were performed with SPSS v25 software, and the significance of the data was examined by applying chi-square and t-tests. **Results:** The results showed that all fingerprints stored in closed boxes (71%) showed higher identification success than those stored in open environments (38.8%). In particular, fingerprints developed more successfully on non-porous surfaces such as glass (65.8%). The ninhydrin method was less effective at low temperatures on porous surfaces. **Conclusion:** The study emphasizes the negative effects of cold weather conditions on fingerprint development and reveals the importance of using closed environments for evidence preservation. It also provides important contributions to evidence-collection processes under cold weather conditions in forensic sciences.

Keywords: Fingerprinting; fingerprint development methods; cyanoacrylate; ninhydrin; climate and environment

ÖZET Amaç: Parmak izleri, suç mahallini suçluyla ilişkilendiren en eski ve en yaygın adli kanıt türlerinden biridir ve benzersiz kalıp dizilerine sahip olmaları nedeniyle kimlik tespitinde önemli bir rol oynamaktadır. Olay yerlerinde elde edilen parmak izi delillerinin çok yönlü incelenmesi, adli bilimler uygulamalarında delillerin yapısının korunması ve adli yargılama süreçlerinde yeniden analiz edilmesine olanak tanımaktadır. Ancak, parmak izi geliştirme yöntemlerinin etkinliği, kullanılan yüzeyin özelliklerine ve çevresel koşullara, özellikle de sıcaklık ve zamana bağlı olarak önemli ölçüde değişmektedir. Bu çalışma, düşük sıcaklık koşullarında (-160°C, -80°C, -20°C ve 0°C) gözenekli ve gözeneksiz yüzeylerde parmak izlerinin gelişim kapasitesini incelemeyi amaçlamaktadır. **Gereç ve Yöntemler:** Siyanoakrilat buharı ve ninhidrin yöntemleri kullanılarak, 10 donörden alınan toplam 800 parmak izi örneği, farklı sıcaklık ve sürelerde (1 gün, 1 hafta, 1 ay, 2 ay, 3 ay) değerlendirilmiştir. İstatistiksel analizler SPSS v25 yazılımı ile gerçekleştirilmiş ve ki-kare ile t-testi uygulanarak verilerin anlamlılık düzeyi incelenmiştir. **Bulgular:** Kapalı muhafaza kutularında saklanan tüm parmak izlerinin (%71), açık ortamlara göre (%38,8) daha yüksek kimliklendirme başarısı gösterdiğini ortaya koymuştur. Özellikle cam gibi gözeneksiz yüzeylerde (%65,8) parmak izlerinin daha başarılı bir şekilde geliştiği tespit edilmiştir. Ninhidrin yönteminin ise gözenekli yüzeylerde düşük sıcaklıklarda daha az etkili olduğu belirlenmiştir. **Sonuç:** Çalışma, soğuk hava koşullarının parmak izi gelişimi üzerindeki olumsuz etkilerini vurgulamakta ve delil muhafazasında kapalı ortam kullanımının delil olabilme niteliğini önemli ölçüde etkilediğini ortaya koymaktadır. Ayrıca adli bilimler alanında soğuk hava koşullarında delil toplama süreçlerine önemli katkılar sunmaktadır.

Anahtar Kelimeler: Parmak izi; parmak izi geliştirme yöntemleri; siyanoakrilat; ninhidrin; iklim ve çevre

The transition between the victim, the perpetrator, and the crime scene is explained by Locard's Principle, known as "Every contact leaves a trace". Accordingly, when 2 objects come into contact with each other, some material is transferred from one to the other. In other words, a suspect leaves something

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at the crime scene or the victim and takes something away from the crime scene or the victim. For this reason, forensic science is considered to start at the crime scene.[1] One of the important purposes of crime scene investigation is to conduct fingerprint research to identify the perpetrator. Fingerprints are among the important pieces of evidence that contribute to solving forensic cases. Their features include high-proof power, simple, fast, effective transferability, and an economical identification tool. Fingerprints are one of the oldest forensic evidence linking the crime scene to the criminal and are based on the assumption that everyone has a unique set of patterns on their fingertips.[2]

The type of fingerprints they belong to varies according to their formation mechanism. Visible prints are formed by staining the fingers with substances such as blood, ink, or paint, while invisible prints are those that are invisible to the naked eye. Embossed prints are formed by pressing the fingers on soft surfaces, such as clay, dough, and putty. The most common fingerprints encountered at the crime scene are invisible ones. Invisible fingerprints are composed of organic and inorganic compounds such as water, lipids, amino acids, and proteins.[3]

Factors such as the surface on which the print is located, the color of the surface, and the organic or inorganic compounds deposited on the surface affect fingerprint development methods.[4,5] Powders, light sources, or chemicals are used to develop prints.[6] Identifying the surface where the fingerprint is located is necessary to select the appropriate fingerprint enhancement technique or reagent.[7] Therefore, the most important step in selecting a fingerprint development method is to determine the type of surface on which the fingerprint can be found. These surfaces are divided into 2 classes: porous and non-porous. Non-porous surfaces are characteristically non-absorbent and, therefore, more prone to degradation of fingerprint residues. These include glass, metal, plastic, polished, or painted wood. Cyanoacrylate (CA), painting methods and fingerprint powders, Sudan black, crystal violet, sticky side, amido black, and Small Particle Reagent (SPR) are usually the best options to use on these surfaces. Porous surfaces are often absorbent and include materials such as paper, cardboard, wood, and other forms of cellulose. Fingerprints left on these media are absorbed into the substrate and are durable. Amino acid reagents provide particularly effective fingerprint development on these surfaces. These techniques include iodine vapor, 1,2 indandione, ninhydrin, 9-diazafluerone (DFO), thermaNin, 5-methylthioninhydrin (5-MTN), and silver nitrate.[2]

The value of fingerprints as evidence stems from the fact that the fingerprints left by the person touching the surface can be detected even if they have few characteristics.[8] The presence of fingerprints suitable for identification obtained from the crime scene findings is valuable in understanding the crime and finding the criminals.

Invisible (latent) fingerprints, which are transferred to the surface before, during, and after contact with any surface, are essential in terms of determining under which conditions fingerprints suitable for identification can be obtained on the findings obtained from the crime scene and which surface types and climatic conditions are suitable for fingerprint development in terms of illuminating the incidents and creating effective solutions in crime investigations.

Environmental and climatic factors affect fingerprint development.[9] Temperature, humidity, wind, and environment change the quality and permanence of fingerprints.[10] These effects can increase the damaging effect on the fingerprints on evidence when the nature of the crime scene or the perpetrator of a crime intentionally seeks to destroy evidence. Criminals have been able to use the water environment to destroy fingerprints on criminal tools and hide criminal tools among snow masses in cold weather. Snow or dew falling on an object with a fingerprint dissolves most chemicals in the fingerprint liquid, except for fatty components, and chemicals on porous surfaces migrate. This reduces the components with which fingerprint development methods can react, thereby reducing the quality of the fingerprint developed.[2] Developing fingerprints from target surfaces at low temperatures is a difficult process, and the level of development is not fully known. Moreover, there is no fingerprint development method optimized for such surfaces.[11] The idea that fingerprints on objects

exposed to damaging conditions cannot be identified has led many researchers to ignore such evidence because of a lack of knowledge in the field.[12]

When the literature was examined, it was found that there are very limited studies on the identification levels of biometric prints obtained from evidence extracted from snow masses.[11,13,14] Our study aims to determine the time-dependent fingerprint development levels on porous and non-porous surfaces with different low temperatures.

MATERIAL AND METHODS

This research was approved by the Ethics Committee of Kütahya University of Health Sciences with the ethical approval code 2023/04-13 on April 5, 2023, and was conducted in accordance with the Helsinki Declaration. Written informed consent was obtained from all participants.

REAGENT AND CHEMICALS

Ninhydrin: 4 grams of ninhydrin (Sirchie, USA) was weighed and dissolved in 20 ml methyl alcohol (Meck, Germany), 70 ml ethyl acetate (Meck, Germany), 10 ml acetic acid (Meck, Germany), and 900 ml petroleum ether (Meck, Germany) to prepare 1000 ml working solution.

GENERATION OF LATENT NATURAL FINGERPRINTS

Fingerprint samples were created according to the guidelines recommended by the International Fingerprint Research Group. The natural fingerprints of 10 different donors, 5 females and 5 males aged between 20 and 30 years, were used in the study, and consent forms were obtained from the donors for this procedure. To create natural fingerprints, hands were washed with soap and water half an hour before the fingerprint samples were deposited on the surfaces to remove any foreign material residues on the donors' fingers. Fingerprint samples were placed on the types of surfaces commonly encountered in crime scene investigation and easily available in daily life. Fingerprints were placed on a microscope slide for the glass surface (non-porous surface) and on 80 g adhesive paper surfaces fixed on a hard surface for the paper surface, and care was taken to ensure that the contact time did not exceed 10 seconds. The 40 latent natural fingerprints created equally on glass and paper surfaces were placed in 0°C, -20°C, -80°C, and -160°C temperatures in separate coolers in open and closed storage boxes to avoid contacting each other.

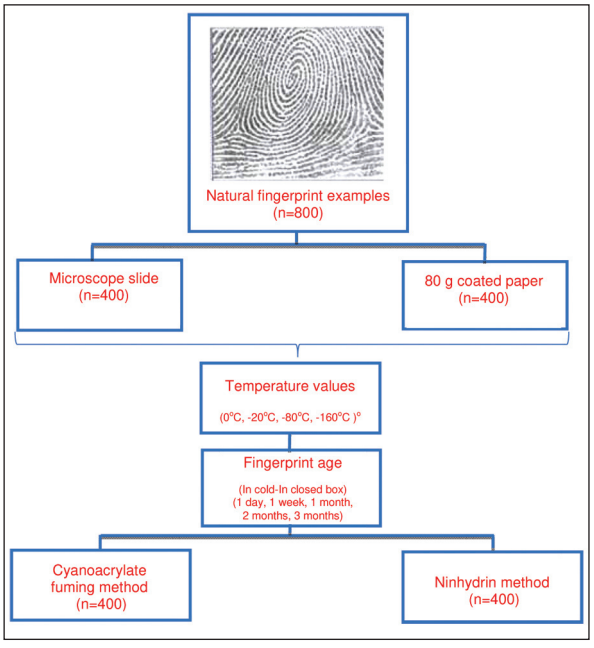

FIGURE 1: Schematic diagram of the study design for fingerprint development at different times and surfaces

The fingerprint study was repeated in periods (1 day, 1 week, 1 month, 2 months, and 3 months), and 5 different trials were conducted. In each trial, 10 donors generated a total of 160 natural fingerprint samples on 2 different surfaces, using 2 different storage boxes for comparison of 4 different temperatures. A total of 800 latent natural fingerprints were used in the study (Figure 1).

DEVELOPMENT OF LATENT FINGERPRINTS

Liquid CA (Evobond 502 Super Glue, Taiwan) was placed in a container and placed on the heating tray to spread homogeneously in the enclosed volume. The temperature of the heating table in the application booth was set to 120°C. The humidity level in the chamber was maintained at 80% for fingerprint development. In order for the fingerprints to develop and for the polymerization reaction to take place between the amino acids in the fingerprint liquid and CA vapor, the development process was carried out for an average of 45-50 minutes in the cabin. The chain reaction that took place enabled the lines in the

fingerprint to form, making the fingerprint visible. The fingerprints developed in white color. In case of poor fingerprint development, CA vapor was applied to the surfaces again. The developed fingerprints were kept for about 12 hours to be fixed on the surface. Photographs were taken for the fingerprints that became visible.

The paper surfaces (porous surfaces) were immersed in the prepared ninhydrin solution for 10 seconds, then removed from the solution and allowed to dry in a fume hood. The prints were kept in a dark environment at room temperature for 14 days to become visible. The fingerprints formed were visible and purple in color. When the fingerprints became visible, they were photographed.

FINGERPRINT ANALYSIS

All developed fingerprints were photographed at the highest resolution using the Nikon D7200 camera-Sigma 105mm F/2.8 EX DG OS HSM Macro Lens (Nikon, Japan). Image sharpening was applied with Adobe Photoshop CS6 (Adobe, USA) to increase the contrast difference of the prints.

Fingerprints were evaluated for identification according to the Home Office Center for Applied Science and Technology (CAST) scoring scale in Table 1.

To objectively grade the level of identification of the developed fingerprints, the study sought at least 12 fingerprint characteristics for an "identifiable fingerprint", which is indicated by scores of 3 and 4 on the fingerprint rating scale (Table 1). Identification of the fingerprints was performed in accordance with The International Association for Identification, Standardization II Committee Report.

STATISTICAL ANALYSIS

All statistical evaluation was performed with IBM SPSS Statistics Version v25.0 (Armonk, NY: IBM Corp, USA). For each group of variables, the mean of the score obtained by the examiner was calculated. The results were plotted as a function of the groups of variables (donor, surface, time, temperature, and fingerprint development method). For categorical variables, data values were presented as numbers and percentages, and the chi-square test was used to test for association. Continuous variables were presented as means and standard deviations. One sample Kolmogorov-Smirnov test was performed to determine the normality of the data. In total, 800 fingerprints were developed for 1 condition (open and closed box). The F test was 1st used to compare the variance of the 2 samples. Then, student's t-test for independent samples was used, assuming equal variances or not, depending on the results of the previous test. This 2nd test provides information about the equality of the means of the 2 samples, i.e., it determines whether they are significantly different. In both cases, the significance level was set at 0.05 ($p<0.05$).

RESULTS

The development levels of a total of 800 fingerprints of 10 donors (5 males/5 females) placed in open and closed storage boxes depending on different temperatures (0°C, -20°C, -80°C, and -160°C) and time (1 day, 1 week, 1 month, 2 months, and 3 months) parameters deposited on the target surfaces were statistically significantly different according to the scoring scale created by the Home Office Centre CAST. The highest number of identifiable fingerprints developed

TABLE 1: Fingerprint evaluation scale

Score	Description	Level of identification
0	No fingerprint evidence	No
1	Weak development; there is proof of contact, but no fingerprint capability	No
2	Limited development, about 1/3 of the fingerprint features are available, but cannot be used for identification purposes	Limited
3	Strong improvement; 1/3 to 2/3 of fingerprint characteristics; identifiable fingerprint	Identifiable fingerprint
4	Very strong development; all fingerprint features available; identifiable fingerprint	Identifiable quality fingerprint

by CA vapor and ninhydrin methods in all conditions during the study period was Donor 1, which showed 100% success with 80 prints developed, while Donor 10 had the lowest number of identifiable fingerprints with 11 prints (13.75%). According to the results analyzed using the Frequencies test, the number of identifiable fingerprints (points 3 and 4) of Donor 1 gave the best result among the other donors. Donor 10 had the lowest number of identifiable prints compared to the other donors, indicating that the most inefficient fingerprint development was obtained from Donor 10 (Table 2).

For the development of a total of 200 fingerprints deposited on CA vapor and ninhydrin-treated target surfaces, a statistically significant difference was observed in the number of identifiable prints (points 3 and 4) using open and closed storage boxes and in all conditions during the study (Figure 2).

The number of identifiable traces developed with CA vapor and directly affected by the cold environment in all periods at different temperatures with an open storage box was 86 (43%), while the number of identifiable traces not directly affected by the cold environment in all periods at different tem-

TABLE 2: Comparison of fingerprint development levels according to donors

	Quantitative fingerprint evaluation scale Identification level Score										
	0		1		2		3		4		p value
Donors (n=80)	n	%	n	%	n	%	n	%	n	%	p<0.05
Donor 1	0	0	0	0	0	0	3	3.75	77	96.25	
Donor 2	0	0	0	0	6	7,5	8	10	66	82.5	
Donor 3	0	0	0	0	12	15	14	17.5	54	67.5	
Donor 4	0	0	0	0	20	25	26	32.5	34	42.5	
Donor 5	0	0	0	0	31	38.75	29	36.25	20	25	<0.001
Donor 6	0	0	3	3.75	37	46.25	31	38.75	9	11.25	
Donor 7	0	0	11	13.75	43	53.75	22	27.50	4	5	
Donor 8	0	0	31	38.75	31	38.75	16	20	2	2.5	
Donor 9	0	0	56	70	11	13.75	13	16.25	0	0	
Donor 10	18	22.5	41	51.25	10	12.5	11	13.75	0	0	

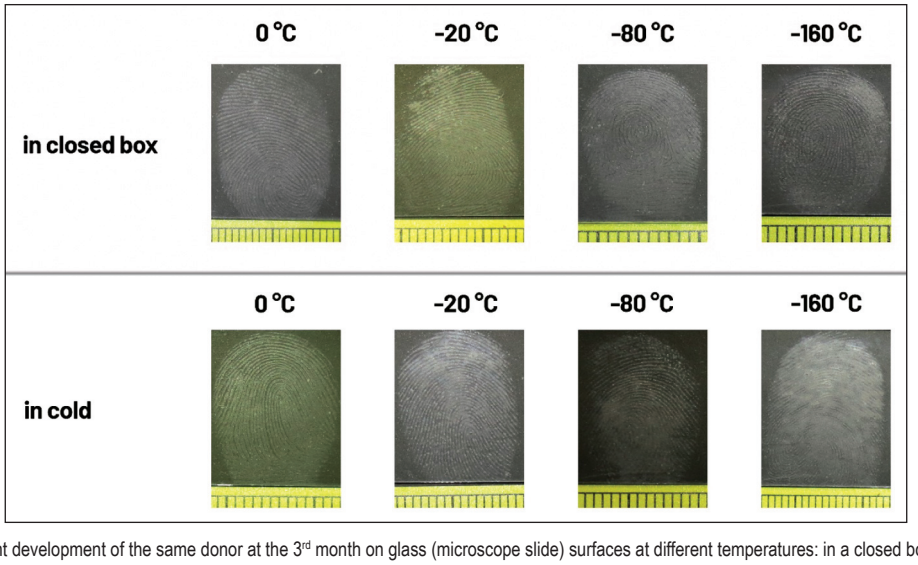

FIGURE 2: Fingerprint development of the same donor at the 3rd month on glass (microscope slide) surfaces at different temperatures: in a closed box, in cold condition

TABLE 3: Comparison of fingerprint development levels according to fingerprint development methods

		Quantitative fingerprint evaluation scale Identification level Score										
Methods		0		1		2		3		4		p value
(n=200)	All conditions	n	%	n	%	n	%	n	%	n	%	p<0.05
CA fuming	In closed box	0	0	8	4	15	7.5	71	35.5	106	53	<0.001
	In cold	0	0	49	24.5	65	32.5	33	16.5	53	26.5	
Ninhydrin	In closed box	0	0	39	19.5	54	27	39	19.5	68	34	
	In cold	18	9	46	23	67	33.5	30	15	39	19.5	

CA: Cyanoacrylate

peratures with a closed storage box was 177 (88.5%). In a similar situation, the number of identifiable traces developed with the ninhydrin method in the open storage box was 69 (34.5%), while the number of identifiable traces developed in the closed storage box was 107 (53.5%) (Table 3).

The relationship between the effectiveness of fingerprint development techniques according to fingerprint development levels in environmental conditions (open and closed storage boxes) is given in Figure 3.

While there was a statistically significant difference in the number of identifiable prints (points 3 and 4) using open and closed storage boxes for the development of a total of 40 fingerprints deposited at each period (1 day, 1 week, 1 month, 2 months, and 3 months) on target surfaces treated with CA vapor , no statistically significant difference was observed between the number of identifiable prints developed with the ninhydrin method under different environmental conditions (open and closed storage box) (Figure 4, Table 4).

While a statistically significant difference was observed in the number of identifiable prints developed on glass surfaces (points 3 and 4) in CA vaporized open and closed storage boxes of a total of 50

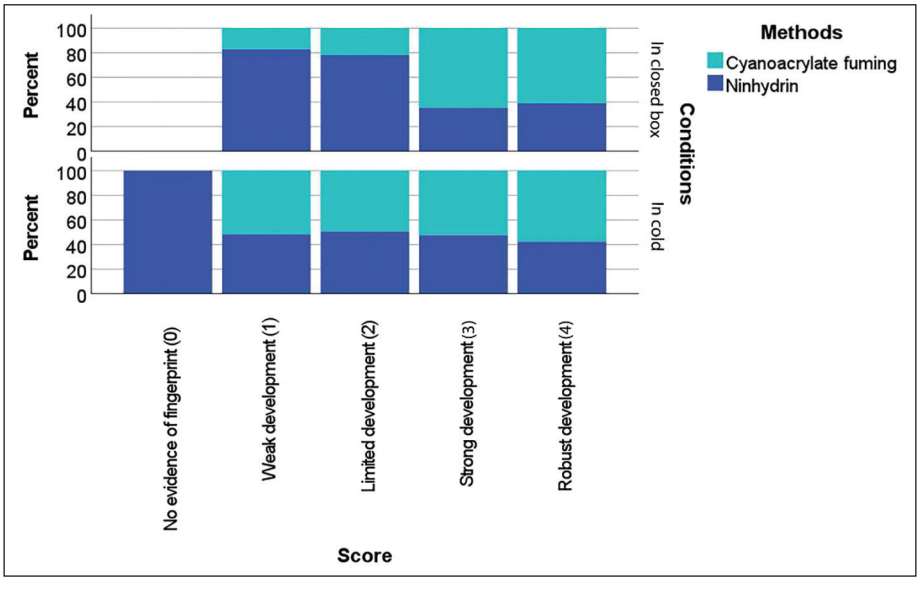

FIGURE 3: Comparison of fingerprint development levels of fingerprint development methods according to environmental conditions

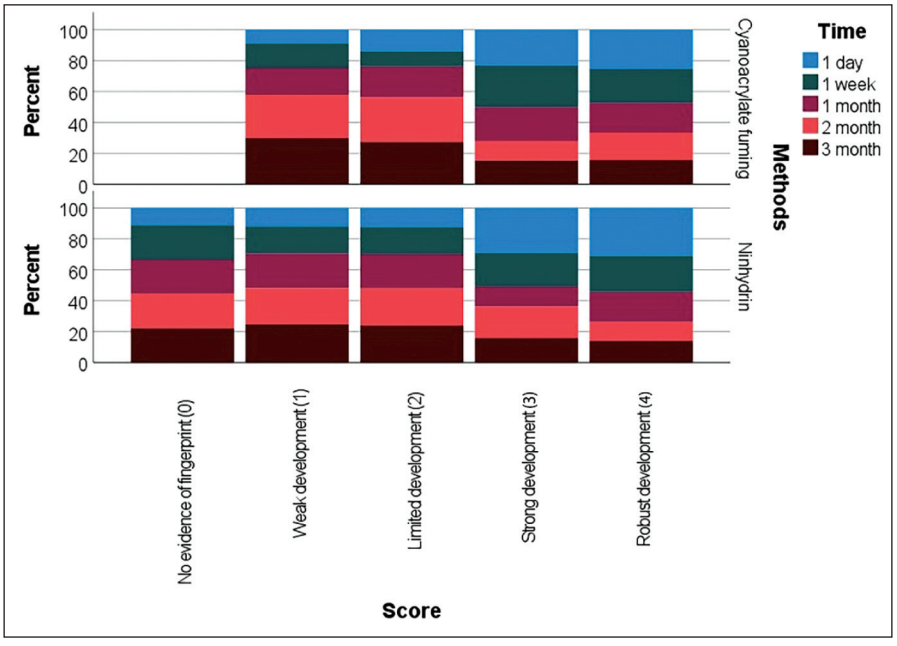

FIGURE 4: Comparison of fingerprint development levels of fingerprint development methods according to time parameter

TABLE 4: Change in the number of fingerprints suitable for identification over time (Scores 3-4)

	Time																			
	1 day				1 week				1 month				2 months				3 months			
Methods	In closed box		In cold		In closed box		In cold		In closed bo		In cold		In closed box		In cold		In closed box		In cold	
(n=40)	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
CA Fuming	40	100	24	60	40	100	23	57.5	37	92.5	17	42.5	29	72.5	12	30	31	77.5	10	25
p value (p<0.05)	<0.001				<0.001				<0.001				<0.001				<0.001			
Ninhydrin	29	72.5	24	60	22	55	18	45	20	50	10	25	18	45	9	22.5	18	45	8	20
p value (p<0.05)	0.500				0.269				0.069				0.094				0.066			

CA: Cyanoacrylate

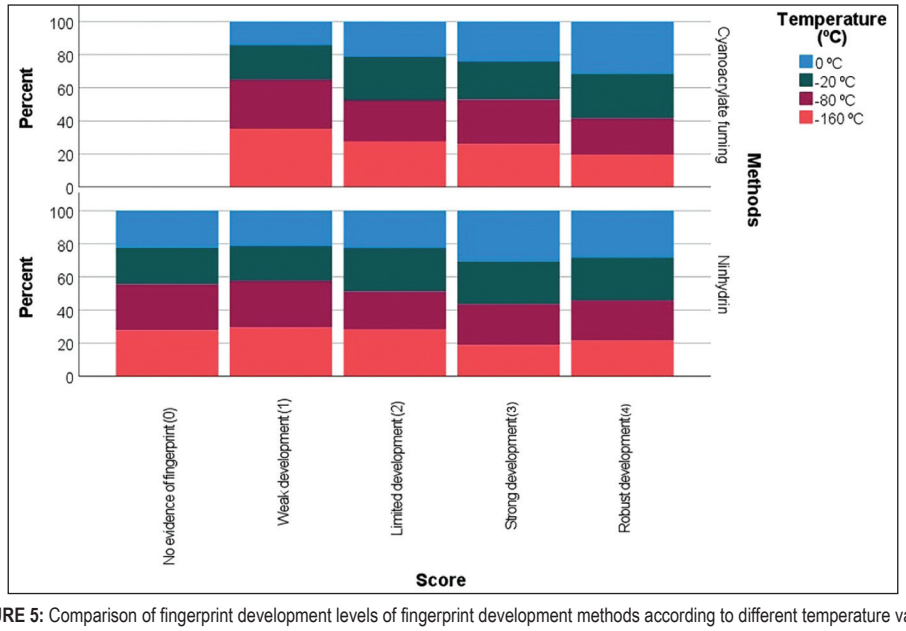

FIGURE 5: Comparison of fingerprint development levels of fingerprint development methods according to different temperature values

TABLE 5: Change in the number of fingerprints suitable for identification over temperatures (Scores 3-4)

	Temperature (°C)															
	0°C				-20°C				-80°C				-160°C			
	In closed box		In cold		In closed box		In cold		In closed box		In cold		In closed box		In cold	
Methods (n=50)	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
CA fuming	47	90	28	56	44	88	23	46	43	86	20	40	43	86	15	30
p value (p<0.05)	<0.001				<0.001				<0.001				<0.001			
Ninhydrin	27	54	24	48	29	58	17	34	27	54	16	32	24	48	12	24
p value (p<0.05)	0.350				0.073				0.068				0.025			

CA: Cyanoacrylate

TABLE 6: Comparison of fingerprint development levels according to surface types

	Quantitative fingerprint evaluation scale Identification Level Score										
	0		1		2		3		4		p value
Surfaces (n=400)	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**p<0.05**
Microscope slide	0	0	57	14.2	80	20	104	26	159	39.8	<0.001
80 g coated paper	18	4.5	85	21.3	121	30.3	69	17.3	107	26.8	

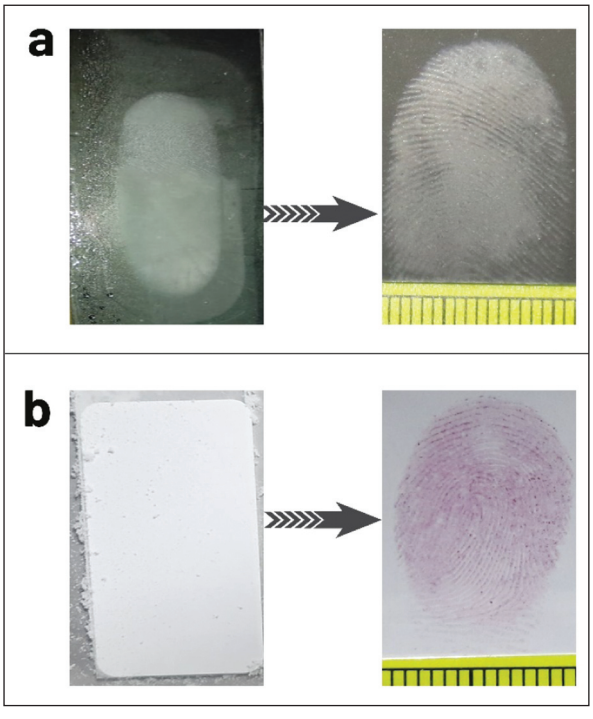

FIGURE 6: Fingerprint development of the same donor at 1st month in cold according to surface types: **a)** Glass surface; **b)** Paper surface

fingerprints deposited at different temperatures (0°C, -20°C, -80°C, -160°C), no statistically significant difference was observed between the number of identifiable prints developed on paper surfaces by ninhydrin method at temperatures other than -160°C (Figure 5, Table 5).

The number of fingerprints suitable for identification decreased significantly with time and temperature variables in all conditions during the study period.

Of the 400 fingerprints developed from the target surfaces according to the CAST scoring system with CA vapor and ninhydrin method, 263 (65.8%) fingerprints were observed on glass surfaces (microscope slide) and 176 (44.1%) on paper surfaces (80 g adhesive paper). In terms of identifiable fingerprints (score 3-4), glass surfaces (microscope slide) provided the best result in the same conditions in terms of surface types (Table 6).

It was observed that the lower growth of identifiable fingerprints on paper surfaces compared to glass surfaces was due to the negative effect of the moisture barrier formed on the target surfaces on fingerprint development (Figure 6).

DISCUSSION

The identification and preservation of fingerprints is critical in forensic science. However, this process is severely affected by temperature (environmental conditions) and time factors. Limited studies on the preservation and enhancement of fingerprints under low-temperature conditions reveal the challenges and impacts of these conditions. Some studies in the relevant literature show that low temperatures cause fingerprint remains to be degraded, which complicates the identification process.[9,13,14] This study examines the effects of temperature and time factors on fingerprint development methods, specifically by comparing different surface types (porous and non-porous) and storage conditions (closed and open).

Longchar et al. pointed out that fingerprint development is limited on non-porous surfaces at low temperatures. In their research, they emphasized that low temperatures reduce the level of identification of fingerprints, and the surfaces become more prone to degradation by chemical reactions.[13] However, despite the non-porous nature of glass surfaces, increased perspiration during contact may lead to increased release of epithelial cells transferred by finger contact.[15] Similar findings were observed in this study, but the use of closed storage boxes increased the stability of the fingerprints. Fingerprints kept in a closed environment, especially on non-porous surfaces such as glass, were found to have higher growth success. While Longchar's study focused on non-porous surfaces under cold weather conditions, our study adds a new dimension to this field by comparing both porous and non-porous surfaces.[13]

When the effect of temperature and humidity changes affect the stability of biochemical components in fingerprint residues was examined, it was found that fatty acids and other organic compounds to degrade rapidly depending on temperature and humidity conditions. In addition, high humidity significantly affects the movement of water-soluble compounds in fingerprints, especially those deposited on porous surfaces.[10,16-18] As more moisture penetrates the surface, substances such as urea and sodium chloride can move away from their original location, leading to the degradation and spread of prints.[2] Similarly, in our study, humidity and low temperatures were found to destabilize fingerprint residues, making chemical development more difficult. This effect was particularly pronounced in open storage boxes. However, this degradation was greatly reduced when closed storage boxes were used, a finding that extends the results of Cadd.[10] This present study shows that fingerprint remains can be preserved longer and more moisture-resistant in closed environments.

Natural fingerprints are rich in the secretions of eccrine glands. The most crucial target components for the detection of these fingerprints, especially on porous surfaces, are the amino acids found in eccrine secretions. These amino acids can be detected unless exposed to high humidity or completely immersed in water.[10] Various chemical methods such as Ninhydrin, DFO, 5-MTN, ThermaNin, and 1,2-Indandione are frequently used to make fingerprints with high concentrations of eccrine components visible.[19,20] This study preferred Ninhydrin due to its high affinity for amino acids in fingerprints. Thanks to its strong interactions with amino acids, ninhydrin allows for a clearer and more permanent identification of fingerprints.[21] It has been known for years that the ninhydrin method is successful on porous surfaces such as paper.[4,16] However, in our study, ninhydrin method was found to be less effective on porous surfaces under low temperature conditions. It was observed that cold weather conditions slowed down the ninhydrin reaction and growth was more limited, especially at prolonged low temperatures. These findings support the literature emphasizing the sensitivity of the ninhydrin method to temperature conditions. Jasuja et al. also conducted fingerprint development studies on submerged surfaces and similarly reported that fingerprint quality decreased on surfaces exposed to moisture.[5] This study shows that the moisture barrier has a similar negative effect in cold environments and reduces fingerprint quality.

Kapoor et al. stated that low temperatures can cause degradation of fingerprints and that the identification process becomes difficult in extremely cold conditions.[9] Similar results were observed in a 2016 study on non-porous surfaces in contact with snow,

where 167 sebum-rich fingerprints were found.[14] This study observed that fingerprint identification level of fingerprints decreased significantly under extremely low-temperature conditions such as-60 °C. However, given that the surfaces used in Kapoor's study were mostly non-porous, the present study contributes to the literature by comparing porous and non-porous surfaces. While the findings of Kapoor et al. show that extremely low temperatures reduce fingerprint retention, the findings of this study point to the importance of closed storage boxes in cold weather conditions.[9]

Another important finding of this study is that the differences between the fingerprint development levels of different donors became evident. Fingerprints from different donors were observed to exhibit different levels of development with both ninhydrin and CA vapor methods. Robson et al. stated that biological differences between individuals may play a role in fingerprint development.[22] In the present study, Donor 1 exhibited a much more successful fingerprint development than the other donors, indicating that biological and physiological differences between individuals may affect fingerprint development processes. In addition, some individuals, such as Donor 10, exhibited poor performance in fingerprint development, suggesting that personal biological factors are an important variable in cold weather conditions.

These findings suggest that individual differences should be taken into account when analyzing fingerprints in forensic science. The study revealed that the level of development of donor fingerprints may vary significantly depending on the preservation conditions and surface type. This emphasizes that preservation conditions and the surface of the evidence should be taken into consideration in evidence collection and evaluation processes in forensic cases.

CONCLUSION

In the field of forensic science, fingerprint identification is vital for the elucidation of crimes and the administration of justice. However, environmental factors adversely affect this process, especially low-temperature conditions. This study investigated the effects of low temperatures on the development capacity of fingerprints and the effectiveness of CA vapor and ninhydrin methods on different surfaces (porous and non-porous) used in these conditions.

The results show that low temperatures significantly negatively impact the retention and development of fingerprints. Fingerprints stored in closed storage boxes showed a much higher identification success than in open environments. In particular, fingerprint development on non-porous surfaces such as glass was more successful. The ninhydrin method was less effective on porous surfaces at low temperatures, which provides important information on which methods should be preferred in cold weather conditions.

Furthermore, the marked variations observed during the development of fingerprints from different donors suggest that biological differences between individuals play an important role in fingerprint development. The differences recorded between donors are a critical factor to be taken into account in evidence collection and evaluation processes in forensic science applications.

As a result, the preservation and development of fingerprint evidence at low temperatures can be significantly optimized by ensuring appropriate preservation conditions. The use of sealed storage boxes is a critical element in fingerprint development processes. These findings provide important contributions to cold-weather evidence preservation and fingerprint development strategies in forensic science and provide a guiding basis for future research. In future studies, it will be possible to further improve fingerprint development processes by combining different surface types and chemical methods. This approach will contribute to the development of forensic sciences and provide more effective results, especially in complex evidence collection processes.

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Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Yakup Gülekçi;* ***Design:*** *Harun Şener;* ***Control/Supervision:*** *Yakup Gülekçi;* ***Data Collection and/or Processing:*** *Yakup Gülekçi, Harun Şener;* ***Analysis and/or Interpretation:*** *Yakup Gülekçi;* ***Literature Review:*** *Harun Şener;* ***Writing the Article:*** *Yakup Gülekçi, Harun Şener;* ***Critical Review:*** *Yakup Gülekçi;* ***References and Fundings:*** *Yakup Gülekçi, Harun Şener;* ***Materials:*** *Yakup Gülekçi.*

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