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Reliability Assessment of Current Methods in Bloodstain Pattern Analysis

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ABSTRACT

To date there have been relatively few error rate or validation studies in BPA and none has investigated the role that contextual information might have on analysts' conclusions. This study was designed to produce the first baseline measure of reliability for the major BPA method of pattern recognition. The approach used was designed to help define the upper limit of pattern classification reliability by focusing attention on method reliability rather than analyst competency.

A panel of experienced bloodstain pattern analysts examined over 730 patterns in two phases of the study, one focussing on three rigid non-absorbent surfaces (painted wood, wallpaper and chipboard) representing commonly encountered crime scene surfaces and the other on three fabric surfaces (cotton sweatpants, polyester trousers and demin jeans) representing clothing. Six different pattern types, *blunt force impact* spatter, *firearms* (back and forward) spatter, *cast-off*, *satellite stains* from a *drip* pattern, *transfer* and *expirated,* were used over the two studies. The extent of available pattern, the nature of the substrate and the type of contextual information (positive, negative and neutral bias) were varied in a balanced experiment designed to determine the effect of these variables on pattern classification accuracy. As a small adjunct to the main focus on pattern recognition, a set of superimposed bloodstains prepared on non-absorbent rigid surfaces was also included for sequence of events determinations.

Where a bloodstain pattern classification was made, either by choosing a single pattern or by nominating more than one, 13.1% of these classifications did not include the correct pattern type for the rigid surfaces and 23.4% for fabric surfaces. These can be considered the first approximations of overall error rates for the pattern classification method. Some patterns were more reliably classified than others. In particular the error rate was 4% for *expirated patterns* on rigid surfaces and 8% for *impact patterns* on fabric surfaces. The highest rates of misclassification were 59% for *satellite stains* from a *drip pattern* on fabric surfaces and 19% for *impact patterns* on rigid surfaces. Generally speaking where the pattern was more difficult to

recognise (e.g. less pattern available or a patterned substrate), analysts became more conservative in their judgment, choosing the inconclusive option.

Study results showed that where a scenario was offered that deliberately pointed analysts towards the correct classification, the proportion of misclassifications that resulted was significantly lower (8% rigid surfaces, 14% fabric surfaces) than that observed for patterns with neutral scenarios (11% rigid surfaces, 26% fabric surfaces). This is an example of the well-known phenomenon of confirmation bias. Where a scenario was offered that deliberately pointed analysts towards an incorrect classification, the proportion of misclassifications that resulted was significantly higher (20% rigid surfaces, 30% fabric surfaces) than that observed for patterns with neutral scenarios (11% rigid surfaces, 26% fabric surfaces).

The supplementary study on superimposed patterns showed that, for the current sequencing methods, the chances of incorrectly concluding the order of deposition in a *spatter/transfer pattern* combination is approximately 12% where *spatter stains* are deposited on top of *transfer stains* and 17% for the reverse sequence.

The implications for practitioners and agencies involved in BPA are discussed.

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EXECUTIVE SUMMARY

Introduction

Bloodstain Pattern Analysis (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. Like other forensic practitioners, bloodstain pattern analysts are grappling with the problem of assessing the reliability of the methodology 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.

It is well known that different bloodletting mechanisms can give rise to bloodstain patterns that possess similar or indistinguishable characteristics. Furthermore, 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. In addition, the surface characteristics of the substrate on which the bloodstain is created, whether a hard smooth surface or an absorbent fabric, might add another level of complexity to the pattern recognition task.

One other compounding problem may also exist. Bloodstain patterns are analysed 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 is considered. These two processes (pattern recognition and reconstruction) frequently overlap. This is not helped by the fact that, at present, there isn't a rigorous protocol for BPA that distinguishes the two processes. This means that at an early stage of the analysis, additional case-specific information, such as medical findings, case circumstances and even witness testimony may be considered during the analyst's interpretation. This has the potential to introduce bias into the pattern recognition process.

To date there have been relatively few published error rate or validation studies in BPA and none has investigated the role that contextual information might have on analysts' conclusions.

This study was designed to produce the first baseline measure of reliability for the major BPA method of pattern recognition.

The strategy adopted was to assemble a panel of experienced bloodstain pattern analysts and ask them to classify a series of patterns covering a range of pattern types. The patterns included stains made under a variety of conditions relevant to a crime scene and included some sets of stains produced under 'ideal' conditions. The type of pattern, 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. 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 study was conducted in two phases. In **Phase 1** bloodstain patterns on non-absorbent rigid surfaces were analysed. This phase was designed to be relevant to the use of BPA at a crime scene. In **Phase 2** absorbent fabric surfaces were used. The phase was designed to replicate, in part, the use of BPA in the laboratory, where bloodstained clothing is frequently analysed.

As a small adjunct to the main focus on pattern recognition, a survey of superimposed bloodstains prepared on non-absorbent rigid surfaces was also included. This was designed to give a preliminary assessment of the effectiveness of bloodstain pattern sequencing methods.

Phase 1 The Reliability of Pattern Classification for Bloodstain Patterns on Rigid non-absorbent Surfaces

Methods

Participants were 27 invited bloodstain pattern analysts from North America, Australasia, and Europe. All were invited based on their experience and standing within the BPA community, and were required to meet the following three criteria; 1) must have completed at least 80 hours training in BPA, 2) must have been active in BPA casework for a minimum of five years, and 3) must be qualified by a court as an expert in BPA and have provided expert testimony.

Bloodstain patterns representing four different common pattern types; *blunt force impact* spatter, *firearms (back and forward) spatter*, *cast-off* pattern, and *expirated* blood pattern were prepared. Patterns were created on 16 inch x 16 inch (40 cm x 40 cm) hard surface targets, mounted on a vertical surface.

Blunt force impact spatter patterns were produced by the impact of a hammer on a pool of blood containing 1 – 6 drops of blood. ***Cast-off patterns*** were created from the swinging of a blood-covered wrench or a small bloodied knife, swung towards and across the target surfaces. ***Expirated patterns*** were created by an experimenter blowing air gently through blood-covered lips or by coughing a small volume of blood from the mouth onto nearby vertical target surfaces. ***Firearms-related bloodstain patterns*** were created by shooting a .22 calibre bullet though a blood soaked sponge. Backspatter or forward spatter was collected on vertically positioned targets.

In addition to the four pattern types, there were two manipulated variables related to pattern construction. These were the ***substrate*** that the pattern was created on, and the ***extent*** of the pattern that was produced on each target.

Patterns were made on three different hard-surface substrates, designed to represent varying levels of anticipated identification difficulty: *paint*, *wallpaper*, and *chipboard*.

There were three levels of pattern extent; *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.

A final variable manipulated the context that accompanied each target pattern. The contextual information was presented in the form of a short vignette, giving background information about how the bloodstain pattern was found and what was known about the case. The scenario either contained information that supported the correct answer (*positive*), was misleading towards a particular incorrect answer (*negative*), or contained no directional information (*neutral)*.

Analysts who consented to be part of the study 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.

Each analyst received 15 or 16 targets, and a response sheet for each target. The response sheet comprised two main parts. In Part 1 analysts were required to choose *one* pattern from a set of pattern types based on standard SWGSTAIN terminology: This part was designed to give an assessment of analysts' confidence in making a singular decision. In Part 2 analysts could select *any* number of patterns from the same list. This part was designed to assess how precise analysts are able to be. In both parts analysts could select an "inconclusive" option.

In Part 1 we chose to determine an error rate based on the proportion of incorrect conclusions. In Part 2 an error was deemed to have occurred when the analyst failed to identify the correct pattern within their set of multiple answers given for a particular pattern. To provide some overall assessment of the performance of pattern classification, a second scoring system scaled participants' responses as a function of both accuracy and precision. This scale rewarded reduced ambiguity in all responses. This method was referred to as the Accuracy Precision (AP) score. AP scores could range from plus 4 (a single correct classification) to minus 4 (four or more nominated patterns, none of which included the true pattern). A fitted fully saturated model was fitted to the data using linear regression. This was followed by a close to balanced 4-way analysis of variance.

Results and Discussion

Overall Pattern Classification Accuracy

Twenty seven analysts made judgements on 15-16 target patterns each, yielding 413 unique assessments. When constrained to a single pattern response in Part 1, over half of the responses recorded as inconclusive. In those cases where a classification was made, there was close to a 50% success rate.

The rate of inconclusive responses dropped to 17% in Part 2. Despite being allowed to select any number of pattern classifications, 13% of these classifications did not include the correct pattern type. Overall, the average AP score per sample was 1.71. The linear regression model showed the main effects were all highly significant ($p < 0.001$).

Effect of Pattern Type

Analysts were prepared to give one unambiguous classification for 38% of the *cast-off patterns*. This was followed in order by *expirated* (33%), *impact* (28%), and *firearms-related spatter* (17%). When examining the proportion of correct and incorrect judgements for the single responses, the higher degree of confidence in classifying *cast-off* and *expirated patterns* appeared justified.

When both single and multiple classifications were considered, the effect of pattern type on the frequency of correct, incorrect, and inconclusive responses was still significant (p =0.028). This was mainly due to the success in identifying *expirated patterns* (81% success rate compared to 64 – 69% for the remaining types). The error rate across these pattern types was 4% for *expirated*, 14% for *cast-off*, 16% for *firearms-related spatter* and 19% for *impact*, giving rise to the overall error rate of 13% noted above.

Further support for the conclusion that *expirated patterns* are particularly easily identifiable was seen in the average AP scores for each pattern type. On average, analysts were the most accurate and precise when making judgements on *expirated patterns*, and the least for judgements about *firearms patterns*. The coefficient for pattern type in the linear regression model was significant ($p < 0.001$).

Effect of Extent

There was a significant overall difference in the frequency of correct, incorrect, and inconclusive responses as a function of pattern extent ($p < .0001$). As might be expected, analysts' accuracy improved as the amount of pattern (essentially the number of stains present on the target) increased.

Although the amount of pattern available influenced analysts' correct and inconclusive decisions, the rate of making incorrect judgements was very similar. Analysts made fewer correct decisions and more inconclusive decisions on patterns that contained only minimum extent. This trend was reversed when the patterns had maximum extent.

AP scores for each pattern extent confirmed the conclusion that patterns with a minimal number of stains in them were not classified as accurately or unambiguously as the more stain-abundant patterns. The pattern extent coefficient in the linear regression model was significant ($p < 0.001$).

Effect of Substrate

There was a significant overall difference in the frequency of correct, incorrect, and inconclusive responses as a function of substrate ($p < .0001$). As expected, the plain white-painted surface was the best surface for making correct pattern classifications and the more "difficult" surfaces gave rise to fewer correct classifications. As observed in the pattern extent effect, the drop in accuracy was matched by an increase in inconclusive responses rather than erroneous ones.

AP scores for each pattern substrate confirmed the conclusion that patterns on the patterned chipboard were not classified as accurately and unambiguously as the other two surfaces. The coefficient for substrate in the linear regression model was significant ($p < 0.001$).

Effect of Context

There was a significant overall difference in the number of correct, incorrect, and inconclusive responses as a function of context ($p =0.015$).

When a positive context was presented, participants were more likely to make a correct decision than when the context was neutral, with the overall error rate dropping significantly from 11% (neutral context) to 8%. They were also less likely to make an inconclusive decision.

The result for positively-biasing context is an example of the well-known phenomenon of confirmation bias.

It is also evident that a negative context influenced participants' decision-making. Participants were incorrect more often when there was a negative context, relative to when there was a positive or neutral context, with the overall error rate increasing significantly from 11% (neutral context) to 20%. They were also less likely to make an inconclusive decision.

Average AP scores for each type of added contextual bias confirmed the conclusion that added bias influenced the conclusions of pattern classification in the direction of the bias. The coefficient for context in the linear regression model was significant ($p < 0.001$).

Phase 2 The Reliability of Pattern Classification for Bloodstain Patterns on Fabric Surfaces

Methods

Participants were 30 invited bloodstain pattern analysts from North America, Australasia, and Europe and were invited on the same basis as for Phase 1 of this study.

Bloodstain patterns comprised five different pattern types; *blunt force impact spatter*, *cast-off*, *expirated*, *satellite stains from a drip pattern*, and *transfer* were prepared. These pattern types were chosen to represent those typically encountered on fabric surfaces in casework. Patterns were created on the upper region of pairs of men's trousers which were worn by one of the experimenters during pattern creation. Two levels of pattern extent were used in this phase, 'maximum' and 'minimum'.

Blunt force impact spatter patterns were created using the impact of a hammer on one drop of blood (minimum extent) or eight drops (maximum extent). ***Cast-off patterns*** were created by the swinging of blood covered fingers of a gloved hand. One finger was coated with blood to make the minimum extent patterns while three bloodied fingers were used for maximum extent patterns. ***Expirated patterns*** were created by an experimenter gently blowing air through blood-covered lips (minimum extent pattern), or by coughing blood from the mouth (maximum extent pattern). ***Drip patterns*** were created by dripping consecutive drops of blood in the same position on a table in close proximity to an experimenter, wearing the target trousers. Three blood drops were used to create the minimum extent pattern, and 12 for the maximum extent. ***Transfer patterns*** were created by contact between a bloodstained wig and the target trousers. To create a minimum extent pattern the wig was touched briefly and lightly against the thigh area of the target trousers. For the maximum extent pattern the wig was touched firmly and for slightly longer.

Patterns were made on three different fabric-surface substrates chosen based on three common types of trousers; polyester dress pants, blue denim jeans and grey cotton sweatpants.

A final variable manipulated the *context* that accompanied each target pattern. This was done in a similar manner to Phase 1.

The procedure for engaging participants was essentially the same as for Phase 1. Each analyst received 12 - 15 targets, and a response sheet corresponding to each target. The response sheet comprised two main parts with the same instructions and the same set of pattern types as used for Phase 1, with the addition of *satellite stains* as a choice. The remaining aspects of the procedure and the methods of determining error rate followed those used for Phase 1.

Results and Discussion

Overall Pattern Classification Accuracy

Thirty analysts made judgements on 12 - 15 target patterns each, yielding 321 unique assessments. When constrained to a single pattern response in Part 1, over half of the responses recorded as inconclusive. In those cases where a classification was made, there was a 64% success rate. This was a higher success rate than the hard surfaces in Phase 1.

The rate of inconclusive responses dropped to 14% in Part 2. Despite being allowed to select any number of pattern classifications, 23% of these classifications did not include the correct pattern type. This was a higher error rate than for hard surfaces. Overall the average AP score per sample was 1.30. This was lower than that observed in Phase 1, probably reflecting the additional difficulty in classifying patterns on fabric surfaces. The linear regression model showed the effects of pattern type, pattern extent and context were all highly significant ($p < 0.001$). The effect of substrate, however, was not significant at the 95% confidence level.

Effect of Pattern Type

Analysts were prepared to give one unambiguous classification for 51% of the *cast-off patterns*. This was followed in order by *drip* (48%), *transfer* (31%), *expirated* (24%) and *impact* (18%). However, unlike the results observed for hard surfaces, the confidence analysts had in unambiguously classify patterns on fabric was not well correlated with the accuracy of classification.

When both single and multiple classifications are considered, the effect of pattern type on the frequency of correct, incorrect, and inconclusive responses was significant ($p < 0.001$). This was mainly due to a lack of success in identifying *satellite stains* from *drip patterns*. The error rate across these pattern types was 8% for *impact*, 14% for *cast-off*, 16% for *expirated*, 18% for *transfer* and 59% for *drip patterns*, giving rise to the overall error rate of 23% noted above.

Further support for the conclusion that *cast-off patterns* are most easily identifiable and *satellite stains* from *drip patterns* are the most problematic was evident in the average AP scores for each pattern type. The coefficient for pattern type in the linear regression model was significant ($p < 0.001$).

Effect of Extent

There was a significant overall difference in the frequency of correct, incorrect, and inconclusive responses for the maximum extent patterns compared with the minimum extent ones ($p < .0001$). As might be expected, analysts' accuracy improved as the amount of pattern increased.

The AP scores for the two pattern extents confirmed the conclusion that patterns with a minimal number of stains in them were not classified as accurately or unambiguously as the more stain-abundant patterns. The pattern extent coefficient in the linear regression model was significant ($p < 0.001$).

Effect of Substrate

There was an apparent improvement in the accuracy of classifying patterns on the sweat pants but this was not statistically significant ($p = 0.130$).

The AP scores for each pattern substrate confirmed the conclusion that there was little difference in the accuracy and precision of classifying patterns on the three fabric surfaces chosen. The coefficient for substrate in the linear regression model was not significant ($p = 0.183$).

Effect of Context

There was a significant overall difference in the number of correct, incorrect, and inconclusive responses as a function of context ($p = 0.003$).

When a positive context was presented, participants were more likely to make a correct decision than when the context was neutral, with the overall error rate dropping significantly from 26% (neutral context) to 14%. They were also less likely to make an inconclusive decision. This was also an example of confirmation bias. The overall error rate for positively-biased contexts was higher than that for the rigid surfaces in Phase 1.

It is also evident that a negative context influenced participants' decision-making. Participants were incorrect more often when there was a negative context, relative to when there was a positive or neutral context, with the overall error rate increasing significantly from 26% (neutral context) to 30%. In contrast to the equivalent comparison in Phase 1, they were also more likely to make an inconclusive decision.

The average AP scores for each type of added contextual bias confirmed the conclusion that added bias apparently influenced the conclusions of pattern classification in the direction of the bias. The coefficient for context in the linear regression model was significant ($p < 0.001$).

Supplementary Study: The Reliability of Bloodstain Pattern Sequencing

Introduction

It is common for bloodstain patterns at crime scenes to be superimposed. The order in which such patterns are deposited can sometimes be valuable evidence of the timing of the events that took place. Despite the value of this type of evidence, there have been few published studies made of bloodstain pattern sequencing and no standardized methods have emerged. The objective of this supplementary study was to formally assess the reliability of current methods for establishing the sequence of superimposed patterns where the first pattern deposited has completely dried.

Methods

Two commonly encountered pattern types were selected for this study, namely *spatter* and *transfer*. A total of 112 bloodstain patterns comprising superimposed *transfer* and *spatter* stains were prepared, half of which were spatter stains superimposed on *transfer* stains and half were *transfer* stains on *spatter*. The materials used were those described in Phase 1.

Transfer stains were created by drawing a blood-soaked cotton glove across the target surface, giving a *swipe* pattern showing four fingers. *Spatter* stains were created by using a hammer to strike one drop of blood. Bloodstains forming the first applied pattern were allowed to dry thoroughly before the second pattern was superimposed.

There were two manipulated variables relating to pattern construction, namely <u>pattern extent</u> (amount of spatter) and <u>target substrate</u>. These variables were identical to those described in Phase 1.

Each analyst received a unique set of 3 or 4 sequencing targets and were informed that each had both a *transfer* and a *spatter pattern* on it. They were asked to determine the sequence these two patterns have been applied in or indicate that they could not reach a conclusion.

Results and Discussion

104 survey responses were received, comprising 50 combinations of *spatter* stains superimposed on *transfer* stains and 54 *transfer* stains on *spatter*. Of the 104 conclusions given, over half (52.9%) were recorded as inconclusive, 32.7% correctly assigned the sequence and 14.4% gave an incorrect interpretation.

Where spatter stains were deposited on top of *transfer stains*, 48% of the patterns were correctly sequenced, whereas for the reverse sequence this figure dropped to 19%. There was a corresponding increase in the proportion of inconclusive responses from 40% to 65%.

These results appear to show that when *spatter stains* are deposited on *transfer stains*, analysts were more willing to give a conclusion, and those conclusions are more likely to be correct. For those targets that analysts were prepared to make an interpretation, 80% were correct when the pattern was *spatter* on *transfer*, but only 53% were correct if the *transfer* followed the *spatter*. The difference in response between the two pattern combinations was statistically significant (p = 0.004).

Overall, the effect of substrate on correct responses was not significant (p = 0.581). The number of incorrect conclusions increased and the number of inconclusive responses decreased slightly, as the extent of *spatter* increased, in both *spatter* on *transfer* and *transfer* on *spatter* combinations. So for example, those targets that had a *spatter pattern* with many stains (i.e., maximum extent) overlaid with a *transfer pattern* gave the highest number of <u>incorrect</u> interpretations. The overall effect of pattern extent was significant (p = 0.046).

Because the bloodstains in this study were allowed to dry completely between the two depositions, there were no perimeter stain effects to give clues as to the order of deposition. In the absence of this, it is possible that the analysts' attention was drawn to the intensity of the individual stains, with the more intense stains reckoned to be the more recent of the two depositions.

Conclusions

The results of this study provide the first approximations of overall error rates for the pattern classification method in BPA. This has been shown to be dependent on the pattern type, the amount of available pattern and the substrate. Generally speaking where the pattern was more difficult to recognise, analysts became more conservative in their judgment, which is what the court would expect from a reliable method.

Study results showed that where a scenario was offered that deliberately pointed analysts towards the correct classification, the proportion of misclassifications that resulted was significantly lower than that observed for patterns with neutral scenarios. This is an example of the well-known phenomenon of confirmation bias. Where a scenario was offered that deliberately pointed analysts towards an incorrect classification, the proportion of misclassifications that resulted was significantly higher than that observed for patterns with neutral scenarios.

It seems prudent for practitioners and agencies to take steps to minimise the effects of contextual information in the practice of BPA. It would also be advantageous for the BPA community to agree on a standard methodology for the analysis of bloodstain patterns which includes a better distinction between classification and reconstruction and relies less on mechanistic descriptions of patterns. It is recommended that these steps be under-pinned by further research into an understanding the cognitive steps taken by BPA analysts during pattern classification and the development of objective methods to classify patterns.

MAIN BODY OF TECHNICAL REPORT

INTRODUCTION

Statement of the Problem

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 identity 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 clothing was deposited when he 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 telling 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, hence the emergence of Bloodstain Pattern Analysis (BPA) as a vital tool for forensic investigators.

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 BPA is the recognition and classification of the bloodstain pattern.

In the past few years there have been 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 (e.g. R v Jenkins, London Court of Appeal 1999, Indiana v Camm, Indiana Supreme Court 2009). At the center of these controversies is the observation that different mechanisms can produce bloodstain patterns that apparently do not have significant individual characteristics to distinguish how the pattern was produced. For example *Impact*[1], *Expiration*[2] *and Transfer*[3] patterns [1] can all feature small bloodstains and can be confused with one another, especially on fabric.

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 Scientific Working Group on Bloodstain Pattern Analysis (SWGSTAIN) has published a paper on the validation of new procedures [2] and is making valuable progress in setting new standards for training and education, terminology and quality assurance for the discipline. However like other forensic practitioners, bloodstain pattern analysts are grappling with the problem of assessing the reliability of the methodology 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 bloodstain pattern analysis testimony in the past, the courts now rightly demand much more.

No scientific method is without error or uncertainty and bloodstain pattern analysis is no exception. Even a casual perusal of responses to quality assurance testing programs, such as the bloodstain pattern analysis trials produced by Collaborative Testing Services, shows that there are some significant differences in pattern classification conclusions reached by trained BPA investigators.

It is well known that different bloodletting mechanisms can give rise to bloodstain patterns that possess similar or indistinguishable characteristics. Furthermore, 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. In addition, the surface characteristics of the substrate on which the bloodstain is created, whether a hard smooth surface or an absorbent fabric, might add another level of complexity to the pattern recognition task.

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[1] An ***impact pattern*** is a bloodstain pattern resulting from an object striking liquid blood.

[2] An ***expirated*** pattern is a bloodstain pattern resulting from blood forced by airflow out of the nose, mouth, or a wound.

[3] A ***transfer stain*** is a bloodstain resulting from contact between a blood-bearing surface and another surface.

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 pattern evidence proffered can be supported by statements that guide the courts in their assessment of the extent of that reliability.

One other compounding problem may also exist. Bloodstain patterns are analysed 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 is considered. These two processes (pattern recognition and reconstruction) frequently overlap. This is not helped by the fact that, at present, there isn't a rigorous protocol for BPA that distinguishes the two processes. This means that at an early stage of the analysis, additional case-specific information, such as medical findings, case circumstances and even witness testimony may be considered during the analyst's interpretation. This has the potential to introduce bias into the pattern recognition process.

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 [3, 4], but so far there has been no significant effort 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 they employ.

It is against this backdrop that the present study has been constructed. Testing the reliability of bloodstain pattern analysis 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 'true answer' can be known. This approach has the risk of underestimating identification errors because some of the dynamics present in a real case investigation are lacking. For example, factors such as the expectations of other stakeholders in the investigation and the knowledge that the outcome of the analyst's findings could influence the life or liberty of a defendant are not easily simulated in an artificially created scenario.

Despite these difficulties it is nevertheless important to take steps towards understanding this reliability. This study was designed to do that.

Literature Review

To date there have been relatively few published error rate or validation studies in BPA. De Forest, et al., discussed the error associated with determining the impact angles of airborne droplets [5]. They attributed a 5 degree margin of error in this determination to droplet oscillations while in flight or droplet expansion when striking the surface. Gestring, et al., showed that this error drastically increased as the stain became more circular and was dependent on the substrate on which the stain was produced [6].

Laturnus has surveyed the measurement of individual bloodstains [7]. This study was the first systematic attempt to evaluate accuracy and methodology used in making this determination. In addition to using different tools to evaluate the stains, the participants also had divergent methods of measuring stain length.

Carter has developed validated methods for determining areas of origin for blood spatter using the computer software program BackTrack™ [8-10].

With the requirements of the Daubert criteria [11] in mind, Meneses, Kish, and Gestring sought to evaluate the error rate for the first step of BPA, namely basic pattern recognition [12]. Since examiner competency and method error rate are linked, this preliminary study evaluated how often trained examiners were able to successfully identify bloodstain patterns. This was accomplished through the use of a web-based survey tool. Ten basic bloodstain patterns were created on cardboard substrates. Participants were shown pictures of the bloodstain patterns and asked to describe the mechanism that created the pattern.

The survey was taken by 92 self-identified experts and 65 control group members of equivalent educational background. Overall the experts correctly identified the pattern type 97% of the time, while the control group only got it right 21% of the time.

While this is a promising start, this research had some limitations that need to be overcome in future studies. As an example, the web delivery system limited the resolution of images it would accept to 150 kb. This forced the researchers to select patterns that could be adequately represented with the limited resolution of the study. Furthermore there was no attempt to investigate the role that contextual information might have on analysts' conclusions.

Fabrics are among the most complex surfaces when it comes to characterizing bloodstain patterns and their causes. It is well known that characteristics of the surface have a significant effect on the formation of bloodstains on fabric [13, 14]. Most of the research in the area of bloodstains on fabric has been focused on this effect [15-22].

Few studies have addressed the question of how to distinguish pattern types on fabric, particularly when those patterns are dominated by small stains. Karger, et al., [18] used small blood drops (0.1 -10 μL) to generate a series of *transfer* stains on a variety of fabrics. These were compared to a series of *drip stains*[4] and *spatter stains*[5] of similar size generated on the same fabrics. Their results showed that *transfer* stains had a tendency to impregnate the weave of the fabric whereas the *drip* and *spattered* droplets remained on the surface of the weave.

Karger concluded that the dynamic characteristics seen in *drip* and *spattered* bloodstains will never be reproduced in *transfer* bloodstains. Therefore, in most cases *transfer stains* can be differentiated from *drip* and *spatter* stains by their lack of dynamic characteristics, though the ability to differentiate between *transfer* and *spatter* bloodstains becomes more difficult with smaller stains and fabrics with rougher or irregular surfaces.

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[4] A ***drip stain*** is a bloodstain that formed as the result of a falling drop that formed due to gravity.
[5] A ***spatter stain*** is a bloodstain resulting from a blood drop dispersed through the air due to an external force applied to a source of liquid blood.

However Karger's study did not appear to consider bloodstains less than 2 mm in size created by relatively high velocity droplets, which are common in *spatter* patterns. Furthermore the *transfer* stains were created by contact with some pressure, which might explain the observed extra penetration of the blood into the fabric.

With the exception of Karger's work, there appears to be a general consensus that the difference in appearance between bloodstains caused by an impact event and those caused by contact transfer is due to the level of penetration of the blood into weave of the fabric [13, 14, 23, 24]. The momentum of *spatter* causes the blood to be projected into the weave, whereas with *transfer* stains, the blood tends to remain in the upper weave of the fabric. Despite these studies no clearly articulated and validated method to distinguish *transfer* and *spatter* patterns has emerged.

Physical aspects of bloodstain pattern formation may not be the only source of error in bloodstain pattern identification. In particular, a considerable body of research over several decades has demonstrated that evaluations and assessments may be influenced by contextual and other cues which may set up particular expectations on the part of the investigator. It is important to note that the effects of such expectations are not trivial, with one meta-analysis of 345 studies indicating a mean effect size of 0.33 [25]. Recognition of the role of such expectancy effects has led to the widespread use of approaches such as the so-called "double-blind" experiment, in which neither participant nor experimenter is aware of the specific conditions generating any single datum point [26]. In the applied setting, however, it may be difficult or impossible for an investigator to remain totally blind to contextual cues. It is important, therefore, to assess the extent to which these may potentially have an impact on the results obtained.

Investigating the role of context in forensic evidence interpretation is a relatively new area of study, but the results so far provide genuine cause for concern. In particular, research has shown that fingerprint experts can be influenced by contextual information that suggests a pair of fingerprints are from the same or a different source [27, 28]. In other studies, even more subtle contextual information presented alongside fingerprint pairs, such as images depicting violent and graphic crimes, increased the number of match decisions made [29, 30]. It is important to note that in these studies, participants were only vulnerable to the influence of context when the information they were making judgements on was ambiguous. That is, the fingerprint pairs did not contain enough information to make a clear decision. To date no equivalent study has been conducted on the role of contextual information in bloodstain pattern analysis.

Research Hypothesis and Strategy

The research hypothesis at the heart of this study was:

"Pattern recognition in BPA is a reliable method when used by fully competent analysts".

The study was designed to produce the first baseline measure of reliability for the major BPA method of pattern recognition.

The strategy adopted was to assemble a panel of experienced bloodstain pattern analysts and ask them to classify a series of patterns covering a range of pattern types. The 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 <u>upper limit</u> of pattern classification reliability by focusing attention on method reliability rather than analyst competency.

The type of pattern, 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.

The study was conducted in two phases. In **Phase 1** bloodstain patterns on non-absorbent rigid surfaces were analysed. This phase was designed to be relevant to the use of BPA at a crime scene. In **Phase 2** absorbent fabric surfaces were used. The phase was designed to replicate, in part, the use of BPA in the laboratory, where bloodstained clothing is frequently analysed.

As a small adjunct to the main focus on pattern recognition, a survey of superimposed bloodstains prepared on non-absorbent rigid surfaces was also included. This was designed to give a preliminary assessment of the effectiveness of bloodstain pattern sequencing methods.

PHASE 1 The Reliability of Pattern Classification for Bloodstain Patterns on Rigid Non-absorbent Surfaces

Methods

Participants

Participants consisted of 27 bloodstain pattern analysts from North America, Australasia, and Europe. All were invited based on their experience and standing within the BPA community, and were required to meet the following three criteria; 1) must have completed at least 80 hours training in BPA, 2) must have been active in BPA casework for a minimum of five years, and 3) must be qualified by a court as an expert in BPA and have provided expert testimony.

Materials

Bloodstain patterns.

Bloodstain patterns comprising four different **pattern types**; *blunt force impact spatter*, *firearms (back and forward) spatter*[6], *cast-off pattern*[7], and *expirated blood pattern* were prepared. These pattern types were chosen to reflect the potential for overlap in pattern characteristics between pattern types, which can be problematic for bloodstain analysts, and were designed to represent those typically encountered at crime scenes. As a further attempt to represent the variability found in crime scenes, two methods were used to create each pattern type.

Cast-off 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 seven days of drawing. Blood for the *firearms spatter* was purchased from Memorial

[6] ***Firearms-related spatter*** in the context of this report refers to bloodstain patterns associated with a gunshot, either ***backspatter*** or ***forward spatter***. A ***backspatter pattern*** is a bloodstain pattern resulting from blood drops that travelled in the opposite direction of the external force applied; associated with an entrance wound created by a projectile. A ***forward spatter pattern*** is a bloodstain pattern resulting from blood drops that traveled in the same direction as the impact force.

[7] A ***cast-off pattern*** is a bloodstain pattern resulting from blood drops released from an object due to its motion.

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.

Patterns were created in a controlled laboratory setting at the Minnesota Bureau of Criminal Apprehension (BCA) Laboratory. They were created on 16 inch x 16 inch (40 cm x 40 cm) hard surface targets, mounted on a vertical surface. Completed targets were coated with a clear lacquer to prevent deterioration and to assist with biohazard safety. This 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.

Blunt force impact spatter. The two methods used to create the *blunt force impact spatter* are described in Table 1. Method 1 (Figure 1) tended to produce finer, more horizontal spatter, where Method 2 tended to produce larger spatter that travelled higher on the wall. Multiple targets were positioned 20 inches (50 cm) from the front, side, and back of the striking zone.

Table 1 Methods used to create *blunt force impact spatter*.

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.
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.

Figure 1 Hammer set to be propelled by rubber band on to a wooden block to create *blunt force impact spatter* (Method 1).

Cast-off pattern. The two methods used to create the *cast-off patterns* are described in Table 2. Method 1 tended to produce larger stains that were in a more broadly linear distribution, where Method 2 tended to give smaller spatter stains that were in a tightly linear distribution.

Table 2 Methods used to create *cast-off patterns*

Method 1	A wrench was liberally coated in blood, and then swung a few times to remove excess blood. An experimenter stood approximately 50 inches (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.
Method 2	A small knife was dipped a few millimetres into a beaker of blood and knocked one to two times to remove excess blood. An experimenter then stood approximately 34 inches (85 cm) from

	the left wall, and 50 inches (130 cm) from the front wall, and swung the knife forcibly towards the targets.

Expirated pattern. The methods used to create the *expirated patterns* are described in Table 3. Method 1 tended to produce smaller stains and generally lacked mucus strands, where Method 2 tended to give a larger range of spatter sizes and frequently contained mucus strands.

Table 3 Methods used to create *expirated blood patterns*.

Method 1	An experimenter transferred blood to his lips with a finger and blew air gently through tightly pursed lips directly towards the targets, which were mounted 6 – 7 inches (15 – 20 cm) from him.
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 towards the targets, which were mounted 20 - 36 inches (50 - 90 cm) from him.

Firearms-related spatter pattern. The methods used to create the *firearms-related spatter* are described in Table 4. Method 2 used to create *firearms-related spatter patterns* is illustrated in Figure 2. For both methods, a .22 calibre bullet was fired from a pistol through a blood soaked sponge. Some targets required multiple shots to obtain the desired amount of pattern.

Table 4 Methods used to create *firearms-related spatter patterns*

Method 1	Backspatter was collected from targets positioned 47 inches (120 cm) from the rear of a blood-soaked sponge.
Method 2	Forward spatter was collected from targets positioned 47 inches (120 cm) from the front of the sponge.

Figure 2 Blood soaked sponge and target arrangement to create *forward spatter* for *firearms-related spatter patterns* (Method 2).

In addition to the four pattern types, there were two manipulated variables related to pattern construction. These were the ***substrate*** that the pattern was created on, and the ***extent*** of the pattern that was produced on each target.

Substrate.

Patterns were made on three different hard-surface substrates, designed to represent varying levels of anticipated identification difficulty (see Figure 3); *paint* (A), *wallpaper* (B), and *chipboard* (C). 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 applied once mounted on the targets. 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.

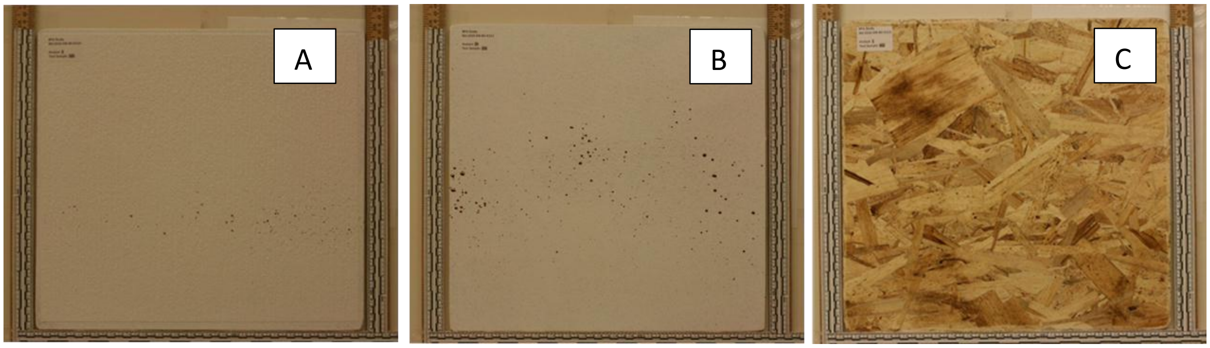

Figure 3 Example of patterns created on a paint (A), wallpaper (B), and chipboard (C) surface.

Extent.

There were three levels of pattern extent; *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 5 Thresholds for determining pattern extent

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

* For *cast-off patterns*, a minimum pattern was determined if there were 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.

Context.

A final variable manipulated the ***context*** that accompanied each target pattern. The contextual information was presented in the form of a short vignette, giving 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. The scenario either contained information that supported the correct answer (*positive*), was misleading towards a particular incorrect answer (*negative*), or contained no directional information (*neutral)*. Two examples are given in Table 6.

Table 6 Examples of scenarios with additional contextual information

Example scenario containing contextual information to suggest the pattern is the result of expirated blood (used for both positive and negative manipulation):
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 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.
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.

Survey Procedure

Analysts were initially invited via an email asking for their participation in the study. 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.

Materials were only sent to an analyst after he or she had indicated their willingness to participate. The general instructions that accompanied these materials are shown in Appendix

1. Each analyst received 15 or 16 targets, and a response sheet for 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.

The response sheet comprised two main parts. Part 1 stated:

"*To assist investigators with the early stages of their enquiries you have been asked for your assessment as to the pattern type that best describes the pattern you have observed on the sample target."*

Analysts were then required to choose *one* of the following patterns (based on standard SWGSTAIN terminology [1]: *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*), *wipe*, or indicate that they "can't identify one best pattern." This part was designed to give an assessment of analysts' confidence in making a singular decision.

Part 2 stated:

"You are now 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."

From the same list of patterns, analysts could now 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.*" This part was designed to assess how precise analysts are able to be.

After completing both parts for each target, analysts emailed or posted their responses to an independent third party. All materials and responses were returned to experimenters via the third party to ensure they remained anonymous.

Error Rate Determination

The calculation of error rates for a method such as pattern recognition is not straight-forward. In Part 1, where only a single answer was required, we chose to determine an error rate based on the proportion of incorrect conclusions.

In Part 2, where multiple answers were permitted, an appropriate error rate is less obvious. In this part of the survey, an error was deemed to have occurred when the analyst failed to identify the correct pattern within the set of multiple answers given for a particular pattern. The results are presented graphically and resulting data tables are analysed statistically using the Pearson chi-square test.

Overall Pattern Classification Performance

A second scoring method was devised to give an assessment of the overall pattern classification performance. In this method participants' responses were scaled as a function of both accuracy and precision. This scale rewarded reduced ambiguity in all responses. For example a single correct classification gives a maximum score of plus 4. Multiple nominated patterns, none of which include the true pattern scores down to minus 4. This method will be referred to as the Accuracy Precision (AP) score. A fitted fully saturated model was fitted to the data using linear regression. This was followed by a close to balanced 4-way analysis of variance. The significance of the various effects was determined by the significance of the coefficients for the respective variables.

The two scoring methods are detailed in Table 7.

Table 7 Scoring systems used

Number of pattern types nominated	Correct pattern nominated in the list	Scoring method #1	Scoring method #2 (AP Score)
>=4	YES	1	1
3	YES	1	2
2	YES	1	3
1	YES	1	4
0	-	0	0
1	NO	-1	-1
2	NO	-1	-2
3	NO	-1	-3
>=4	NO	-1	-4

Results and Discussion

Pattern Classification Accuracy

Twenty seven analysts made judgements on 15-16 target patterns each, yielding 413 unique assessments. The overall accuracy of these assessments is summarised in Table 8 and Figure 4, which display the distribution of correct, incorrect, and inconclusive judgements for Parts 1 and 2.

When constrained to a single pattern response in Part 1, analysts were reluctant to commit to a classification, with over half of the responses recorded as inconclusive. In those cases where a classification was made, there was a 56% success rate. The intent of this part of the survey was to test the accuracy of pattern classification under conditions where an analyst might give a preliminary finding to an investigator for intelligence purposes. It was clear that even though this was not required to be a final “court-ready” conclusion, many analysts were unwilling to commit to a single answer.

The rate of inconclusive responses dropped to 17% in Part 2. Here, multiple choices were allowed but analysts needed to be prepared to present these in court. Despite being allowed to select any number of pattern classifications, 13% of these classifications did not include the correct pattern type.

Table 8 Overall pattern classification accuracy

Response	Part 1	Part 2
Correct	26.2%	69.5%
Incorrect	20.6%	13.1%
Inconclusive	53.2%	17.4%
Total responses	**412**	**413**

For those patterns incorrectly classified in the single-answer format of Part 1, only slightly over half (52%) were subsequently correctly classified in the multiple-answer format of Part 2 of the survey. Of the 40 patterns that were incorrectly classified in both Parts, over half of responses in Part 2 (26) remained single-answer responses. This suggests that analysts had reached a conclusion early in the decision-making process, and were confident in this conclusion.

Overall, the average AP score per sample was 1.71 (equivalent to the nomination of between 3 and 4 patterns including the correct one). The linear regression model showed the main effects were all highly significant ($p < 0.001$).

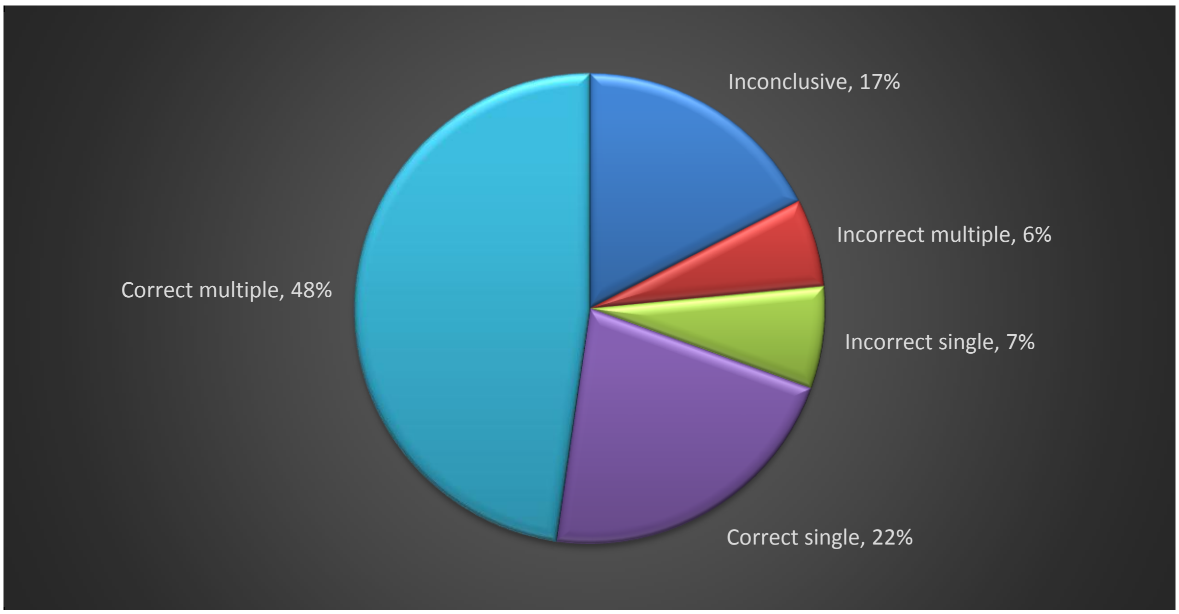

Figure 4 A breakdown of the accuracy of pattern classification in Phase 1, Part 2 of the study where both single and multiple answers were allowed.

In the remaining analysis, only Part 2 responses are considered.

Effect of Pattern Type

Analysts appeared to have had varying degrees of confidence in identifying the different bloodstain patterns in this survey. Where the analyst had the opportunity of specifying more than one pattern, some patterns were nevertheless given a single classification. These patterns were apparently sufficiently clear to give the analyst enough confidence to exclude all but one pattern type in his/her conclusion.

Figure 5 shows the number of pattern types nominated by the analyst for each of the known patterns. Analysts were prepared to give one unambiguous classification for 38% of the *cast-off patterns*. This was followed in order by *expirated* (33%), *impact* (28%), and *firearms-related spatter* (17%). When examining the proportion of correct and incorrect judgements for the single responses, we can see that the higher degree of confidence in classifying *cast-off* and *expirated* patterns appears justified. As seen in Figure 6, it is evident that, when an analyst was confident enough to make an unambiguous classification, this was done with a high degree of accuracy for these two pattern types, P = 0.95 (*cast-off*) and P = 0.91 (*expirated*), but not for *impact* (P = 0.48) and *firearms-related spatter patterns* (P = 0.47).

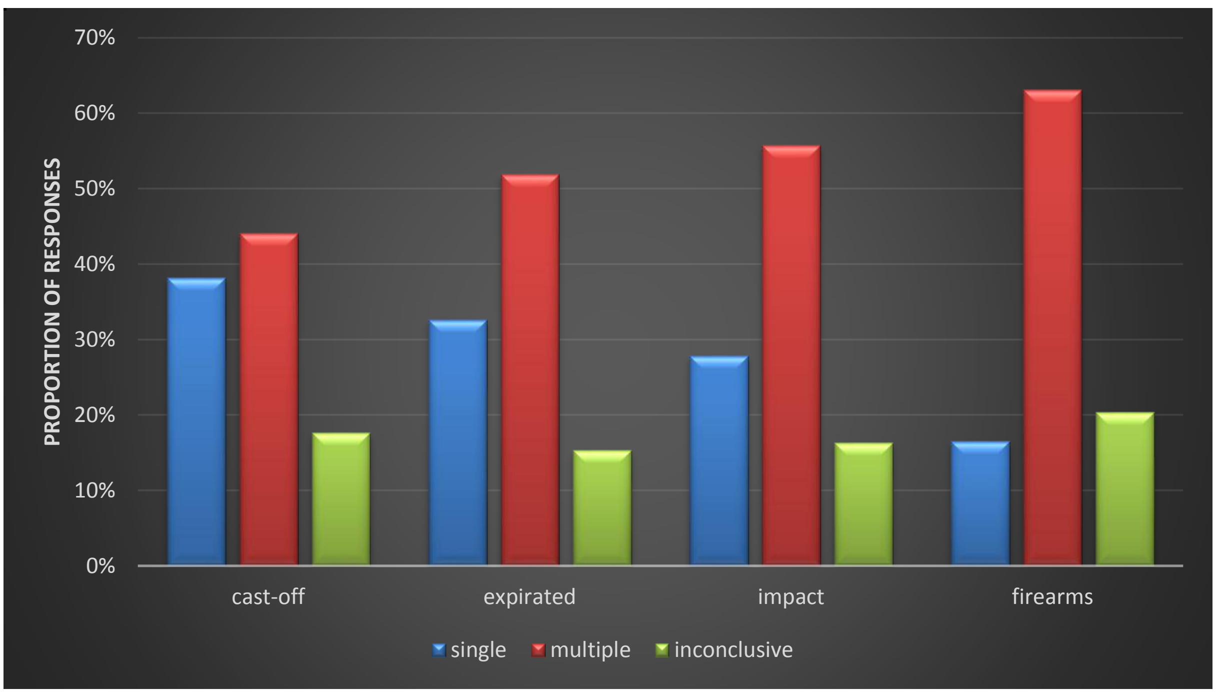

Figure 5 The distribution of the number of pattern types nominated for each classification in Phase 1. Single = one pattern type; Mulitple = two or more; Inconclusive = no patterns nominated

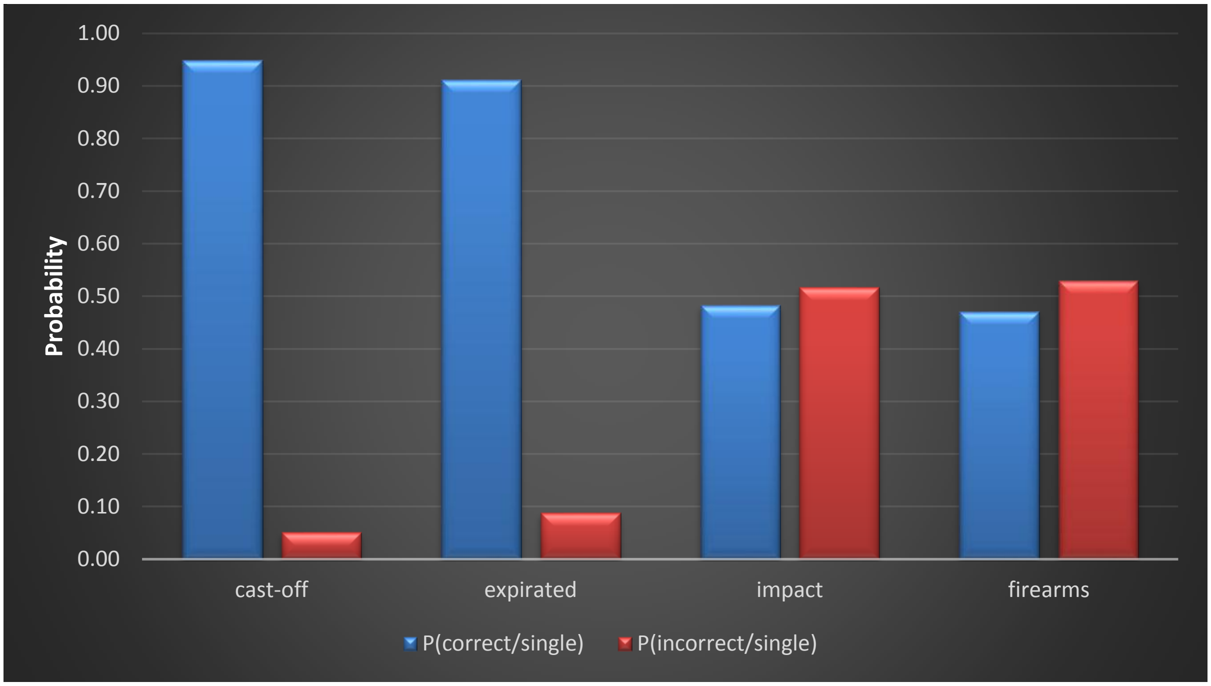

Figure 6 The probability of correctly classifying those patterns for which a single pattern type was nominated (Phase 1).

Most of the distinctive features of a *cast-off pattern*, such as a narrow distribution of linear/curvilinear stains, were generally present in the *cast-off patterns* prepared in this study. Likewise the characteristic mucus strands and air bubbles were present in most of the *expirated patterns*. It is not too surprising therefore that analysts had a high degree of success in uniquely identifying these two pattern types.

Other than a lack of distinctive features in a pattern, we cannot be certain why the proportion of single incorrect answers for *impact* and *firearms-related spatter patterns* was so high. It is possible that the features that were observed 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, we observed that the majority of these single-choice *impact patterns* were incorrectly classified as *cast-off*. *Firearms-induced spatter* patterns in this survey did not always have a large proportion of the very small "mist" stains and this may explain why the majority of the single-choice *firearms patterns* were identified as *impact patterns*.

When both single and multiple classifications are considered, the effect of pattern type on the frequency of correct, incorrect, and inconclusive responses was still significant; $\chi^2(6, N = 413) = 14.12$, $p = 0.028$ (Figure 7). This was mainly due to the success in identifying *expirated patterns* (81% success rate compared to 64 – 69% for the remaining types). The error rate across these pattern types was 4% for *expirated*, 14% for *cast-off*, 16% for *firearms* and 19% for *impact*, giving rise to the overall error rate of 13% noted above.

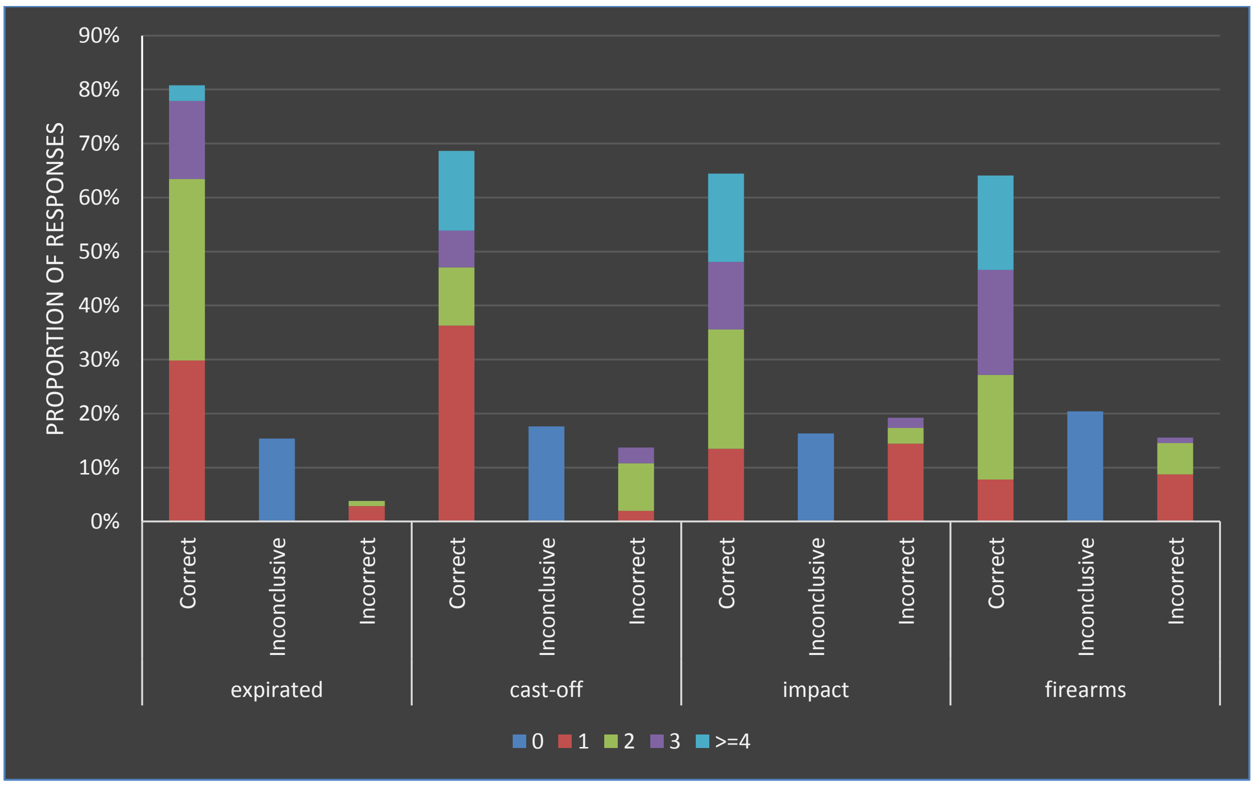

Figure 7 The distribution of results across bloodstain pattern types where multiple answers were permitted (Phase 1). Colored sections refer to the number of patterns nominated in a multiple answer.

Further support for the conclusion that *expirated patterns* were more easily identifiable can be seen in the average AP scores for each pattern type (Table 9). On average, analysts were the most accurate and precise when making judgements on *expirated patterns*, and the least for judgements about *firearms patterns*. The coefficient for pattern type in the linear regression model was significant ($p < 0.001$). The differences in the average AP score for *expirated* and each of the other three patterns was significant (Post hoc Bonferroni test, $p < 0.05$) but that between the *cast-off*, *impact* and *firearms-related spatter patterns* was not significant (Post hoc Bonferroni test, $p > 0.05$).

Table 9 Average AP scores for pattern types

Pattern Type	**Average** AP Score
expirated	2.47
cast-off	1.77
impact	1.36
firearms	1.22

Effect of Extent

Figure 8 shows the effect of pattern extent on classification accuracy. There was a significant overall difference in the frequency of correct, incorrect, and inconclusive responses as a function of pattern extent, $\chi^2(4, N = 413) = 26.74$, $p < .0001$. As might be expected, analysts' accuracy improved as the amount of pattern (essentially the number of stains present on the target) increased.

Although the amount of pattern available influenced analysts' correct and inconclusive decisions, the rate of making incorrect judgements was very similar. Analysts made fewer correct decisions and more inconclusive decisions on patterns that contained only minimum extent. This trend was reversed when the patterns had maximum extent, with more correct decisions and fewer inconclusive decisions being made in this condition.

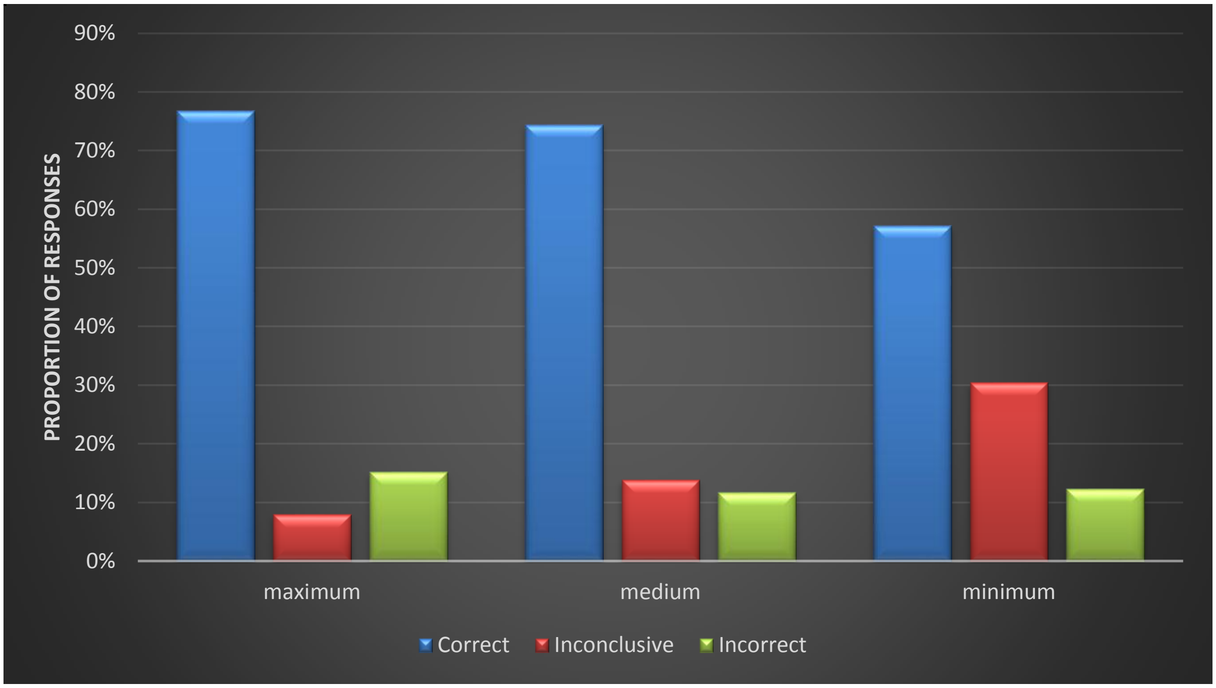

Figure 8 Effect of pattern extent on classification accuracy (Phase 1)

Analysts were more confident with increasing pattern extent, evidenced by the proportion of single-choice classifications increasing from 17% for minimum, to 30% for medium and 40% for maximum extents.

Table 10 lists the AP scores for each pattern extent, confirming the conclusion that patterns with a minimal number of stains in them were not classified as accurately or unambiguously as the more stain-abundant patterns. The pattern extent coefficient in the linear regression model was significant ($p < 0.001$).

Table 10 Average AP scores for variable pattern extents

Pattern Extent	Average AP Score
maximum	2.04
medium	1.91
minimum	1.18

Effect of Substrate

Figure 9 shows the effect of substrate on pattern classification accuracy. There was a significant overall difference in the frequency of correct, incorrect, and inconclusive responses as a function of substrate, $\chi^2(4, N = 413) = 38.64$, $p < .0001$. As expected, the plain white-painted surface was the best surface for making correct pattern classifications and the more "difficult" surfaces gave rise to fewer correct classifications. It was evident that, as observed in the pattern extent effect, the drop in accuracy was matched by an increase in inconclusive responses rather than erroneous ones.

The chipboard surface had a highly patterned finish with many surface features that could have been confused with small bloodstains. Participants had little or no scope for using any enhancement methods that might have assisted them with visualizing the patterns. It is not surprising, therefore, that analysts were less confident with the chipboard surface, evidenced by the 20% proportion of single-choice classifications compared with 32% for wallpaper and 34% for the painted surface.

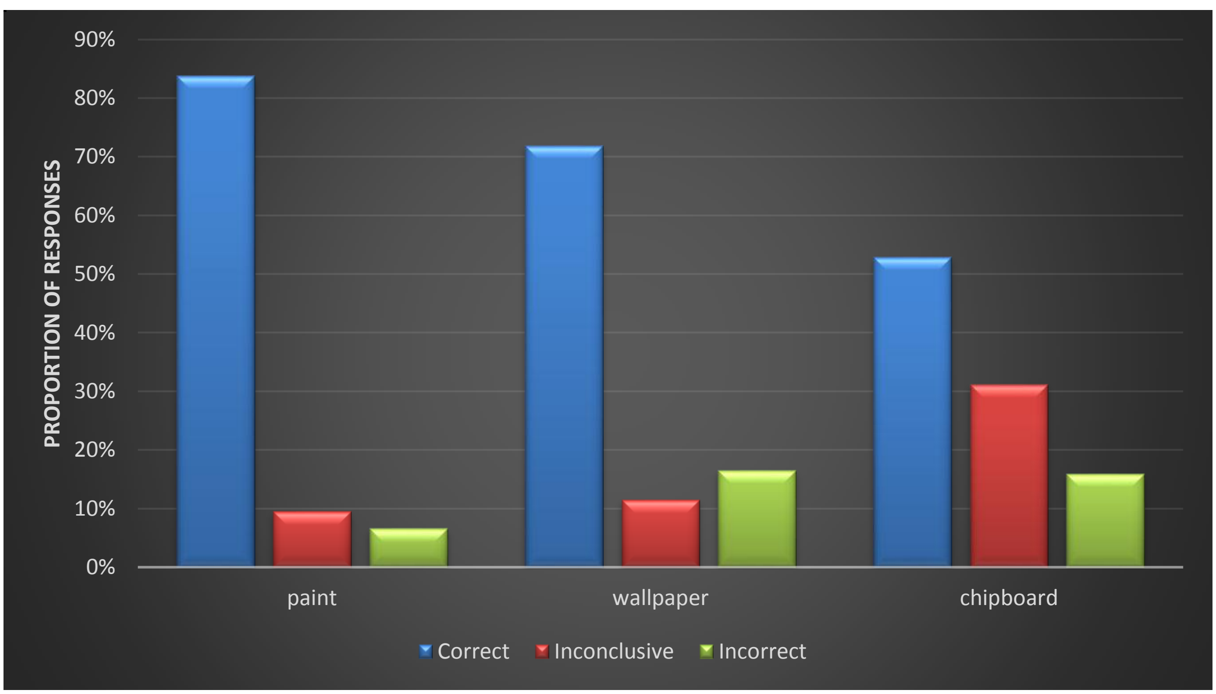

Figure 9 Effect of rigid non-absorbent surface substrate on pattern classification accuracy

Table 11 lists the AP scores for each pattern substrate, confirming the conclusion that patterns on the patterned chipboard were not classified as accurately and unambiguously as the other two surfaces. The coefficient for substrate in the linear regression model was significant ($p < 0.001$).

Table 11 Average AP scores for various substrates

Pattern Substrate	Average AP Score
paint	2.22
wallpaper	1.82
chipboard	1.09

Effect of Context

Figure 10 shows the effect of context on pattern classification accuracy. There was a significant overall difference in the number of correct, incorrect, and inconclusive responses as a function of context, $\chi^2(4, N = 413) = 12.39$, $p = 0.015$.

When a positive context was presented, participants were more likely to make a correct decision than when the context was neutral, with the overall error rate dropping significantly from 11% (neutral context) to 8%, $\chi^2(2, N = 275) = 6.07$, $p = 0.048$. They were also less likely to make an inconclusive decision.

It is also evident that a negative context influenced participants' decision-making. Participants were incorrect more often when there was a negative context, relative to when there was a positive or neutral context, with the overall error rate increasing significantly from 11% (neutral context) to 20%, $\chi^2(2, N = 274) = 8.00$, $p = 0.018$. They were also less likely to make an inconclusive decision.

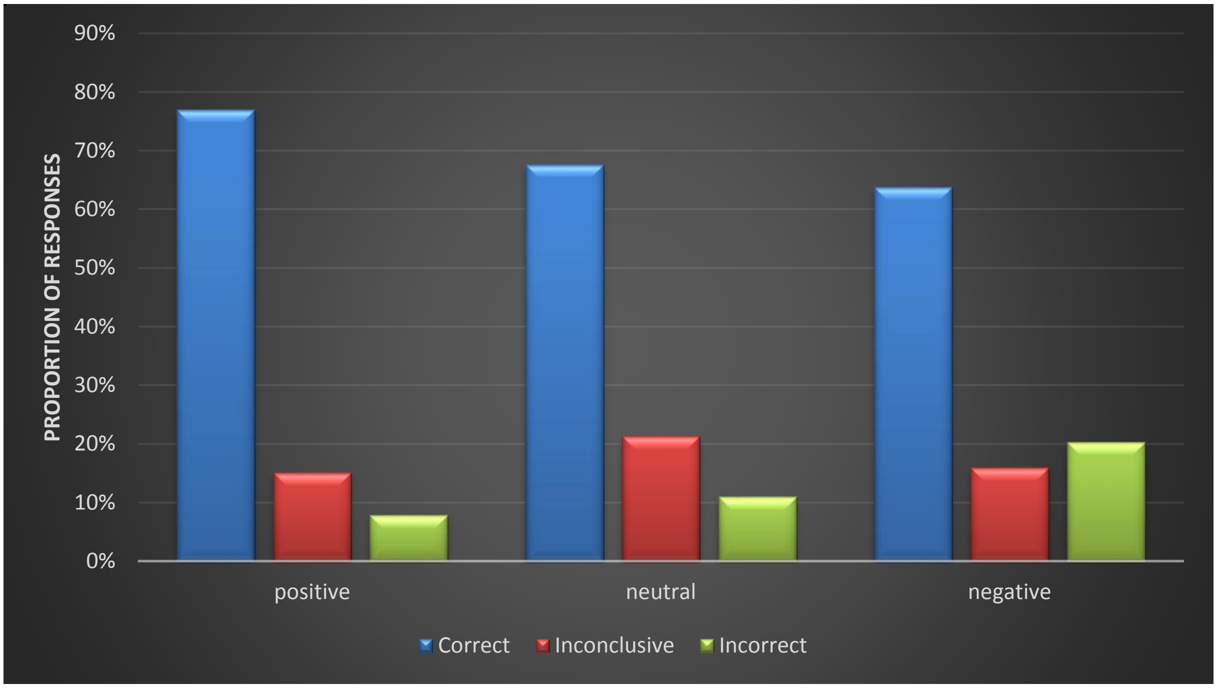

Figure 10 Effect of context on pattern classification accuracy (Phase 1)

Figure 11 shows a breakdown of context effects in terms of whether analysts chose a single pattern classification or multiple. Patterns with contextual information designed to bias the response towards the correct answer had an increased proportion (40%) of single-choice classifications compared with neutral context patterns (21%). Negatively biased patterns also had an increased proportion (25%) of single-choice classifications compared with neutral context patterns but the difference was much smaller. These observations suggest that the context provided the information analysts needed to be confident in their single classification. The result for positively-biasing context is an example of the well-known phenomenon of confirmation bias.

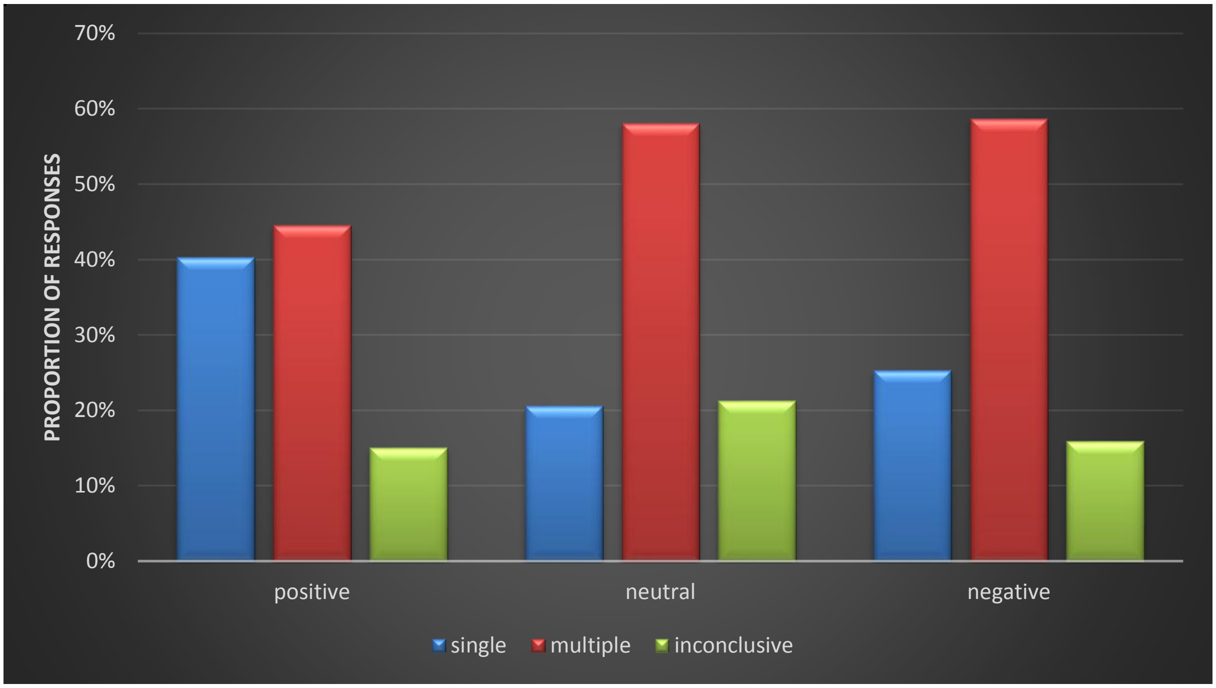

Figure 11 Level of ambiguity in pattern classification as a function of context information (Phase 1)

Table 12 lists the average AP scores for each type of added contextual bias which support the view that added bias influences the precision of pattern. The coefficient for context in the linear regression model was significant ($p < 0.001$).

Table 12 Average AP scores for each type of added contextual bias

Contextual bias	Average AP Score
positive	2.28
neutral	1.51
negative	1.32

Looking specifically at the influence of positive and negative bias separately, the difference in the average AP score for positive-biased and neutral contexts was significant (Post hoc Bonferroni test, $p < 0.05$) but that between negative-biased and neutral samples was not significant (Post hoc Bonferroni test, $p > 0.05$). In other words, whilst negative bias has decreased accuracy significantly, precision hasn't been affected to the same degree.

PHASE 2 The Reliability of Pattern Classification for Bloodstain Patterns on Fabric Surfaces

Methods

Participants

Thirty (30) bloodstain pattern analysts from North America, Australasia, and Europe were invited based on their experience and standing within the BPA community, and were required to meet the following three criteria; 1) must have completed at least 80 hours training in BPA, 2) must have been active in BPA casework for a minimum of five years, and 3) must be qualified by a court as an expert in BPA and have provided expert testimony.

Materials

Bloodstain patterns and pattern extent.

Bloodstain patterns comprising five different **pattern types**; *blunt force impact spatter*, *cast-off*, *expirated*, *satellite stains*[8] *from a drip pattern*[9], and *transfer* were prepared. These pattern types were chosen to reflect the potential for overlap in pattern characteristics between pattern types, which can be problematic for bloodstain analysts, and were designed to represent those typically encountered on fabric surfaces in casework.

Blood for the *expirated* 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 were used within seven days of drawing.

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[8] A **satellite stain** is a smaller bloodstain that originated during the formation of the parent stain as a result of blood impacting a surface.

[9] A ***drip pattern*** is a bloodstain pattern resulting from a liquid that dripped into another liquid at least one of which was blood.

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. Two levels of **pattern extent** were used in this phase, 'maximum' and 'minimum'.

Participants were instructed not to apply any chemical tests and to assume that all red-brown stains on the trousers were blood.

Blunt force impact spatter pattern. One experimenter, wearing the target trousers, knelt with his right knee on the ground and left leg bent at 90 degrees (Figure 12). A striking zone mounted on a platform was set up 26 inches (67 cm) from the front right thigh of the experimenter and 23 inches (58 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. This method paralleled that used in Phase 1 for *impact spatter* production.

Figure 12 Preparation of *blunt force impact spatter* patterns on fabric surfaces

Cast-off pattern. 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.

Both hands were swung outwards and downwards toward the crotch of a second experimenter, who stood upright wearing the target trousers (Figure 13).

Figure 13 Preparation of *cast-off patterns* on fabric surfaces

Expirated pattern*.* The *expirated* pattern was created by having one experimenter sit with his back to the wall, within 50 cm of the second experimenter, who stood wearing the target trousers. The first experimenter then moistened his lips with blood and blew gently towards the crotch area of the target trousers (**minimum extent** pattern), or mixed the blood in his mouth before coughing and spitting it towards this area (**maximum extent** pattern).

Drip pattern*.* An experimenter, wearing the target trousers, stood 8 – 9 inches (20 – 23 cm) away from a 16 inch (41 cm) high table. Consecutive drops of blood were dropped in the same position on the table from a height of 47 inches (120 cm) above the table. Three blood drops were used to create the **minimum extent** pattern, and 12 for the **maximum extent**.

Transfer pattern*.* A wig was sprayed sparingly with blood using a hand sprayer. To create a **minimum extent** pattern the wig was touched briefly and lightly against the thigh area of the target trousers, worn by a second experimenter (Figure 14). For the **maximum extent** pattern the wig was touched firmly and for slightly longer.

Figure 14 Preparation of *transfer patterns* on fabric surfaces

Substrate.

Patterns were made on three different fabric-surface substrates, designed to represent varying levels of anticipated identification difficulty. Three fabrics were chosen based on three common types of trousers; *dress*, *denim,* and *sweat* and were washed and dried three times by a commercial laundry service. Dress trousers were 'Arrow' brand, beige in colour and constructed from 100% polyester fabric. Jeans were 'Roebuck & Co. brand, 'stone-washed' blue denim. Sweat pant trousers were 'Russell' brand, grey brushed cotton (Figure 15)

Polyester dress trousers — Blue denim jeans — Brushed cotton sweatpants

Figure 15 Fabric surface substrates

Context.

A final variable manipulated the *context* that accompanied each target pattern. Contextual information was presented in the form of a short vignette, giving background information about how the bloodstain was found and what was known about the case. This could include information such as eyewitness reports, the position of the stain/victim, injuries sustained by the victim, or any weapons that were found or assumed to have been used. The scenario either contained information that supported the correct answer (*positive*), was misleading (*negative*), or contained no directional information (*neutral*).

Table 13 Examples of scenarios with additional contextual information

Example scenario containing contextual information to suggest the pattern is the result of expirated blood (used for both positive and negative manipulation):
Larry, his eight year old daughter and several friends are leaving a pub after an end of the 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.
Example scenario containing neutral contextual information
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 done on the pants and the blood matches that of a person in 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.

Survey Procedure

The procedure for engaging participants was the same as for Phase 1. Many of the participants in Phase 1 also participated in Phase 2. The general instructions that accompanied the test materials are shown in Appendix 1. Each analyst received 12 - 15 targets, and a response sheet corresponding to each target. A number was placed on a label that was attached to each at the top of each pair of trousers.

The response sheet comprised two main parts with the same instructions and the same set of pattern types as used for Phase 1, with the addition of *satellite stains* as a choice. The remaining aspects of the procedure followed that used for Phase 1.

Error Rate Determination

The method of determining error rate were identical to that used in Phase 1. For both scoring systems, the choice of either *drip pattern* or *satellite stains* was consider a correct answer for target surfaces prepared with drip patterns.

Overall Pattern Classification Performance

The method of determining the overall pattern classification performance using the "AP score" was identical to that used in Phase 1.

Results and Discussion

Pattern Classification Accuracy

Thirty analysts made judgements on 12 - 15 target patterns each, yielding 321 unique assessments. The overall accuracy of these assessments is summarised in Table 14 and Figure 16, which display the distribution of correct, incorrect, and inconclusive judgements for Parts 1 and 2.

When constrained to a single pattern response in Part 1, analysts were reluctant to commit to a classification, with over half of the responses recorded as inconclusive. In those cases where a classification was made, there was a 64% success rate. This was a higher success rate than the hard surfaces in Phase 1. The intent of this part of the survey was to test the accuracy of pattern classification under conditions where an analyst might give a preliminary finding to an investigator for intelligence purposes. It was clear that, even though this was not required to be a final "court-ready" conclusion, as for Phase 1, many analysts were unwilling to commit to a single answer.

The rate of inconclusive responses dropped to 14% in Part 2. Here, multiple choices were allowed but analysts needed to be prepared to present these in court. Despite being allowed to select any number of pattern classifications, 23% of these classifications did not include the correct pattern type. This was a higher error rate than for hard surfaces.

Table 14 Overall pattern classification accuracy

Response	Part 1	Part 2
Correct	26.3%	62.3%
Incorrect	14.7%	23.4%
Inconclusive	58.9%	14.3%
Total responses	**319**	**321**

For those patterns incorrectly classified in the single-answer format of Part 1, only 23% were subsequently correctly classified in the multiple-answer format of Part 2 of the survey. Of the 36 patterns that were incorrectly classified in both Parts, half of responses in Part 2 remained single-answer responses. This suggests that analysts had reached a conclusion early in the decision-making process, and were confident in this conclusion. This was a similar pattern to that observed in Phase 1.

Overall the average AP score per sample was 1.30 (equivalent to the nomination of between 3 and 4 patterns, including the correct one). This was lower than that observed in Phase 1, probably reflecting the additional difficulty in classifying patterns on fabric surfaces with precision. The linear regression model showed the effects of pattern type, pattern extent and context were all highly significant ($p < 0.001$). The effect of substrate, however, was not significant at the 95% confidence level.

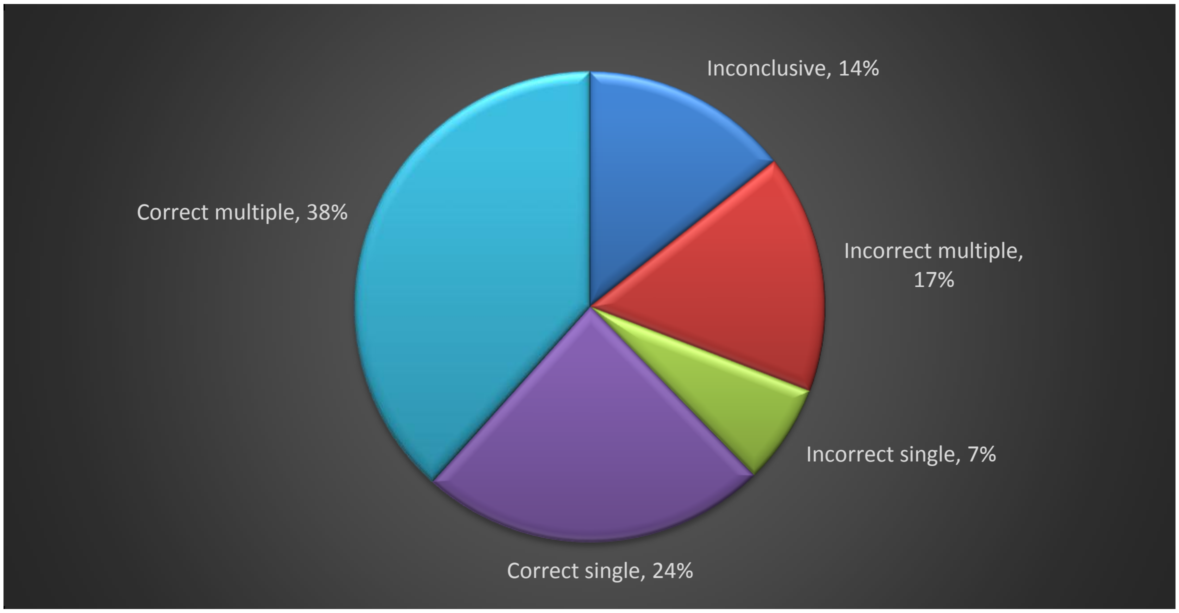


Figure 16 A breakdown of the accuracy of pattern classification in Phase 2, Part 2 of the study where both single and multiple answers were allowed.

In the remaining analysis, only Part 2 responses are considered.

Effect of Pattern Type

Figure 17 shows the number of pattern types nominated by the analyst for each of the known patterns. Analysts were prepared to give one unambiguous classification for 51% of the *cast-off patterns*. This was followed in order by *drip* (48%), *transfer* (31%), *expirated* (24%) and *impact* (20%). However, unlike the results observed for the rigid non-absorbent surfaces, the confidence analysts had in unambiguously classify patterns on fabric was not well correlated with the accuracy of classification (Figure 18). While unambiguous classifications of *cast-off* patterns were made with a high degree of accuracy (P = 0.84), the accuracy in singular classifications of *drip patterns* was low (P = 0.46). The most accurately classified single-choice patterns were *transfer* (94%) and *impact patterns* (88%).

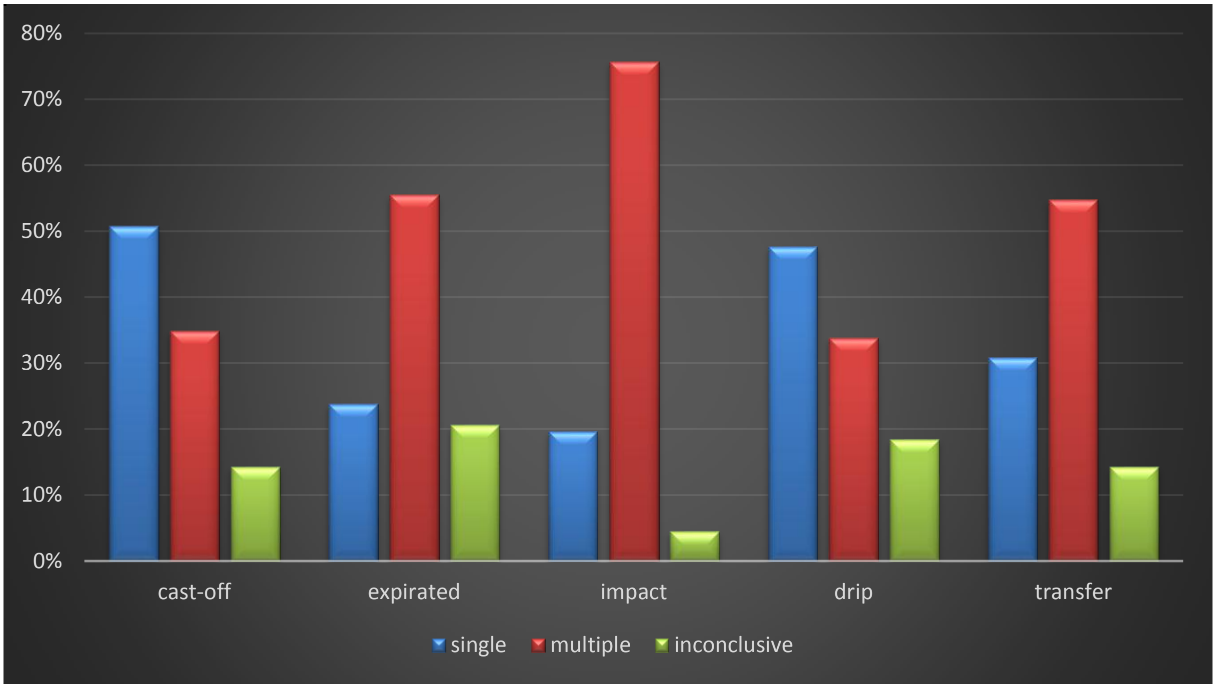


Figure 17 The distribution of the number of pattern types nominated for each classification in Phase 2. Single = one pattern type; Mulitple = two or more; Inconclusive = no patterns nominated

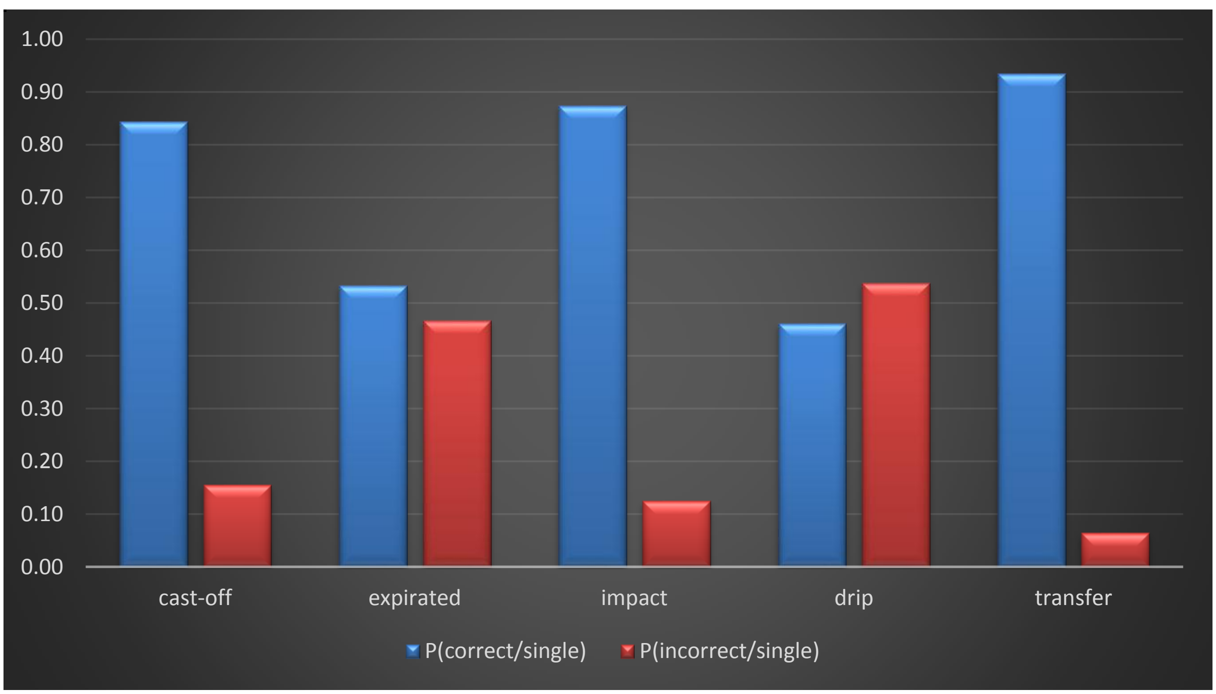


Figure 18 The probability of correctly classifying those patterns for which a single pattern type was nominated (Phase 2).

As for hard surfaces, most of the distinctive features of a *cast-off pattern*, such as a narrow distribution of linear/curvilinear stains, were generally present in the *cast-off patterns* prepared in this study. However unlike the results for *expirated patterns* in Phase 1, the characteristics features of these patterns were apparently not evident in these patterns on fabric surfaces.

When both single and multiple classifications are considered, the effect of pattern type on the frequency of correct, incorrect, and inconclusive responses was significant; $\chi^2(8, N = 321) = 64.58$, $p < 0.001$ (Figure 19). This was mainly due to the lack of success in identifying *satellite stains* from *drip patterns.* The error rate across these pattern types was 8% for *impact*, 14% for *cast-off*, 16% for *expirated*, 18% for *transfer* and 59% for *drip patterns*, giving rise to the overall error rate of 23% noted above.

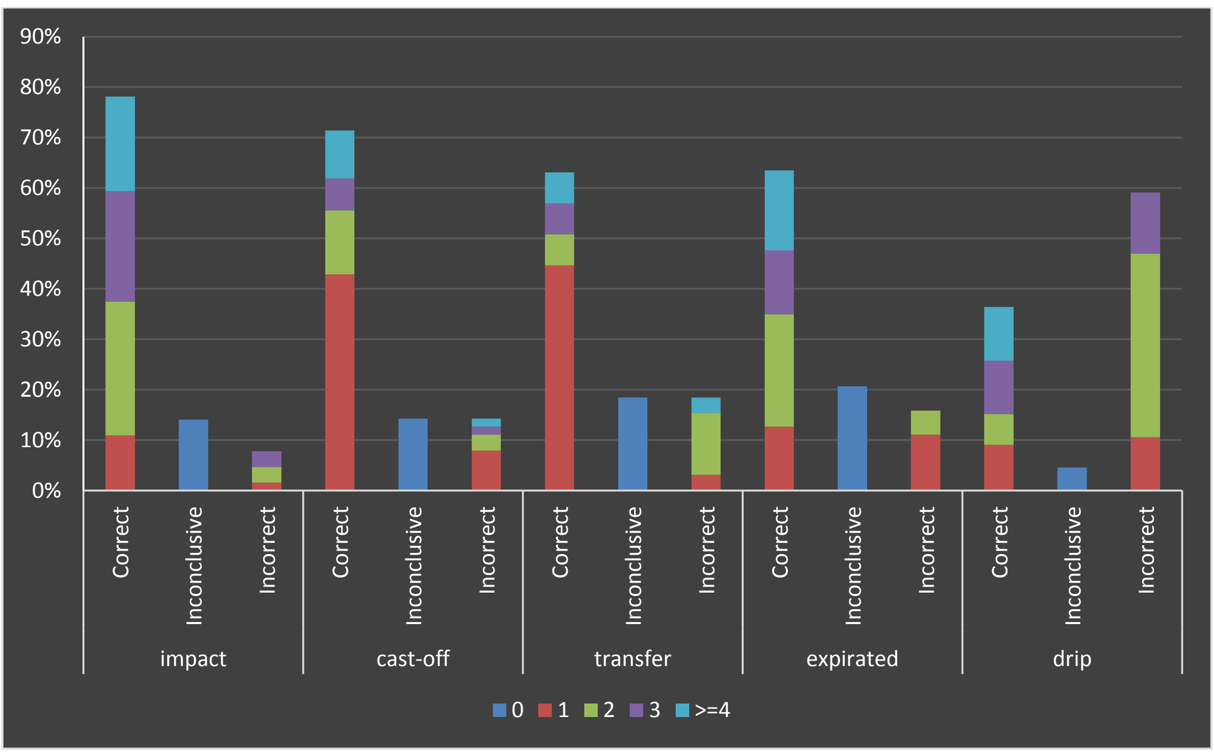


Figure 19 The distribution of results across bloodstain pattern types where multiple answers were permitted (Phase 2). Colored sections refer to the number of patterns nominated in a multiple answer.

The AP score measures both accuracy and precision and on this basis *cast-off patterns* scored highest and *satellite stains* from *drip patterns* were the most problematic (Table 15). The coefficient for pattern type in the linear regression model was significant ($p < 0.001$). The differences in the average AP score for *drip patterns* and each of the other three patterns was significant (Post hoc Bonferroni test, $p < 0.05$) but that between the *cast-off*, *impact*, *transfer* and *expirated patterns* was not significant (Post hoc Bonferroni test, $p > 0.05$).

Table 15 Average AP scores for pattern types

Pattern Type	Average AP Score
cast-off	2.06
transfer	1.75
impact	1.69
expirated	1.38
drip	-0.33

One of the issues that has been debated in BPA circles is the distinction between spatter and transfer patterns on fabric. Of interest then in this study was the observation that, of the 63 true spatter patterns on fabric that were misclassified, 3 were classified as transfer patterns. Of the 12 true transfer patterns that were misclassified, all were classified as one or more types of spatter.

Effect of Extent

Figure 20 shows the effect of pattern extent on classification accuracy. There was a significant overall difference in the frequency of correct, incorrect, and inconclusive responses for the maximum extent patterns compared with the minimum extent ones, $\chi^2(2, N = 321) = 19.31$, $p < .0001$. As might be expected, analysts' accuracy improved as the amount of pattern (essentially the number of stains present on the target) increased.

Although the amount of pattern available influenced analysts' correct and inconclusive decisions, the rate of making incorrect judgements was very similar. Analysts made fewer correct decisions and more inconclusive decisions on patterns that contained only minimum extent. This trend was reversed when the patterns had maximum extent, with more correct decisions and fewer inconclusive decisions being made in this condition. This matched the results observed for hard surfaces.

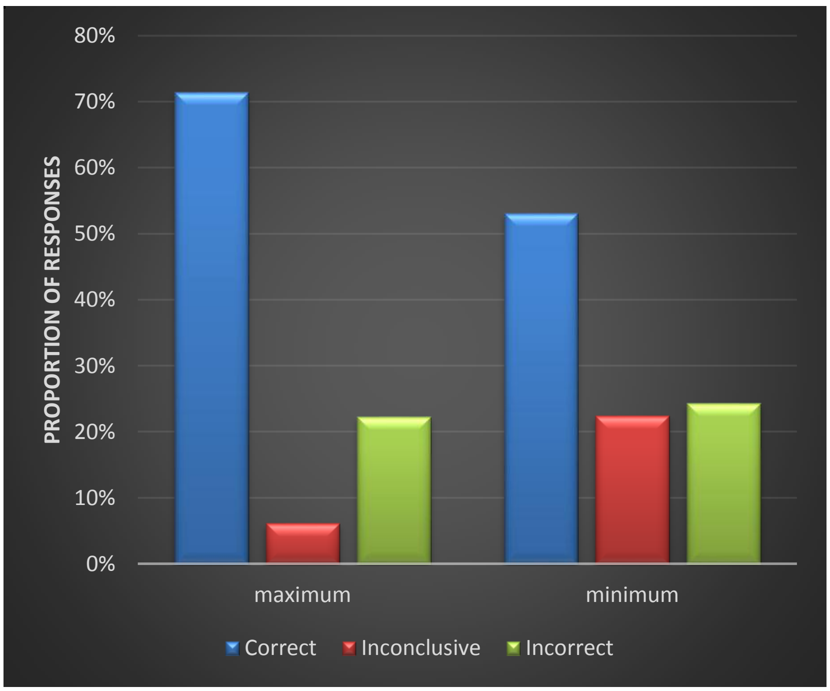


Figure 20 Effect of pattern extent on classification accuracy (Phase 2)

Table 16 lists the AP scores for the two pattern extents, confirming the conclusion that patterns with a minimal number of stains in them were not classified as accurately or unambiguously as the more stain-abundant patterns. The pattern extent coefficient in the linear regression model was significant (p < 0.001).

Table 16 Average AP scores for variable pattern extents

Pattern Extent	Average AP Score
maximum	1.65
minimum	0.94

Effect of Substrate

Figure 21 shows the effect of substrate on pattern classification accuracy. There was an apparent improvement in the accuracy of classifying patterns on the sweat pants but this was not statistically significant, $\chi^2(4, N = 321) = 7.12$, $p = 0.130$.

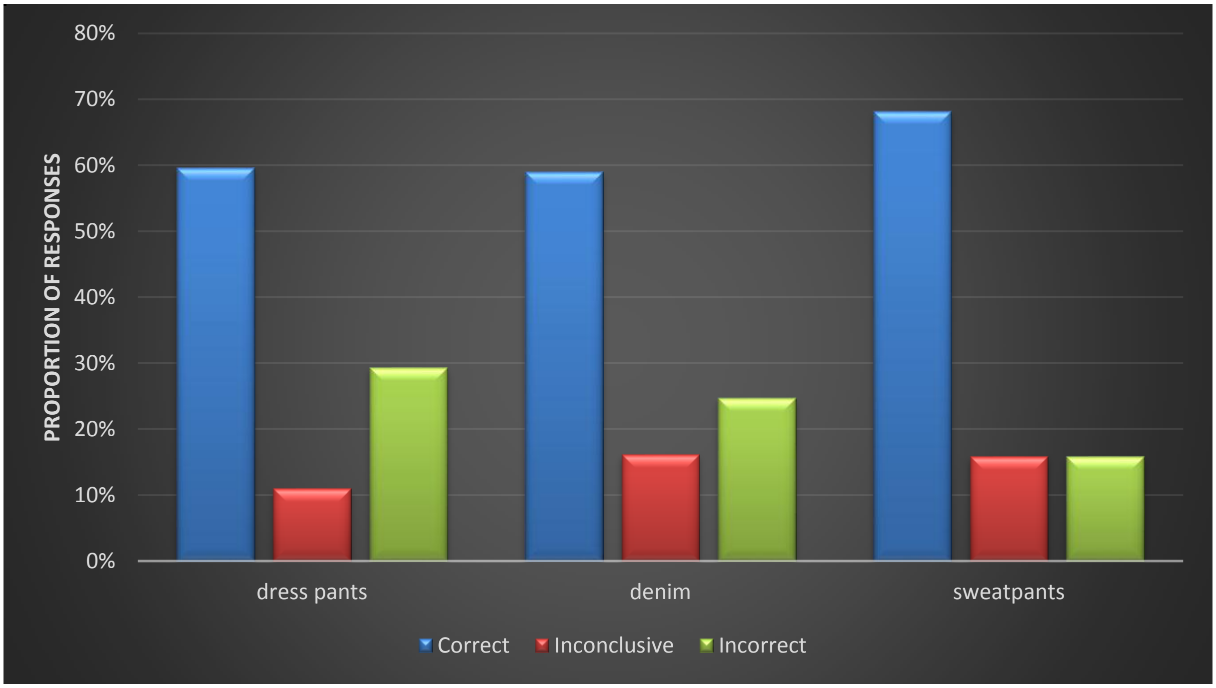


Figure 21 Effect of fabric substrate on pattern classification accuracy

Table 17 lists the AP scores for each pattern substrate, confirming the conclusion that there was little difference in the accuracy and precision of classifying patterns on the three fabric surfaces chosen. The coefficient for substrate in the linear regression model was not significant (p =0.183).

Table 17 Average AP scores for various substrates

Pattern Substrate	Average AP Score
sweatpants	1.64
denim jeans	1.15
dress pants	1.11

Effect of Context

Figure 22 shows the effect of context on pattern classification accuracy. There was a significant overall difference in the number of correct, incorrect, and inconclusive responses as a function of context, $\chi^2(4, N = 321) = 16.13$, $p = 0.003$.

When a positive context was presented, participants were more likely to make a correct decision than when the context was neutral, with the overall error rate dropping significantly from 26% (neutral context) to 14%, $\chi^2(2, N = 213) = 11.10$, $p = 0.004$. . They were also less likely to make an inconclusive decision. The overall error rate for positively-biased contexts was higher than that for the rigid non-absorbent surfaces in Phase 1.

It is also evident that a negative context influenced participants' decision-making. Participants were incorrect more often when there was a negative context, relative to when there was a positive or neutral context, with the overall error rate increasing significantly from 26% (neutral context) to 30%, $\chi^2(2, N = 215) = 5.90$, $p = 0.052$. In contrast to the equivalent comparison in Phase 1, they were also more likely to make an inconclusive decision.

Although the overall error rate for classification of patterns on fabric surfaces was higher than that observed for the rigid non-absorbent surfaces of Phase 1, the relationship between error rate and the type of contextual information was similar.

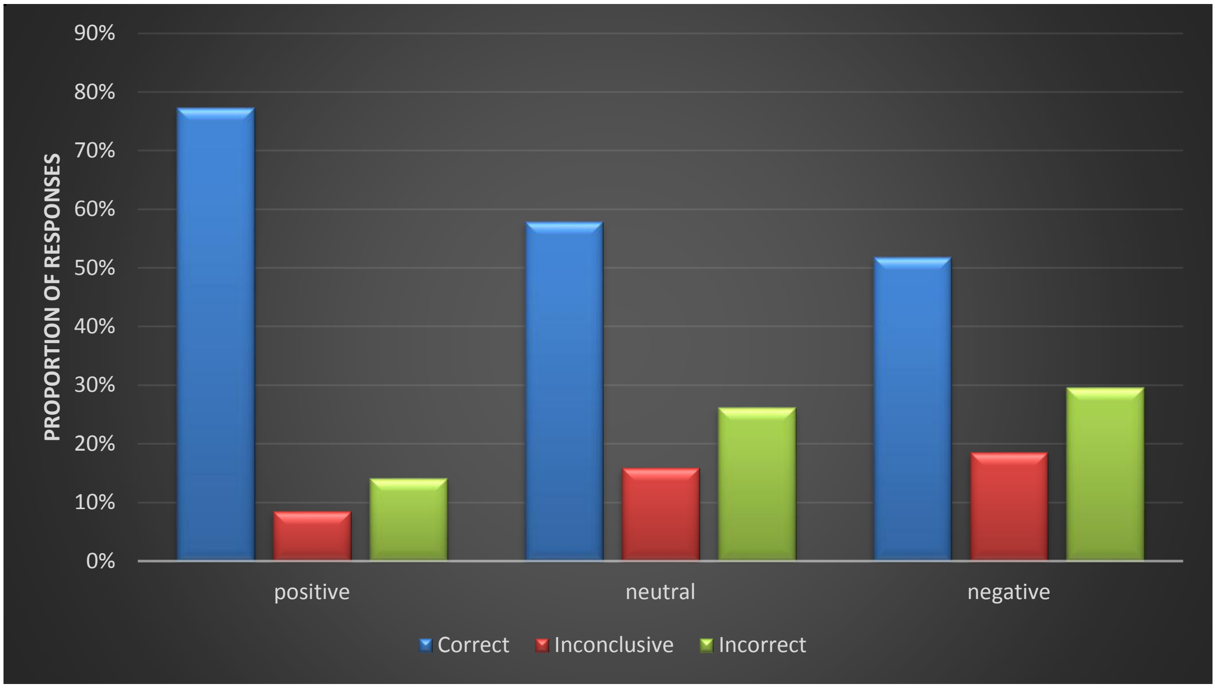


Figure 22 Effect of context on pattern classification accuracy (Phase 2)

Figure 23 shows a breakdown of context effects in terms of whether analysts chose a single pattern classification or multiple. Patterns with contextual information designed to bias the response towards the correct answer had an increased proportion (41%) of single-choice classifications compared with neutral context patterns (24%). Negatively biased patterns also had an increased proportion (28%) of single-choice classifications compared with neutral context patterns but the difference was much smaller. These observations suggest that the context provided the information analysts needed to be confident in their single classification. The result for positively-biasing context is an example of the well-known phenomenon of confirmation bias. These results are similar to those observed in Phase 1.

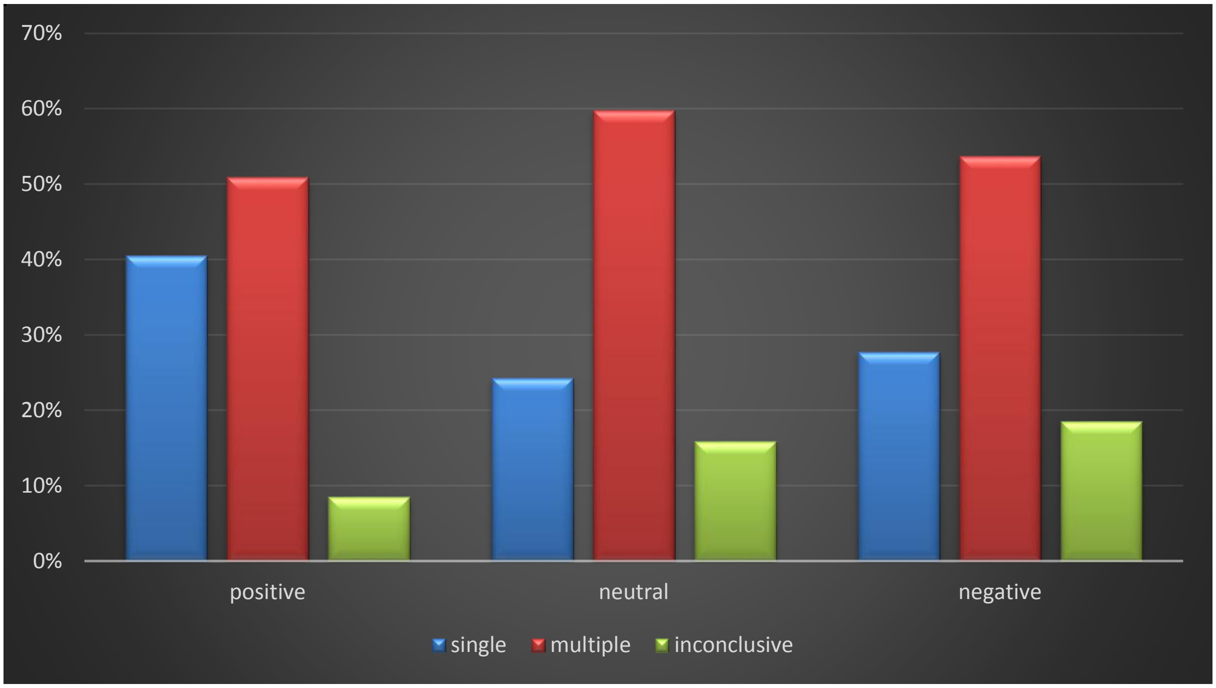


Figure 23 Level of ambiguity in pattern classification as a function of context information (Phase 2)

Table 18 lists the average AP scores for each type of added contextual bias which support the view that added bias influences the precision of pattern classification. The coefficient for context in the linear regression model was significant ($p < 0.001$).

Table 18 Average AP scores for each type of added contextual bias

Contextual bias	Average AP Score
positive	2.07
neutral	0.98
negative	0.86

Looking specifically at the influence of positive and negative bias separately, the difference in the average AP score for positive-biased and neutral contexts was significant (Post hoc Bonferroni test, $p < 0.05$) but that between negative-biased and neutral samples was not significant (Post hoc Bonferroni test, $p > 0.05$). In other words, while negative bias has decreased accuracy significantly, precision hasn't been affected to the same degree. This matches the results for the patterns on hard surfaces (Phase 1).

SUPPLEMENTARY STUDY: The Reliability of Bloodstain Pattern Sequencing

Introduction

It is common for bloodstain patterns at crime scenes to be superimposed. The order in which such patterns are deposited can sometimes be valuable evidence of the timing of the events that took place [31]. The observation, for example, that a bloodied shoeprint impression has spatter stains from a beaten victim on top of the impression indicates that those stains occurred *after* the shoeprint impression was made. This information would be highly relevant if, for example, the defendant claimed he arrived at the scene after the victim had been beaten. Despite the value of this type of evidence, there have been few published studies made of bloodstain pattern sequencing and no standardized methods have emerged.

Determining the sequence of events from bloodstain patterns frequently involves altered patterns. For example, the presence of *perimeter stains*[10] in a pattern is evidence that more than one event took place with a lapse of time between them. If blood is initially dripped onto a surface and subsequently wiped prior to complete drying, a perimeter ring of staining results, providing evidence of the sequence of events. If one pattern dries before the second is superimposed[11], however, sequencing becomes more difficult. Hurley and Pex [32] concluded that it was difficult to distinguish a dried *spatter* pattern overlaid by a bloodied shoe impression from a combination of patterns in the reverse sequence. They recommended particular caution when attempting to determine such a sequence from photographs. While these authors produced photographs to illustrate their conclusions no controlled experiments were presented.

The objective of this supplementary study was to formally assess the reliability of current methods for establishing the sequence of superimposed patterns where the first pattern deposited has completely dried.

[10] A perimeter stain is an altered stain that consists of the peripheral characteristics of the original stain.
[11] In the context of this paper a superimposed pattern is the deposition of that pattern on top of an existing pattern

Methods

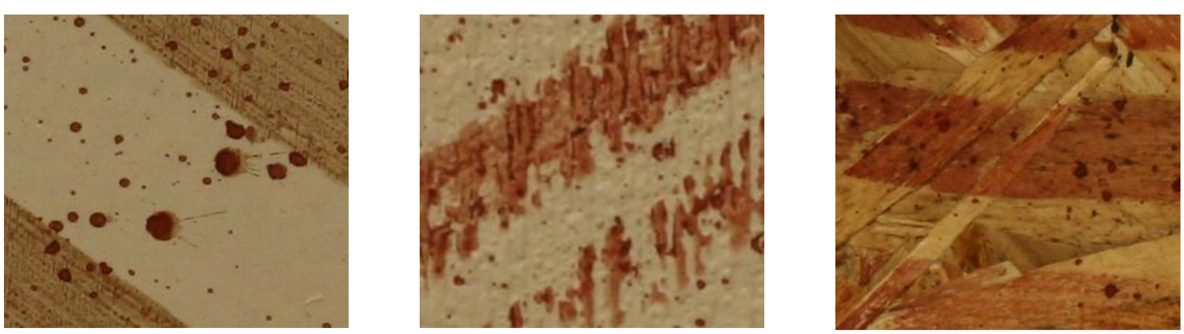
Two pattern types were selected for this study, namely *spatter*[12] and *transfer*[13]. These patterns are commonly encountered at bloodied crime scenes and can often be superimposed. A total of 112 bloodstain patterns comprising superimposed *transfer* and *spatter* stains were prepared, half of which were spatter stains superimposed on *transfer* stains and half were *transfer* stains on *spatter*.

The materials used were those described in Phase 1.

Transfer stains were created by drawing a blood-soaked cotton glove across the target surface, giving a *swipe*[14] pattern showing four fingers. Excess blood was removed from the glove before swiping. *Spatter* stains were created by using a hammer to strike one drop of blood placed on a wooden block in the center of the striking zone. The hammer was propelled by rubber bands and gravity. Bloodstains forming the first applied pattern were allowed to dry thoroughly before the second pattern was superimposed.

There were two manipulated variables relating to pattern construction, namely <u>pattern extent</u> (amount of spatter) and <u>target substrate</u>. These variables were identical to those described in Phase 1.

Examples of these target surfaces are shown in Figure 24.



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[12] A *spatter stain* is a bloodstain resulting from a blood drop dispersed through the air due to an external force applied to a source of liquid blood.
[13] A *transfer stain* is a bloodstain resulting from contact between a blood-bearing surface and another surface.
[14] A *swipe* pattern is a bloodstain pattern resulting from the transfer of blood from a blood bearing surface onto another surface, with characteristics that indicate relative motion between the two surfaces.

A B C

Figure 24 Example of patterns created on a paint (A), wallpaper (B), and chipboard (C) surfaces

Each analyst received a unique set of 3 or 4 sequencing targets and a response sheet for 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. The response sheet stated: "This sample has both a *transfer* and a *spatter pattern* on it. You are asked to determine the sequence these two patterns have been applied in. Please choose ONE of the following:

- *Spatter first followed by transfer*
- *Transfer first followed by spatter*
- *I cannot determine which pattern occurred first"*

Each possible variable combination (sequence order X substrate X extent) was replicated a minimum of 5 times. As was the case for Phase 1 of this study, all targets were coated with a clear lacquer for the protection of the bloodstain pattern. This was not expected to have any effect on the performance of the sequencing analysis, but this was not tested.

Results and Discussion

Of the 112 samples distributed to participants, responses to 104 were received. These comprised 50 combinations of *spatter* stains superimposed on *transfer* stains and 54 *transfer* stains on *spatter*. Of the 104 conclusions given, over half (52.9%) were recorded as inconclusive, 32.7% correctly assigned the sequence and 14.4% gave an incorrect interpretation.

Figure 25 shows a breakdown according to the original pattern combination presented. It is apparent from these results that there was a marked difference in the response of analysts to the two pattern sequences they were presented with. Where spatter stains were deposited on top of *transfer stains*, 12% of the patterns were incorrectly sequenced, whereas for the reverse sequence this figure increased to 17%. There was a corresponding increase in the proportion of inconclusive responses from 40% to 65%.

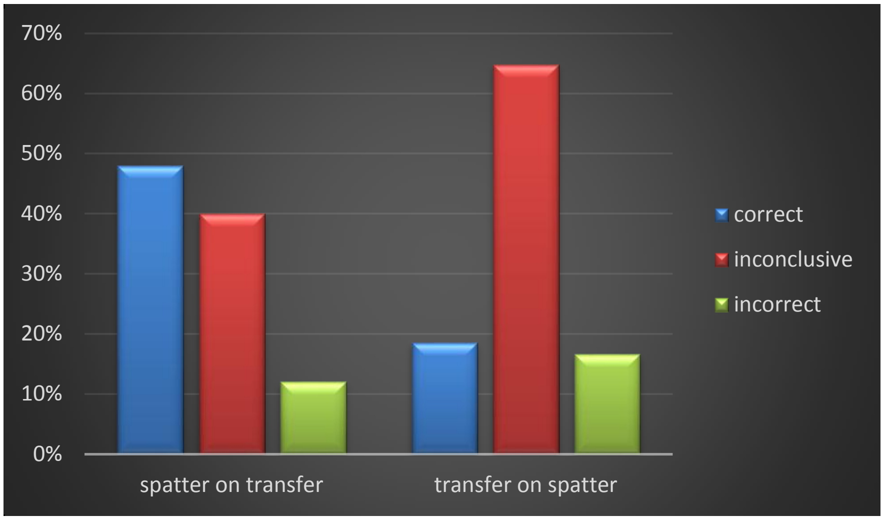


Figure 25 Accuracy in the determination of pattern deposition sequence

These results appear to show that when spatter stains are deposited on *transfer stains*, analysts were more willing to give a conclusion, and those conclusions were more likely to be correct. For those targets that analysts were prepared to make an interpretation, 80% were correct when the pattern was *spatter* on *transfer*, but only 53% were correct if the *transfer* followed the *spatter*. The difference in response between the two pattern combinations was statistically significant, $\chi^2(2, N = 104) = 5.26, p = 0.004$.

Overall, the effect of substrate on correct responses was not significant ($p = 0.581$), although Figure 26 shows a higher proportion of correct interpretations for painted surfaces when the pattern combination was *spatter* on *transfer*.

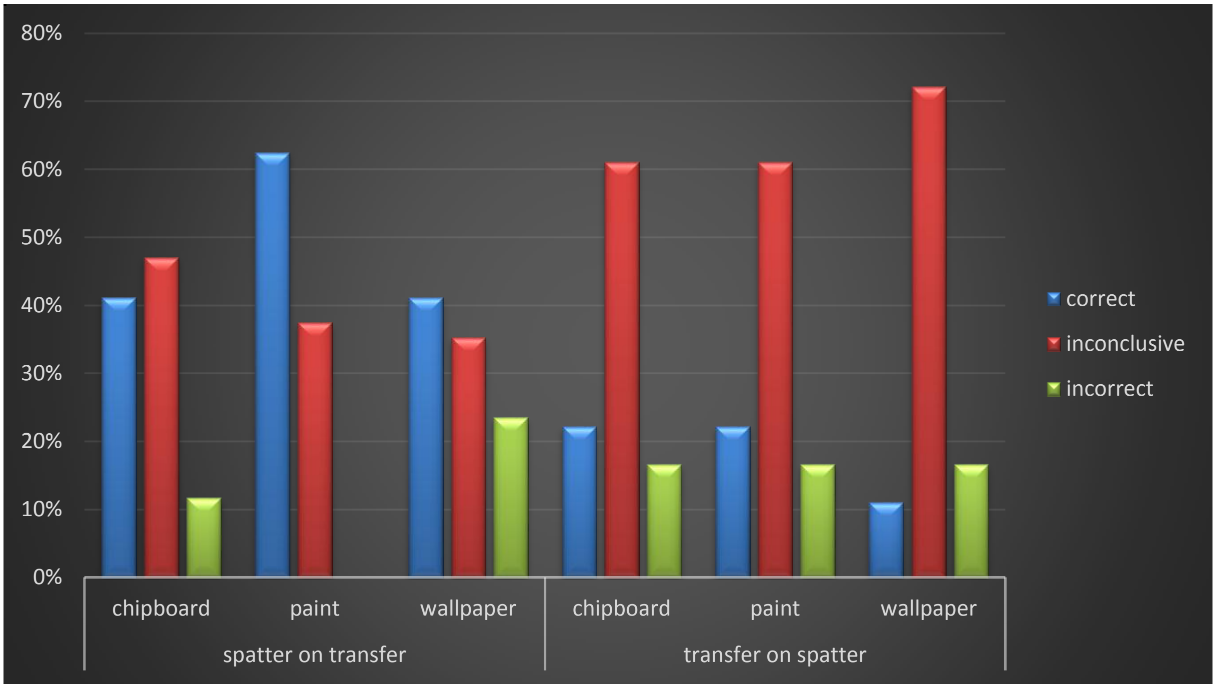


Figure 26 Effect of substrate on sequencing conclusions

Figure 27 shows that the number of incorrect conclusions increased and the number of inconclusive responses decreased slightly, as the extent of spatter increased, in both spatter on *transfer* and *transfer* on *spatter* combinations. So for example, those targets that had a *spatter pattern* with many stains (i.e., maximum extent) overlaid with a *transfer pattern* gave the highest number of incorrect interpretations. No errors were made, in this pattern combination, when the *spatter pattern* was at its minimum extent, although 70% of the responses were inconclusive. However, the overall effect of pattern extent was significant, $\chi^2(4, N = 104) = 9.71$, $p = 0.046$.

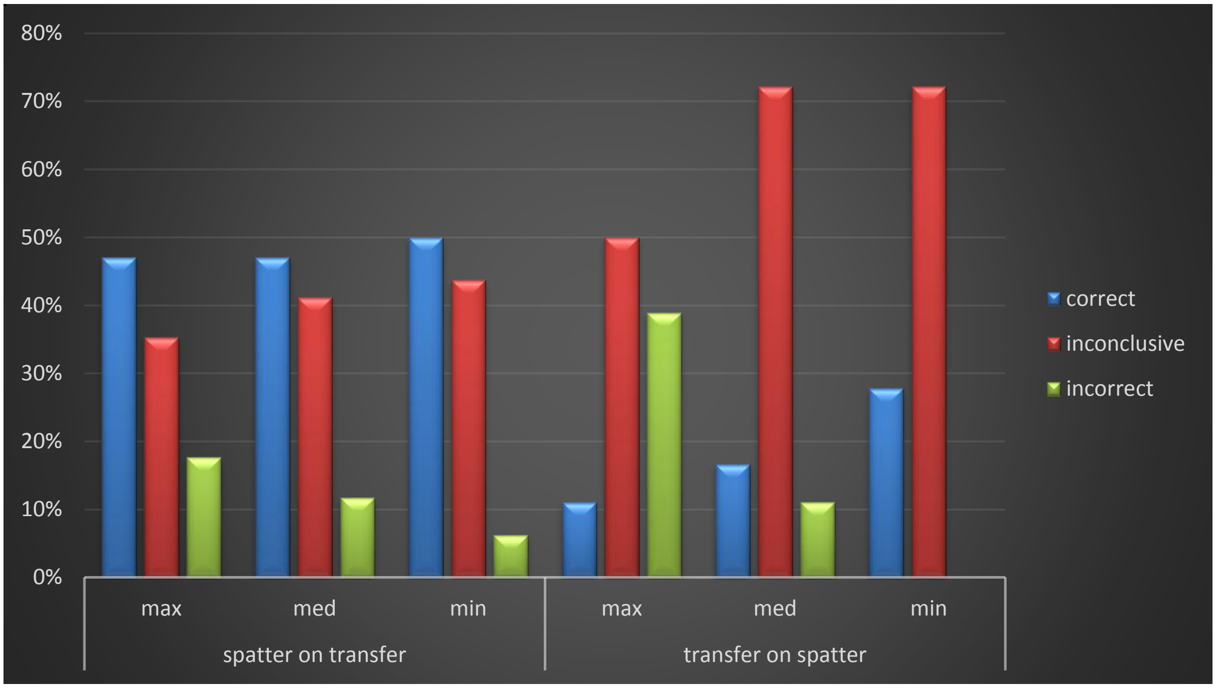
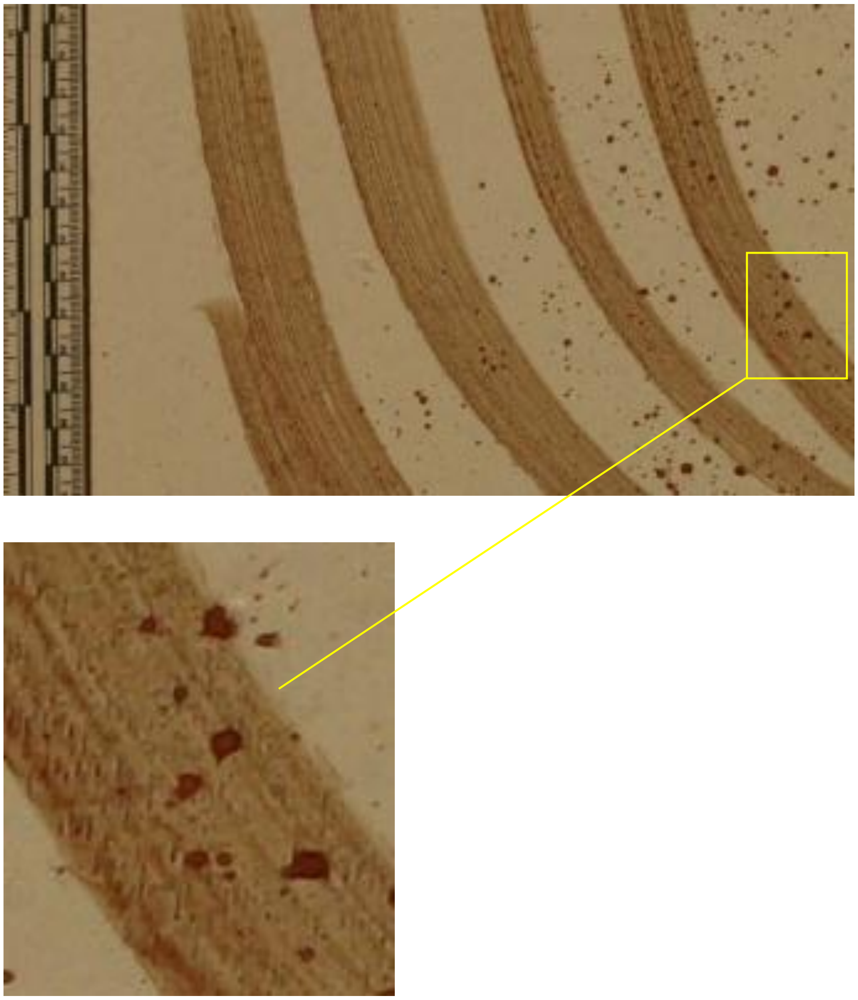


Figure 27 Effect of pattern extent on sequencing conclusions

Because the bloodstains in this study were allowed to dry completely between the two depositions, there were no perimeter stain effects to give clues as to the order of deposition. In the absence of this, it is possible that the analysts' attention was drawn to the intensity of the individual stains, with the more intense stains reckoned to be the more recent of the two depositions. Spatter stains deposited on *transfer stains* will generally appear darker in color, suggesting they have been deposited last (e.g Figure 28).

Figure 28 ***Spatter*** **deposited after** ***transfer pattern***



However *spatter stains* deposited under *transfer stains* may also appear darker in colour, especially if the *transfer stain* is a thin smear (e.g. Figure 29). Under these circumstances the *spatter stains* may also give the impression they have been deposited on top of the *transfer stain*. This may also account for the fact that patterns with well-defined, maximum extent *spatter* overlaid by *transfer stains* had a highest proportion of incorrect conclusions. Where the *spatter stains* were fewer in number this misdiagnosis was not evident. The number of incorrect conclusions increased as the extent of *spatter* increased in both *spatter* on *transfer* and *transfer* on *spatter*, while the number of inconclusive responses decreased slightly. This suggests that an increase in the number of datum points in the pattern is giving an increasingly false sense of confidence for an analyst when making a judgement about sequencing.

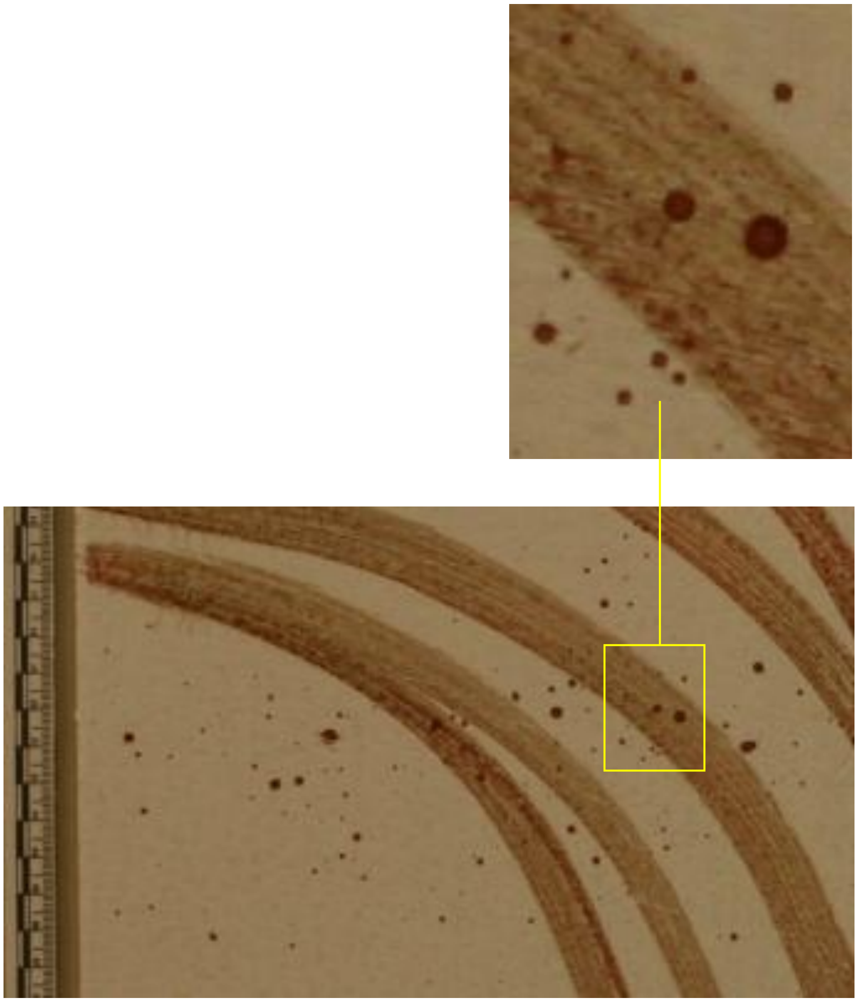


Figure 29 *Transfer pattern* after *spatter*

CONCLUSIONS

Discussion of Findings

The purpose of this study was to assess the accuracy of the current methods used by analysts in the classification of bloodstain patterns. To do this well-trained and highly experienced analysts examined over 730 patterns in two phases of the study, one focussing on rigid non-absorbent surfaces representing surfaces frequently encountered at crime scenes and the other on fabric surfaces representing clothing. Six different pattern types were used over the two studies. 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.

In Part 2 of each phase analysts were required to classify the pattern to a standard required for court. To do this they were allowed to select one or more pattern classifications that they determined could not be excluded. Within the chosen range of conditions, the overall rate of inconclusive answers was 17.4% for rigid surfaces and 14.3% for fabric surfaces. This gives some measure of the difficulty in the interpretation of the patterns created in this study.

Where a classification was made, either by choosing a single pattern or by nominating more than one, 13.1% of these classifications did not include the correct pattern type for the rigid surfaces and 23.4% for fabric surfaces. These can be considered the first approximations of overall error rates for the pattern classification method.

Some patterns were more reliably classified than others. In particular the error rate was 4% for *expirated* patterns on rigid surfaces and 8% for *impact* patterns on fabric surfaces. The characteristic features of *expirated patterns* (e.g. mucus strands and air bubbles) were generally evident on the rigid non-absorbent surface targets, making these patterns more recognisable, but apparently less evident on fabric. It is not clear why analysts had more success identifying *impact* patterns on fabric surfaces. It is possible that whenever the pattern comprised a number of small spatter stains (the majority of samples in the survey) analysts decided that *impact spatter* simply could not be excluded.

The highest rates of misclassification were 59% for *satellite stains* from a *drip pattern* on fabric surfaces and 19% for *impact patterns* on rigid surfaces. The identification of *drip patterns* often relies on the presence of a central 'parent' stain on a horizontal surface with associated *satellite stains*. When evaluating *drip patterns* in a classroom or crime scene setting analysts most often have the parent stain associated with the *drip pattern* making identification relatively easy. In clothing examinations, the parent stain is most often not present because it is on some object the clothing was adjacent to and left at the scene. Given the absence of a 'parent' stain in the patterns created in this phase of the study, it is possible that analysts decided to exclude this pattern type.

Many of the *impact patterns* on the rigid non-absorbent surfaces had a somewhat narrow distribution of stains, similar to *cast-off*. This may account for the higher error rate for this pattern type in Phase 1.

Cast-off patterns were generally moderately accurately classified in both phases (14%), presumably because most of the distinctive features of a *cast-off pattern*, such as a narrow distribution of linear/curvilinear stains, were generally present in the *cast-off patterns* prepared in this study.

Looking more closely at the other variables we used in this study, it is evident that where the amount of available pattern was limited or the substrate made stain visualisation more difficult (e.g. chipboard) the proportion of correctly classified patterns was less. 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 recognise, analysts became more conservative in their judgment, which is what the court would expect from a reliable method.

The error rates estimated from this study are based, in part, on the chosen conditions for the various variables used in the presentation of samples for analysis. These were designed to be a fair representation of real casework but remain a subjective judgement of the experimenters. The conditions included the use of a coating of laquer on the rigid surfaces and removing the requirement to perform any chemical tests on the bloodstains. Firearms spatter did not contain any other trace evidence that could be utilized to assist with pattern classification. These conditions were not expected to lead to erroneous classifications but it is possible they contributed to a lowering of the AP score.

An alternative baseline measure of error rate might be considered on the basis of the combinations of variables that gave rise to the lowest overall error, across all pattern types, in the absence of contextual effects. For the rigid surfaces the lowest error rate was 6.7% (with only two misclassifications made). This occurred for the white-painted surfaces over all pattern extents. For the fabric surfaces, the lowest error rate was 12.1% (with four misclassifications made). This occurred for the grey sweatpants, over all pattern extents.

Of particular interest in this study was whether contextual information had any effect on classification decisions. Study results showed that where a scenario was offered that deliberately pointed analysts towards the correct classification, the proportion of misclassifications that resulted was significantly lower (8% rigid surfaces, 14% fabric surfaces) than that observed for patterns with neutral scenarios (11% rigid surfaces, 26% fabric surfaces). This is an example of the well-known phenomenon of confirmation bias and reveals a vulnerability to contextual effects that justifies further investigation.

Of more concern is the potential for this vulnerability to bias translating into misclassifications. Where a scenario was offered that deliberately pointed analysts towards an incorrect classification, the proportion of misclassifications that resulted was significantly higher (20% rigid surfaces, 30% fabric surfaces) than that observed for patterns with neutral scenarios (11% rigid surfaces, 26% fabric surfaces).

So this study has produced evidence that analysts use contextual information in making pattern classification and this information can influence their accuracy. This highlights the fact that the boundary between pattern recognition and crime scene reconstruction is often blurred. This is not helped by the fact that, at present, there isn't 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 even witness testimony is being allowed to factor into analyst's interpretations. This problem is further compounded by the fact that current pattern classifications used in BPA are described in terms of pattern formation mechanisms, which actually makes them components of a reconstruction theory, rather than a summary of pattern characteristics.

The supplementary study on superimposed patterns showed that, for the current sequencing methods, the chances of incorrectly concluding the order of deposition in a *spatter/transfer pattern* combination is approximately 12% where *spatter stains* are deposited on top of *transfer stains* and 17% for the reverse sequence. This test was done in the absence of *perimeter stain* effects.

Implications for Policy and Practice

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. However it is known in cognitive science that experts can in fact be more susceptible to bias. The assumption made in this study could therefore be profitably tested. Regardless of this it seems prudent for practitioners and agencies to take steps to minimise the effects of contextual information. The practicalities of this may vary from agency to agency and may not be straight-forward, as many analysts are immersed in an investigation in ways that make it difficult to control the flow of information. However opportunities for improvement may be available, such as via the peer review system, where information control might be easier. It would seem advantageous for the BPA community to agree on a standard methodology for the analysis of bloodstain patterns which includes a better distinction between classification and reconstruction and relies less on mechanistic descriptions of patterns.

We suspect that many bloodstain pattern analysts do not attempt to determine the sequence of deposition of bloodstain patterns. For those who do, it would be worth reflecting on the results of this study. No defined methodology was prescribed for the sequencing analysis in this study and it is possible that a reliable methodology exists or could be developed. Either way it is incumbent on analysts to validate and publish their method and seek peer review.

Implications for Further Research

It is acknowledged that a study of this sort has limitations, not the least of which is the fact that analysts were not making decisions in the reality of a courtroom situation. For the first time however a useful baseline has been established for the expected error rate in bloodstain pattern classification, the most widely used of the various BPA methods. Inevitably a number of questions have arisen which are worthy of further research. These include:

- *How are pattern classification decisions made?*
- *Can we establish a minimum set of characteristics that must be observed before a "reliable" classification can be made?*
- *What is an acceptable error rate for BPA?*
- *What type of contextual information is the most influential?*
- *What contextual information is legitimate and helpful?*
- *What would a standardised methodology that minimises the potential for bias look like?*
- *Is there a way of more reliably determining pattern deposition sequence?*

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DISSEMINATION OF RESEARCH FINDINGS

Conference Presentation:

N. Osborne, Taylor, M C, Kish, P E , Laber, T L, Owens, G, *Reliability Measures for Current Methods in Bloodstain Pattern Analysis,* IABPA Training Conference, San Diego, 1 – 4 October, 2013

Published Paper:

Terry L. Laber, Michael C. Taylor, Paul E. Kish, *The Reliability of Current Methods of Sequencing Bloodstain Patterns*, Journal of Bloodstain Pattern Analysis (2014), 30(1): 3 – 10.

APPENDIX 1 PARTICIPANT GENERAL INSTRUCTIONS

Phase 1:

Enclosed are 15 or 16 'Classification Samples' for you to inspect. Each of these samples has one pattern on it. The samples are wooden squares of three different types, chipboard, wallpaper and a plain painted surface.

All patterns were made on vertical targets and each target has a unique number. Each target has your analyst number on it. The location of the target label indicates the top of the target. If the target label becomes detached the target number can be found written on the back of the target.

Targets were prepared with human blood and should be treated with standard laboratory safety procedures. Each target has been coated with a clear lacquer to prevent deterioration and assist with biohazard safety. If there is a black cross marked on any stain this stain is an artefact and should not be considered.

Phase 2:

Enclosed are 12 'Classification Samples' for you to inspect. Each of these samples has one pattern on it. The samples are pairs of trousers of three different types: denim jeans, polyester dress pants and cotton sweatpants. Each pair has a unique number. Each pair has your analyst number on it. Targets were prepared with human blood and should be treated with standard laboratory safety procedures. This is an assessment of pattern recognition methods only so no additional chemical tests are required. All red-brown stains on the trousers should be assumed to be blood.

Phases 1 & 2:

In the survey you will be presented with a set of pattern types and two questions.

(1) You will first be asked to choose the pattern type that best represents the pattern in the sample. This is to give the investigators an early indication of what pattern you think is present. **You must choose only one pattern type in this question or indicate that you cannot select one best pattern type.**

(2) You will then be asked to choose those pattern type(s) that you consider could account for the stains on the sample target. This is to show what you would include in a court report. **To answer this question, you may choose one pattern type, in which case your answer should be the same as for part (1), or more than one type.**

Each sample has a scenario with it because we recognize that bloodstain pattern classification is usually done with the benefit of additional contextual information. We have done our best to create realistic scenarios, indeed many are based on real cases. There may be some for which you feel there should be more information, but we would ask that you consider these on the basis of what is provided and treat them with the same care you would a answer you would give in court. The SWGSTAIN BPA terminology list is included with this letter. We would ask that you use terms according to the definitions in this list.

Phase 1:

In addition we have sent you 3 or 4 '***Sequencing samples***' that have two patterns on them, namely a transfer pattern and a spatter pattern. We would like you to determine the sequence of application of these two patterns. There are no scenarios for these samples. Your answer should be what you would be prepared to testify to in court.

…

Finally if you have any questions about the survey these can be addressed to …