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PAPER

CRIMINALISTICS

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The Reliability of Pattern Classification in Bloodstain Pattern Analysis, Part 1: Bloodstain Patterns on Rigid Non-absorbent Surfaces*

ABSTRACT: This study was designed to produce the first baseline measure of reliability in bloodstain pattern classification. A panel of experienced bloodstain pattern analysts examined over 400 spatter patterns on three rigid non-absorbent surfaces. The patterns varied in spatter type and extent. A case summary accompanied each pattern that either contained neutral information, information to suggest the correct pattern (i.e., was *positively biasing*), or information to suggest an incorrect pattern (i.e., was *negatively biasing*). Across the variables under examination, 13% of classifications were erroneous. Generally speaking, where the pattern was more difficult to recognize (e.g., limited staining extent or a patterned substrate), analysts became more conservative in their judgment, opting to be inconclusive. Incorrect classifications increased as a function of the negatively biasing contextual information. The implications of the findings for practice are discussed.

KEYWORDS: forensic science, bloodstain pattern analysis, error rate, reliability, contextual bias, cognitive science

Bloodstains are a common by-product of violent crime, and analysis of these stains is a vital part of a crime scene investigation. Despite the fact that DNA analysis can now routinely identify the individuals that have bled at a scene, other important questions can remain unanswered. For example, it is not uncommon for a suspect to claim that the blood found on his/her clothing was deposited when he/she was trying to aid the victim. In these situations, understanding the mechanism by which the stains were deposited onto an article of clothing could be more informative than knowing from whom the blood originated. This is where the analysis of bloodstain patterns can often give valuable clues as to how the blood came to be where it was found.

Although the dynamics of the formation of a bloodstain pattern appear to be infinitely variable, it is nevertheless true that bloodstain patterns have reproducible characteristics that allow a connection to be made between the distribution of bloodstains and the underlying mechanism of their formation. Thus, at the heart of bloodstain pattern analysis (BPA) is the recognition and classification of the bloodstain pattern.

BPA has been used in criminal investigations since the 1800s. Like many other disciplines from the early days of forensic science, its use and acceptance occurred without rigorous validation. The Organization of Scientific Area Committees (OSAC) BPA Subcommittee (previously the Scientific Working Group on Bloodstain Pattern Analysis (SWGSTAIN)) has made valuable progress in setting standards for training and education, terminology, quality assurance, and validation of new procedures for the discipline (1–3). Like other forensic practitioners, however, bloodstain pattern analysts are grappling with the problem of assessing the reliability of the methodology that they use. At this time, very little is known about this beyond the instincts of experienced instructors and investigators who have observed the reproducibility of bloodstain patterns over many crime scenes and practical sessions in the classroom. While such experience has served as the main basis for assessing the reliability of BPA testimony in the past, the courts now rightly demand much more. Indeed, establishing accuracy and reliability measures in forensic disciplines was a key recommendation in the National Research Council's 2009 (4) report on the state of forensic science.

There are several factors that may influence the reliability of bloodstain pattern classifications. First, different bloodletting mechanisms can give rise to bloodstain patterns that possess similar or indistinguishable characteristics. For example *blunt force impact* and *expiration* patterns (2) can both feature small bloodstains and as such may be confused with one another. Second, at times, a pattern might only comprise one, or a small number of stains, meaning an analyst must decide if he/she has sufficient data to make a reliable classification. Finally, the sur-

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face characteristics of the substrate on which the bloodstain is created, whether a rigid smooth surface or an absorbent fabric, might add another level of complexity to the pattern recognition task. These issues have been highlighted in several high profile homicide trials in which bloodstain pattern analysts have found themselves at the center of controversial arguments relating to the explanation of the mechanisms that produce very small bloodstains on clothing (5,6).

Although the size and distribution of individual bloodstains are often measured, pattern recognition methods rely primarily on a qualitative assessment of the appearance of the pattern. It is essential therefore that these methods are well understood, their reliability is demonstrable and that any bloodstain pattern conclusion proffered can be supported by statements that guide the courts in their assessment of the extent of that reliability.

One of the complications for any study of method reliability is the variability in the methods used. At this time, there is no discipline standard in the methodology employed by bloodstain pattern analysts. Two suggestions have been made to meet this need (7,8), but so far no significant effort has been made to establish these or any other approaches as standards. In fact, it is possible that some bloodstain pattern analysts would struggle to articulate the methodology that they employ.

Testing the reliability of BPA methods is not a straightforward task. For example, it is generally impossible to know with certainty the "true" mechanistic cause of a bloodstain pattern at a crime scene. For this reason, procedures to test method reliability are limited to artificially created scenarios for which the ground truth can be known. This approach has the risk of under or over estimating identification errors because some of the dynamics present in a real case investigation are lacking.

When considering the reliability of any forensic method, it is important to assess whether factors outside of the evidence can influence the reliability of interpretations. In particular, a growing body of research has demonstrated that expert interpretations may be influenced by the presentation of contextual information (9–18).

Perhaps more so than in any other forensic discipline, contextual information is a necessary part of BPA. That is because bloodstain patterns are analyzed in the context of a case with the objective to assist with the reconstruction of events. This means that once the pattern is classified, its relevance to the case investigation must be considered. These two processes (pattern classification and scene reconstruction) frequently overlap. At present, there is no rigorous protocol for BPA that distinguishes these processes. This means that, at an early stage of the analysis, analysts may consider additional case-specific information, such as medical findings, case circumstances, and even witness testimony. If the BPA methodology is not reliable, this integration of case information may create a fertile breeding ground for contextual bias (19).

The Present Study

The research hypothesis at the heart of this study was as follows: *Pattern recognition methods employed in BPA are reliable when used by fully competent analysts.*

To test this, a panel of experienced bloodstain pattern analysts classified a series of bloodstain spatter patterns. These patterns included stains made under a variety of conditions relevant to a crime scene and included some sets of stains produced under "ideal" conditions. That is to say, patterns produced to provide the maximum chance of accurate classification. While it is acknowledged that training and experience are important ingredients in the accurate conclusions reached by forensic analysts, the approach used here was designed to help define the *upper limit* of pattern classification reliability by focusing attention on method reliability rather than analyst competency.

The type of pattern, pattern extent, the nature of the substrate, and the direction of contextual cues were varied in a balanced experiment designed to determine the effect of these variables on pattern classification accuracy.

Method

Participants

Participants were 27 bloodstain pattern analysts from North America, Australasia (New Zealand and Australia), and Europe. All were invited based on their experience and standing within the BPA community and were required to meet the following three criteria: (i) must have completed at least 80 h training in BPA, (ii) have been active in BPA casework for a minimum of 5 years, (iii) and be qualified by a court as an expert in BPA and have provided expert testimony.

Materials

Bloodstain pattern targets (40 cm × 40 cm) were prepared in a controlled laboratory setting at the Minnesota Bureau of Criminal Apprehension (BCA). This size was chosen to aid with shipping the materials to study participants. The completed targets were coated with a clear lacquer to prevent deterioration and to assist with biohazard safety. This coating meant that no chemical tests to identify blood or saliva were possible. Participants were expected to assume that any visible red-brown stains were indeed bloodstains.

Three variables were manipulated when preparing the bloodstain pattern targets: *type of pattern*, *pattern extent*, and *target substrate.*

Type of Pattern—One of four different bloodstain pattern types were prepared for each target: *blunt force impact* spatter, *firearms-related* (back or forward) spatter, *cast-off* pattern, and *expirated* spatter. These spatter pattern types were chosen to reflect the potential for overlap in pattern characteristics between pattern types, which can be problematic for bloodstain pattern analysts, and were designed to represent those typically encountered at crime scenes.

Cast-off pattern and *blunt force impact* spatter targets were made with fresh human blood, donated by project volunteers. Blood was drawn into tubes containing EDTA anticoagulant and was used within 7 days of drawing. Blood for the *firearms-related* spatter was purchased from Memorial Blood Center, 737 Pelham Boulevard, Saint Paul, MN 55114, and was used within 30 days of drawing. Blood for the *expirated* patterns was drawn from an experimenter on the same day it was used and was used unrefrigerated. To represent the variability found in crime scenes and to create varied pattern extents, two methods were used to create each pattern type (Tables 1–4). Targets were mounted on a vertical surface during preparation.

Pattern Extent—The extent of pattern on each target was categorized into three levels: *minimum*, *medium*, and *maximum*. Category membership was determined by an approximation of the total number of stains in the pattern and the number of stains larger than 1 mm in diameter (see Table 5).

TABLE 1—*Methods used to create blunt force* impact *spatter. For both pattern-creating methods, multiple targets were positioned 50 cm from the front, side, and back of a striking zone.*

Method 1	One drop of blood was placed on a wooden block in the center of the striking zone. A hammer was propelled by rubber bands and gravity onto the blood pool. This method tended to produce fine horizontally directed spatter
Method 2	Six drops of blood were placed on a wooden block to the right side of the center of the striking zone and extending outside of that zone. The hammer was allowed to fall under gravity alone onto the blood pool. This method tended to produce larger spatter stains that travelled higher on the adjacent vertical surface

TABLE 2—*Methods used to create* cast-off *bloodstain patterns.*

Method 1	A wrench was liberally coated in blood and then swung a few times to remove excess blood. An experimenter stood approximately 130 cm from the left and front walls that held the targets and swung the wrench forcibly from left to right, on an angle, and overhead and downwards. This method tended to produce large stains with a broadly linear distribution
Method 2	A small knife was dipped a few millimeters into a beaker of blood and tapped one to two times to remove excess blood. An experimenter then stood approximately 85 cm from the left wall and 130 cm from the front wall and swung the knife forcibly toward the targets. This method tended to give smaller spatter stains in a tightly linear distribution

TABLE 3—*Methods used to create* expirated *bloodstain patterns.*

Method 1	An experimenter transferred blood to his lips with a finger and blew air gently through tightly pursed lips directly toward the targets, which were mounted 15–20 cm from him. This method tended to produce smaller stains and generally lacked mucus strands
Method 2	An experimenter took a small volume of blood (<1 mL) and mixed it gently with saliva before coughing from the front of the mouth directly toward the targets, which were mounted 50–90 cm from him. This method tended to give a larger range of spatter sizes and frequently contained mucus strands

TABLE 4—*Methods used to create* firearms-related *bloodstain patterns. For both methods, a 0.22 caliber bullet was fired from a pistol through a blood-soaked sponge. Some targets required multiple shots to obtain the desired amount of pattern.*

Method 1	Back spatter was collected from targets positioned 120 cm in front of a blood-soaked sponge
Method 2	Forward spatter was collected from targets positioned 120 cm to the rear of the sponge

TABLE 5—*Thresholds for determining pattern extent.*

Total *N* Stains	*N* Stains > 1 mm	Extent
<50*	<10	Minimum
<50	>10	Medium
50–500	<50	Medium
50–500	>50	Maximum
>500		Maximum

*For *cast-off patterns*, a minimum pattern was deemed to be fewer than four tightly linear stains, or fewer than 10 broadly linear stains. If there were more than 10 linear stains, the pattern was considered to have medium extent.

Substrate—Targets were one of three different rigid-surface substrates designed to represent varying levels of anticipated identification difficulty; *paint*, *wallpaper*, and *chipboard*. Two coats of white Zinsser 1-2-3 primer were used for the painted substrate. The wallpaper was white Brewster Easy Texture paintable wallpaper (STRIA Pattern 99417F), with one coat of Zinsser 1-2-3 primer. The target was rotated during pattern construction so that the wallpaper texture ran vertically. The chipboard surface was made from oriented strand board (OSB), which comprises wood logs (e.g., pines and aspen) that are chipped and oriented in random directions.

TABLE 6—*Example of contextual information.*

Example scenario containing contextual information* to suggest the pattern is the result of expirated blood
Police were called to a late-night disturbance outside an inner-city club. On arrival, they found the body of a 23-year-old man in a dark alleyway, with a crowd of youths standing nearby watching the paramedics, who comment that they thought the man died from severe internal injuries following a beating. The man's external bloodletting injuries were confined to his nose and mouth. An officer noticed bloodstains on the side door of the club. The club owner was interviewed and told police that he had not been present during the disturbance but had heard the noise and had come outside and saw the deceased lying in the alleyway and several youths running off. He says the bloodstaining occurred when the victim was alive and was coughing up blood. Police bring you a section of the door for your bloodstain pattern examination. DNA tests confirm the blood on the door of the club was from the 23-year-old victim found in the alleyway. You are requested to determine the nature of the bloodstaining to confirm the club owner's account.
*If the target pattern was an expirated bloodstain pattern, this contextual information would be considered positively biasing. If the target pattern was a pattern other than expirated blood, then this contextual information would be considered negatively biasing.
Example scenario containing neutral contextual information
Police get a call from a hotel manager who reports that one of her cleaning staff found bloodstains on the wall in one of the hotel rooms during a routine room service. She reports that the guest who occupied the room had checked out. The police locate the guest who denies all knowledge of the blood and appears to be able to account for all his movements during his stay. A DNA test shows the blood in the room is not from him. Police have brought you this sample from the room and asked you to examine it to help determine the significance of the pattern present.

Contextual Information—In addition to varying the type of bloodstain pattern, pattern extent, and target substrate, case summaries were created to manipulate the contextual information associated with each target. Contextual information was presented in the form of a short vignette that provided background information about how the bloodstain pattern was found and what was known about the case. This included information such as eyewitness reports, the position of the pattern/victim, injuries sustained by the victim, and any weapons that were found or assumed to have been used. All scenarios indicted a single bleeder and included a DNA result. The scenario either contained information that supported the correct classification (*positively biasing*), was misleading toward a particular incorrect classification (*negatively biasing*), or contained no directional information (*neutral)*. No analyst received the same vignette twice. Two examples are given in Table 6.

Procedure

Analysts were initially invited via email. In both the invitation email and in a letter to the analysts after they had agreed to participate, they were informed that the aim of the study was not to test competency, but rather the reliability of BPA methodology. Furthermore, they were informed that all responses would remain anonymous and could in no way be linked to any specific analyst. To further ensure anonymity, an independent third-party liaised with study participants.

Materials were only sent to analysts after they had indicated a willingness to participate. Each analyst received 15 or 16 targets, and a response sheet associated with each target. A number was placed at the top of each target; this identified which target corresponded to each response sheet and indicated the pattern alignment during pattern construction. No two analysts received the same targets.

Each of the manipulated variables was counterbalanced across the other variables and across the entire sample.

The response sheet included the following instructions: *"You are preparing your final report for investigators, which could end up being presented in court. Please give your opinion as to the pattern type or types that could account for the stains on the sample target."*

A list of pattern types, along with SWGSTAIN definitions, was provided as follows: *cast-off, drip trail, impact, saturation, splash, transfer, drip, expiration, pool, spatter from gunshot trauma (forward or back spatter), swipe, insect stain, drip stain, flow, projected* (e.g., *arterial*), and *wipe*.

Analysts could select *any* number of patterns, or indicate that "*I can't state that any of the above patterns would account for the stains on the sample target*."

After classifying all target patterns, analysts emailed or posted their responses to the independent third-party.

Results

Error and Accuracy Rate Determination

Analysts' responses were considered *correct* if they selected the pattern type that represented the true mechanistic cause for pattern (or selected this pattern type among multiple selections). Analysts' responses were considered *incorrect* if the true pattern type was not selected in their choice(s). If analysts could not state that any of the listed patterns could account for the target pattern, their responses were considered *inconclusive*. If analysts had classified the pattern by indicating all listed types as possible, these responses would have been considered inconclusive; none did so.

Pattern Classification Accuracy

Twenty-seven analysts made judgements on 15–16 target patterns each, yielding 416 unique assessments. Three assessments were removed from the analysis because no response was provided; 413 responses remained. In total, analysts were correct for 69.5% of classifications and made errors for 13.1% of classifications. The remaining 17.4% of responses were inconclusive. Chi-squared (χ^2) tests were performed to determine whether the frequency of correct, incorrect, and inconclusive responses varied significantly ($p < 0.05$) as a function of each of the variables under examination.

Effect of Pattern Type

There was a significant overall difference in the frequency of analysts' correct, incorrect, and inconclusive responses as a function of pattern type, χ^2 (6, $N = 413$) = 13.871, $p = 0.031$. This was mainly due to analysts' success in identifying *expirated* patterns (81% correct compared to 64–69% for the remaining types; Fig. 1).

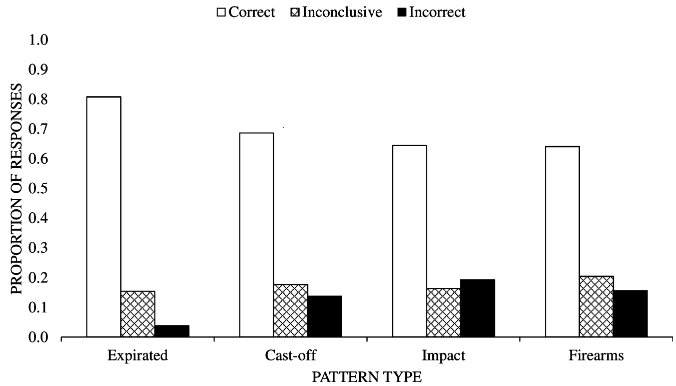

FIG. 1—*Proportion of response outcomes as a function of pattern type.*

Effect of Pattern Extent

There was a significant overall difference in the frequency of correct, incorrect, and inconclusive responses as a function of pattern extent, χ^2 (4, $N = 413$) = 26.74, $p < 0.0001$. As might be expected, analysts' accuracy improved as the extent of bloodstaining in the pattern (essentially the number of stains present on the target) increased (Fig. 2). Rather than the decrease in staining extent increasing analysts' propensity to make errors, the decrease in correct classifications was matched with an increase in inconclusive classifications.

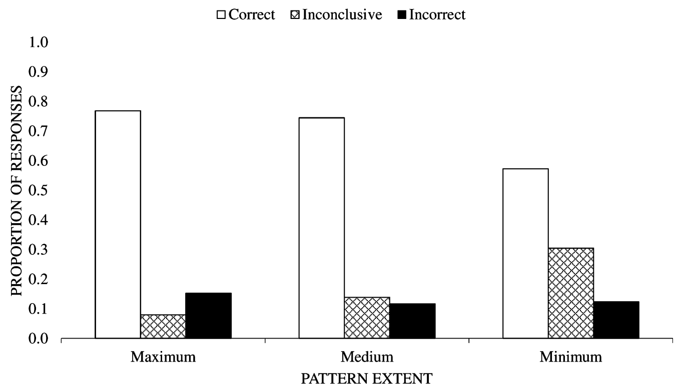

FIG. 2—*Proportion of response outcomes as a function of pattern extent.*

Effect of Target Substrate

There was a significant overall difference in the frequency of correct, incorrect, and inconclusive responses as a function of the substrate on which the bloodstain patterns were deposited, χ^2 (4, $N = 413$) = 38.64, $p < 0.0001$. Analysts made the greatest number of correct classifications on the white-painted surface, followed by the wallpaper surface (Fig. 3). The chipboard surface resulted in the lowest proportion of correct responses and greatest proportion of inconclusive responses. The chipboard surface had a highly patterned finish with many surface features that could have been confused with small bloodstains. Analysts had little or no scope for using any enhancement methods that might have assisted them with distinguishing bloodstains from artefacts. Analysts' decrease in correct classifications was matched by an increase in inconclusive classifications, rather than an increase in erroneous classifications.

Effect of Contextual Information

There was a significant overall difference in the number of correct, incorrect, and inconclusive responses as a function of the direction of the contextual cues, χ^2 (4, $N = 413$) = 12.39,

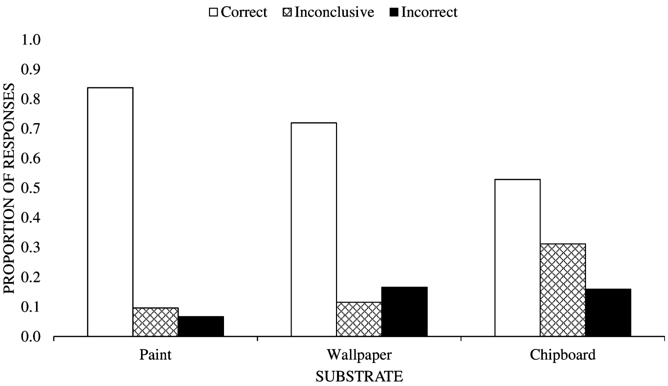

FIG. 3—*Proportion of response outcomes as a function of target substrate.*

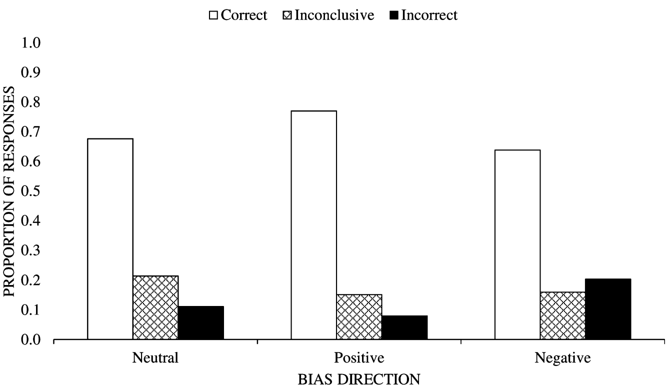

FIG. 4—*Proportion of response outcomes as a function of direction of contextual cues.*

p = 0.015 (Fig. 4). When a positive context was presented, analysts were less likely to make an incorrect classification than when the context was neutral, with the overall error rate dropping from 11% to 8%. Conversely, when a negative context was presented analysts were more likely to make an incorrect classification than when the context was neutral, with the overall error rate increasing to 20%. The rate of inconclusive decisions was highest when the contextual information contained no directional cues (21%), relative to when there were positively (15%) or negatively biasing cues (16%).

Discussion

The purpose of this study was to assess the reliability of classification decisions in bloodstain pattern analysis. To do this, well-trained and highly experienced analysts examined over 400 spatter patterns on rigid non-absorbent surfaces, representing surfaces frequently encountered at crime scenes. Four spatter pattern types commonly encountered in crime scene investigations were used. The extent of available pattern, the nature of the substrate, and the type of contextual information were varied in a balanced experiment designed to determine the effect of these variables on pattern classification accuracy.

Analysts were required to classify the pattern to a standard required for court. To do this, analysts were allowed to select one or more pattern classifications that they determined could not be excluded. Within the chosen range of conditions, the 17.4% overall rate of inconclusive decisions gives some measure of interpretation difficulty for the patterns created in this study.

Where a classification was made, either by choosing a single pattern or by nominating more than one pattern, 13.1% of these classifications did *not* include the correct pattern type. This finding can be considered the first approximation of an overall error rate for bloodstain pattern classification on rigid non-absorbent surfaces.

Some patterns were more reliably classified than others. In particular, the error rate was 4% for *expirated* patterns compared with 19% for *impact* patterns. The characteristic features of *expirated* patterns (e.g., mucus strands and air bubbles) were generally evident within these patterns, which could explain why this pattern type was the most recognizable. The second most recognizable pattern type was *cast-off* spatter. Many of the distinctive features of a cast-off pattern, such as a linear or curvilinear distribution of stains, were also generally present in the cast-off patterns prepared in this study.

Other than a lack of distinctive features in a pattern, it is not clear why the proportion of incorrect classifications for *impact* and *firearms-related* spatter patterns was higher. It is possible that the features that were observed in these patterns were those shared by other pattern types. For example, many of the *impact* patterns had a somewhat narrow distribution of stains, similar to *cast-off*. Indeed, on closer observation of the data, many of the *impact* patterns were incorrectly classified as *cast-off*. *Firearms-related* spatter patterns in this study did not always have a large proportion of the very small "mist" stains usually associated with this pattern type, which may explain why firearms related spatter was excluded as a mechanism for some of these patterns.

Looking more closely at the other variables used in this study, it is evident that where the amount of available pattern was limited or the substrate made stain visualization more difficult (e.g., chipboard) the proportion of correctly classified patterns decreased. However, the reduction in classification accuracy was generally accompanied by an increase in the proportion of inconclusive responses. So where the pattern was more difficult to recognize, analysts became more conservative in their judgment, which is what is to be expected from a reliable method.

The error rates estimated from this study are based, in part, on the conditions chosen for examination. These conditions were designed to be a fair representation of real casework but remain the subjective judgement of the experimenters. In particular, the patterns used in the study were restricted to common spatter types. Had other more easily recognized pattern types, such as *drip stains*, *drip patterns*, *transferred* blood, and *saturation* patterns been included, the proportion of correct classifications may have been higher. In addition, the size of the targets meant that in many cases the analysts received only a portion of the total pattern. As well as reducing the number of bloodstains available for analysis, the limited pattern size meant that it may not have been possible to perform other analyses such as area of origin determinations. Even with a small number of stains and only a portion of the complete pattern available, however, many analysts were prepared to make a classification. Finally, the use of a coating of lacquer removed the potential to perform any chemical tests on the bloodstains, which may have hindered analysts' ability to confirm, for example, the presence of saliva to indicate expirated blood. It is worth noting that some of these limitations exist in casework, especially where analysts are working solely from photographs. While any of these limitations could have reduced the classification success rate, none would be expected to increase erroneous classifications, because such errors mean the correct pattern type has been *excluded*. Rather, an increase in inconclusive classifications would be expected, which was indeed the observed outcome in this study for the pattern extent and substrate limitations.

Of particular interest in this study was whether contextual information can influence classification decisions. Indeed, where a scenario was offered that deliberately pointed analysts toward the correct classification, the proportion of misclassifications that resulted was lower (8%) than that observed for patterns with neutral scenarios (11%).

Of more concern, the proportion of misclassifications that resulted when the contextual information pointed toward an incorrect pattern type was considerably higher (20%) than when the contextual information was neutral (11%). This study, therefore, has produced evidence that analysts consider contextual information when classifying bloodstain patterns and that this information can influence accuracy. These findings may be evidence for *confirmation bias* (19), where analysts interpreted the pattern in line with the expectation created by the contextual cues.

In situations where data from a bloodstain pattern is limited, it may be tempting for analysts to seek out contextual information in order to *help* reach a decision. Unfortunately, contextual bias is most likely to occur when data are ambiguous (20–24), and in these situations, efforts to avoid contextual information are particularly important. The nature of forensic science is such that analyses are rarely conducted without a degree of ambiguity and the need to apply subjective judgements. With a reliable methodology, however, it should be possible to reach sound conclusions even in the absence of ideal conditions.

Analysts' use of contextual information to inform classification decisions could reflect the fact that the boundary between pattern classification and crime scene reconstruction is often blurred. This blurred boundary is not helped by the fact that, at present, there is not a rigorous protocol for BPA that distinguishes the two processes. This means that, at the stage of pattern classification, additional case-specific information, such as medical findings, case circumstances, and eye-witness statements could influence pattern interpretation decisions (25). This problem is compounded by the fact that the BPA terminology used to describe pattern classifications generally describe the mechanism of pattern formation (e.g., cast-off, expiration). Thus classifications actually form components of a reconstruction theory, rather than purely representing a summary of pattern characteristics. Moving forward, it could be advantageous for the BPA community to agree on a standard methodology for the analysis of bloodstain patterns that includes a better distinction between classification and reconstruction, and on terminology that relies less on mechanistic descriptions of patterns.

Conclusions

One significant implication of this study is the inference that contextual information is being integrated into pattern classification decisions. The assumption made here is that this is not a competency issue, given that the participants in this study were all experienced bloodstain pattern analysts. This vulnerability to context effects justifies further investigation. Based on the findings of this study, it seems prudent for practitioners and agencies to take steps to minimize the effects of contextual information. The practicalities of this may vary from agency to agency and may not be straightforward, as many analysts are immersed in an investigation in ways that make it difficult to control the flow of information. However, further research efforts could see valid contextual information management methods emerge.

A study of this sort has limitations, not the least of which is the fact that analysts were not making decisions in the context of a real case, with the associated demands of a court. Within the restrictions of the study, however, a useful baseline has been established for the expected error rate in bloodstain pattern classification.

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