

PAPER**CRIMINALISTICS**

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The Reliability of Pattern Classification in Bloodstain Pattern Analysis—PART 2: Bloodstain Patterns on Fabric Surfaces*,†

ABSTRACT: This study was designed to produce the first baseline measure of the reliability of bloodstain pattern classifications on fabric surfaces. Experienced bloodstain pattern analysts classified bloodstain patterns on pairs of trousers that represented three fabric substrates. Patterns also varied in type (impact, cast-off, expiration, satellite stains from dripped blood, and transfer) and extent. In addition, case summaries that accompanied each pattern contained contextual cues that either supported the correct answer (i.e., *positive bias*), were misleading toward an incorrect answer (i.e., *negative bias*), or contained no directional information (i.e., *neutral*). Overall, 23% percent of the resulting classifications were erroneous. The majority (51%) of errors resulted from analysts misclassifying satellite stains from dripped blood. Relative to the neutral information, the positive-bias information increased correct classifications and decreased erroneous classifications, and the negative-bias information decreased correct classifications and increased erroneous classifications. The implications of these findings for BPA are discussed.

KEYWORDS: forensic science, bloodstain pattern analysis, reliability, contextual bias, fabric surfaces, cognitive science

Analysis of the size, shape, location, and distribution of bloodstains can provide telling information as to the deposition of those bloodstains. In a crime scene investigation, this information can help to determine the actions involved that may have led to the bloodshed event, and might illuminate whether the event was, for example, homicide or suicide, or self-defense or murder.

Like many forensic disciplines, bloodstain pattern analysis (BPA) is subjective in nature, and often the experience of the bloodstain pattern analyst forms the basis for determining the reliability of an interpretation or conclusion. Recently, however, Taylor et al. (1) conducted the first large systematic investigation of the reliability of bloodstain pattern classifications on rigid non-absorbent surfaces. Experienced bloodstain pattern analysts classified bloodstain patterns representing variables likely to be encountered in casework. Patterns varied in the mechanism of deposition (i.e., type of spatter pattern: impact, cast-off, expiration, and firearms-related), the pattern extent, and the substrate that the bloodstain pattern appeared on. Furthermore, each pattern was paired with a case scenario containing either cues that supported

correct (i.e., ground truth) classification, suggested a pattern type other than the correct pattern, or cues that were not directional (i.e., the information was neutral). Across the variables under examination, classification errors were made on 13% of the bloodstain patterns. In general, as the patterns became more difficult to judge (e.g., small number of stains, patterned substrate), analysts were more likely to indicate that they did not know what the pattern was than to be incorrect. Of concern, Taylor et al. (1) found evidence for *contextual bias* (2) in BPA, that is, correct, incorrect, and inconclusive classifications varied as a function of the direction of the contextual cues.

While these data provide interesting insight into the reliability of bloodstain pattern classifications on rigid non-absorbent surfaces, often BPA is required on clothing and other absorbent fabric surfaces. Analysis of bloodstains on fabrics can be especially problematic, as the absorbency of the material can distort the appearance of the stain (3–6). Indeed, controversial arguments have ensued in the courtroom as to the deposition of bloodstains on fabric (e.g., 7,8). The argument is often whether the bloodstains are the result of a transfer mechanism (e.g., could have occurred when defendant rendered aid to the victim) or a spatter mechanism (e.g., defendant was in close proximity to the victim at the time of the bloodshed event).

Using the same experimental paradigm as Taylor et al. (1), this study provides a baseline measure of reliability for bloodstain pattern classification methods on fabric surfaces.

Method

Participants

Bloodstain pattern analysts ($N = 37$) from North America, Australasia (New Zealand and Australia), and Europe were

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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) must have been active in BPA casework for a minimum of 5 years, and (iii) must be qualified by a court as an expert in BPA and have provided expert testimony.

Materials

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

Five different pattern types were prepared: *blunt-force impact spatter*, *cast-off pattern*, *expiration pattern*, *satellite stains from dripped blood*, and *transfer* (9). These pattern types were chosen to reflect the potential for overlap in pattern characteristics and were designed to represent those commonly encountered in casework.

Blood

Blood for the *expiration* patterns was drawn from an experimenter on the same day it was used, and was used unrefrigerated. The remaining patterns were made with fresh human blood, donated by project volunteers, with added EDTA anticoagulant and was used within 7 days of drawing.

Bloodstain Patterns

Patterns were created in a controlled laboratory setting at the Minnesota Bureau of Criminal Apprehension (BCA) Laboratory. They were created on pairs of men's trousers which were worn by one of the experimenters during pattern creation. The extent of staining in each pattern was manipulated during pattern creation so that there were two levels: *minimum* and *maximum* extent.

Blunt-force Impact Spatter Patterns

One experimenter, wearing the target trousers, knelt with his right knee on the ground and left leg bent at 90 degrees. A striking zone mounted on a 17-cm-high platform was set up approximately 70 cm from the front right thigh of the experimenter and 60 cm from the inner left thigh. For *minimum extent* patterns, one drop of blood was placed on a wooden block in the center of a striking zone. A hammer, mounted on the platform, was propelled by rubber bands and gravity onto the blood pool. For *maximum extent* patterns, eight drops of blood were used.

Cast-off Patterns

An experimenter dipped a gloved right hand into blood, coating one finger in blood to create *minimum extent* patterns, or three fingers for *maximum extent* patterns. The hand was swung outwards and downwards toward the crotch of a second experimenter, who stood upright wearing the target trousers.

Expiration Patterns

One experimenter sat with his back to the wall, approximately 50 cm from the second experimenter who stood wearing the target trousers. The first experimenter then moistened his lips with his own blood and blew gently toward the crotch area of the target trousers (*minimum extent* pattern), or mixed the blood in his mouth before coughing and spitting it toward this area (*maximum extent* pattern).

Satellite Stains from Dripped Blood

An experimenter, wearing the target trousers, stood 20–25 cm away from a 40-cm-high table. Consecutive drops of blood were dropped in the same position on the table from a height of 120 cm above the table. Three blood drops were used to create the *minimum extent* patterns, and 12 drops for the *maximum extent* patterns.

Transfer Patterns

A wig was sprayed sparingly with blood using a hand sprayer. To create *minimum extent* patterns, the wig was touched briefly and lightly against the thigh area of the target trousers worn by a second experimenter. For the *maximum extent* pattern, the wig was touched firmly and for slightly longer.

Substrate

Patterns were made on three different fabric substrates, selected to represent varying levels of anticipated identification difficulty (Fig. 1). Three fabrics were chosen based on three common types of men's trousers: *dress trousers*, *denim jeans*, and *sweatpants*. All were washed and dried three times by a commercial laundry service. Dress trousers were "Arrow" brand, beige in color and constructed from 100% polyester fabric. Jeans were "Roebuck & Co. brand," "stone-washed" blue denim. Sweat pant trousers were "Russell" brand, gray brushed cotton.



Polyester dress trousers

Blue denim jeans

Brushed cotton sweatpants

FIG. 1—Example of target substrates that the bloodstain patterns were presented on.

Contextual Information

Case scenarios containing contextual cues accompanied each target pattern. These were presented in the form of a short vignette, giving background information about how the bloodstain was found and what was known about the case (Table 1). The case scenarios could include information such as eyewitness reports, injuries sustained by the victim, any weapons that were found or assumed to have been used, and the DNA report. The scenario contained cues that either supported the correct answer (i.e., *positive bias*), were misleading toward an incorrect answer (i.e., *negative bias*), or contained no directional information (i.e., *neutral*).

Response Sheet

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 (9), was provided as follows: *cast-off*, *drip pattern*, *drip stain*, *drip trail*, *expiration*, *flow*, *impact*, *insect stain*, *pool*, *projected* (e.g., *arterial*), *satellite stains*, *saturation*, *spatter from gunshot trauma* (*forward or back spatter*), *splash*, *swipe*, *transfer*, 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.”

Procedure

Analysts were initially invited via email. Analysts were informed that the study was not to test individual competency and 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. Participation in *PART 1: Bloodstain Patterns on Rigid Non-Absorbent Surfaces* (1) did not exclude analysts from participating in this study.

Presentation of each of the manipulated variables was counter-balanced across the other variables and across the entire sample in a balanced factorial design.

Materials (trousers and response sheets) were only sent to analysts after they had indicated a willingness to participate. A label was attached to each pair of trousers to identify which response sheet it was associated with. Analysts were instructed not to apply any chemical tests to the materials, and to assume that all red-brown stains on the trousers were blood. After classifying all target patterns, analysts emailed or posted their responses to the independent liaison.

Results

Error and Accuracy Rate Determination

Analysts’ responses were considered *correct* if they selected the pattern type that represented the ground-truth mechanistic cause for the pattern (or selected this pattern type among multiple selections). The choice of either *drip pattern* or *satellite stains* was considered a correct answer for target surfaces prepared with dripped blood. Analysts’ responses were considered *incorrect* if the ground-truth 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 response was considered *inconclusive*. If analysts had classified the pattern by indicating all listed types as possible, these responses would also have been considered *inconclusive*; none did so.

Pattern Classification Accuracy

Across the study, 321 unique assessments were made. Overall, analysts were correct for 62.3% of classifications and made errors for 23.4% of classifications. The remaining 14.3% of the assessments were inconclusive. Chi-square 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

The frequency of correct, incorrect, and inconclusive responses varied significantly as a function of pattern type, $\chi^2(8, N = 321) = 64.58, p < 0.001$ (Fig. 2). This was mainly due to analysts’ failure to identify *satellite stains from dripped blood*. The error rates for individual pattern types were 8% for *blunt-force impact*, 14% for *cast-off*, 16% for *expiration*, 18% for *transfer*, and 59% for *satellite stains from dripped blood*, giving rise to the overall error rate of 23.4% noted above.

Effect of Pattern Extent

The frequency of correct, incorrect, and inconclusive responses varied significantly as a function of the pattern extent, $\chi^2(2, N = 321) = 19.31, p < 0.0001$ (Fig. 3). Analysts’ accuracy improved as the pattern extent (essentially the number of stains present on the target) increased. Although the pattern extent influenced analysts’ correct and inconclusive responses—analysts made fewer correct responses and more inconclusive responses

TABLE 1—Examples of case scenarios.

Example case scenario containing contextual cues to suggest an expiration pattern*

Larry, his 8-year-old daughter, and several friends are leaving a pub after an end-of-season soccer party. All but the young daughter are very intoxicated. Larry says he sees someone lying in the car park and he rushes to the person to see if he is alright. Upon reaching the man, Larry notices he is having difficulty breathing due to blood which was emanating from his nose and mouth, so he puts him on his side to clear his airways. Eventually, the injured man’s friends show up and they accuse Larry of being responsible for punching the man in the face. The police arrive and question everyone. Unfortunately, those who were in the vicinity at the time were too drunk to make any reliable statements as to what happened. However, the daughter was able to confirm her dad’s account of what happened. The police see blood spatter on the man’s trousers and seize them for bloodstain pattern analysis. DNA shows the blood on the trousers is that of the injured man.

*If the pattern was an expiration pattern, this scenario would be considered a *positive bias*. If the pattern was anything other than expired blood, this scenario would be considered a *negative bias*.

Example case scenario containing neutral contextual information (i.e., no directional cues)

A local Salvation Army store manager called the police when one of his employees discovered apparent blood on a recently donated pair of trousers. The police have DNA tests performed on the pants, and the blood matches that of a person in the missing persons DNA databank. Wearer DNA produces a DNA profile that matches a male sex offender who has not yet been located. Therefore, the trousers were submitted to the laboratory for analysis. Police want to know how the blood got on the trousers. Your interpretation is sought.

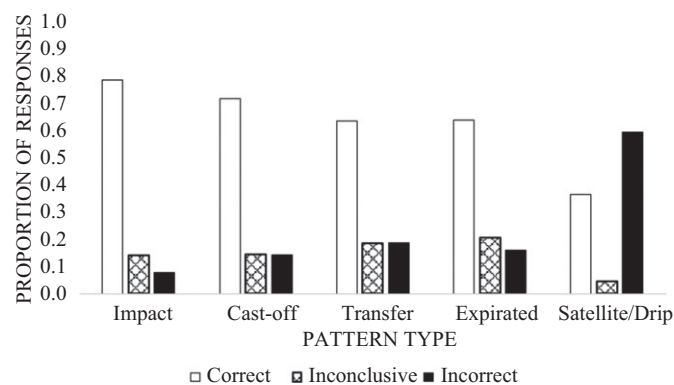


FIG. 2—Proportion of response outcomes as a function of pattern type.

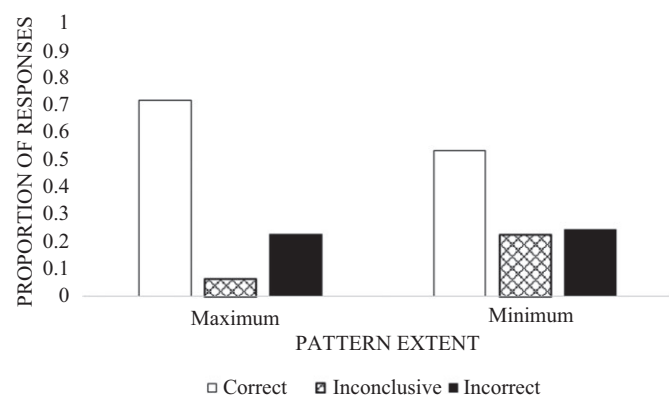


FIG. 3—Proportion of response outcomes as a function of pattern extent.

for patterns considered to have minimum pattern extent—incorrect responses did not vary between the two extents.

Effect of Target Substrate

Incorrect classifications were highest for patterns presented on dress trousers; however, the frequency of correct, incorrect, and inconclusive responses as a function of substrate did not vary significantly, $\chi^2(4, N = 321) = 6.50, p = 0.165$ (Fig. 4).

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 contextual cues, $\chi^2(4, N = 321) = 16.13, p = 0.003$ (Fig. 5). Relative to the neutral context, contextual information to suggest the correct pattern type increased correct responses from 58% to 77% and decreased incorrect responses from 26% to 14%. Relative to the neutral context, contextual information to suggest an incorrect pattern type decreased correct responses from 58% to 52% and increased incorrect responses from 26% to 30%. Inconclusive responses were highest in the negative-bias condition (19%), and lowest in the positive-bias condition (8%).

Discussion

The purpose of this study was to assess the reliability of bloodstain pattern classifications on fabric surfaces. Thirty-seven

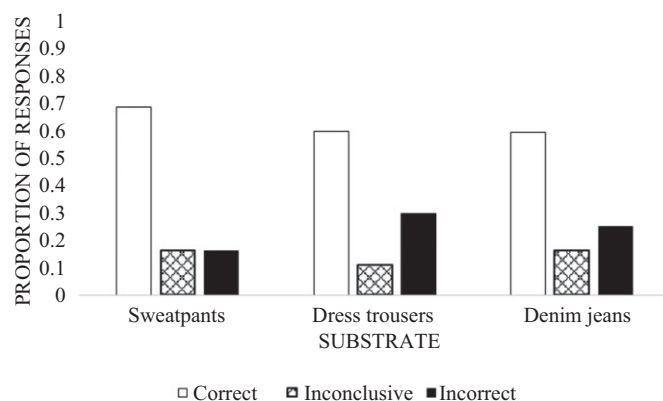


FIG. 4—Proportion of response outcomes as a function of target substrate.

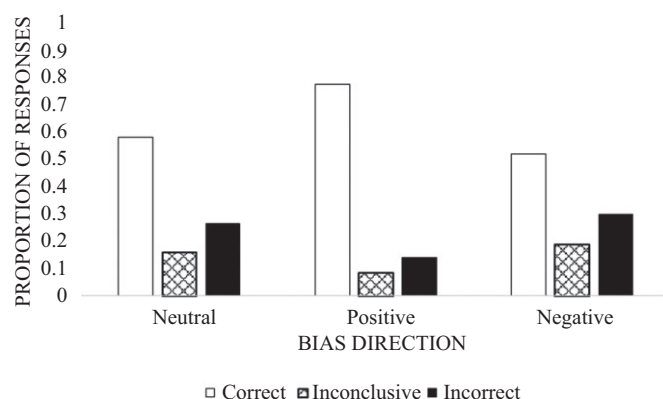


FIG. 5—Proportion of response outcomes as a function of the direction of contextual cues.

trained and experienced bloodstain pattern analysts examined over 300 patterns presented on three common fabrics used for men's trousers—dress trousers (i.e., polyester), denim jeans, and sweat pants (i.e., cotton). The mechanism for blood deposition (i.e., pattern type), pattern extent, and the contextual information accompanying each pattern was varied to assess the effect of these variables on classification accuracy.

Classifications were required to reflect those that analysts would normally be prepared to state in court. As such, analysts were able to select any number of patterns from a list of pattern types that could account for the target pattern. Overall, 23% of these classifications did *not* include the correct pattern type. This finding gives the first approximation of the reliability of bloodstain pattern classification methods for the pattern types and fabric substrates investigated. Although we did not set out to assess the competence of individual analysts, we noted that only four analysts across the study did not make any erroneous classifications.

Over half of the incorrect classifications occurred when the mechanism was *satellite stains from dripped blood*. For the majority (85%) of these incorrect classifications, analysts identified the pattern as *blunt-force impact spatter*. There are at least two possible explanations for the high rate of error in classifying satellite stains from dripped blood. First, the identification of satellite stains often relies on the presence of a central “parent” stain (9), which was not available in the present study. Second, it is possible that analysts excluded satellite stains because of the location of the staining. Blood was dripped onto a 40-cm-high

table, meaning the satellite stains appeared on the trousers at approximately knee height or above. In a crime scene setting, satellite stains are more likely to be observed near the cuff of trousers, due to blood dripped onto the ground. The identification of satellite spatter from a drip stain without the context of the parent stain made this classification considerably more difficult.

Given the construction of the *satellite stains* in this study, it could be argued that an overall error rate that excludes this pattern type (14%) is more appropriate. What cannot be ignored, however, is the fact that the misclassification of this pattern type as blunt-force impact spatter could have implications for an investigation. Instead, these findings can serve as a caution to analysts not to exclude satellite spatter from dripped blood based primarily on the absence of a parent stain or due to the location of the stains.

The rate of incorrectly classifying *expiration patterns* was 16%. This is markedly higher than the classification of the same pattern type on rigid non-absorbent surfaces (1), where the rate was 4%. The characteristic features of an expiration pattern—air bubbles and mucus strands—were present on many of the non-absorbent surfaces (1), but not always on the absorbent surfaces, which could explain the difference in analysts' ability to recognize this pattern type on fabric.

The ability to accurately distinguish between spatter and transfer patterns on fabric is often a crucial concern in BPA. In this study, when the pattern was a spatter pattern (i.e., blunt-force impact, cast-off, expiration, or satellite stains), there were 63 misclassifications (24.6% of possible 256), and when the pattern was a transfer pattern, there were 12 misclassifications (18.5% of possible 65). On closer examination of these data, three (4.8%) of the misclassified spatter patterns were incorrectly classified as a transfer pattern—all other misclassified spatter patterns were misclassified as another type of spatter (e.g., *expiration pattern* misclassified as a *blunt-force impact pattern*). All erroneous transfer pattern classifications were misclassified as one or more types of spatter. Thus, it appears that a transfer pattern is more likely to be misclassified as a spatter pattern than a spatter pattern is to be misclassified as a transfer pattern. Given that the distinction between spatter and transfer patterns on fabric can have serious implications for an investigation, improving the ability to reliably distinguish and classify these two pattern types should be a focus for future research in BPA.

When considering pattern extent, correct classifications increased—and inconclusive classifications decreased—as the pattern extent increased (essentially the number of stains in the pattern). A similar pattern of results was observed for classifications on rigid non-absorbent surfaces (1). The frequency of correct, incorrect, and inconclusive responses did not vary significantly as a function of the three fabric substrates under investigation. In Taylor et al., (1), inconclusive decisions increased and correct classifications decreased when the target substrate was highly patterned (i.e., chipboard). Within each of the fabric substrates, the colors were light and uniform, which could explain why the pattern of responding remained stable between each. Fewer accurate classifications may have resulted if a patterned or dark fabric had been included.

The findings from this study suggest that bloodstain pattern classifications on fabric surfaces are vulnerable to contextual bias. That is, analysts' classifications varied according to the provision of contextual cues to suggest the mechanistic cause of the pattern. This finding is consistent with Taylor et al. (1) who

found evidence for contextual bias in bloodstain pattern classifications on rigid non-absorbent surfaces and contributes to the growing acknowledgment that contextual bias is an issue in forensic science (10–22).

Although this study has highlighted the potential risks of being in possession of contextual information, there may be safe ways to use such information to inform BPA interpretation. At present, however, there is no well-defined and validated procedure to do this. Such a procedure will likely include information triage—where contextual information is screened to determine its reliability—and thorough documentation of any use made of contextual information to inform an analyst's final opinion. Further investigations (see 23–26) into the specific conditions under which analysts are vulnerable to contextual bias, and the types of contextual information that are especially biasing, will help to inform the safe use of contextual information in BPA. Until such a procedure is properly validated, analysts would be wise to restrict access to contextual information to help minimize the potential for bias in their decision-making.

We have previously noted (1) that current BPA classification methods involve some measure of reconstruction, which is exacerbated by the mechanism-focussed terminology of the discipline. There is an argument for the development of a completely new classification method that is based purely on observable and measurable pattern characteristics and is devoid of any mechanistic overtones. Such a method should be less vulnerable to contextual bias, especially if it is based on computer-assisted pattern analysis.

Conclusions

For the pattern types (cast-off, impact, expiration, satellite stains from dripped blood, and transfer) and the fabric substrates (denim, dress, sweatpants) under investigation, this study has established a baseline-estimated error rate in the classification of bloodstain patterns on fabric. The error rate for classifications on fabric surfaces was higher than that observed on rigid non-absorbent surfaces (1). Although this finding was mainly due to the misclassification of satellite stains from dripped blood, the analysis of bloodstain patterns on fabric surfaces presents some additional challenges. Fabric surfaces are complex and highly variable with factors such as fiber composition, structural characteristics, surface treatments, dyeing, wear, and laundering all potentially affecting the final appearance of a bloodstain. Despite the frequency of clothing examinations in forensic laboratories around the world, the dynamics of bloodstain formation on textile surfaces remains under-researched. Until such time as blood-fabric interactions are better understood, analysts would be wise to continue to be conservative in their assessment of bloodstain patterns on such surfaces, and to focus on making observation-based conclusions in the absence of potentially biasing contextual information.

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