IABPA Founded 1983

Utilisation of Bloodstain Pattern Analysis in Casework

Gareth Griffiths [1] B.Sc (Hons), Duncan Parker [1] Ph.D, Graham Williams [1] Ph.D

1 - School of Justice, Security & Sustainability, Staffordshire University, Leek Road, Stoke-on- Trent, Staffordshire, ST4 2DE, United Kingdom

** - Corresponding Author – Gareth.Griffiths@research.staffs.ac.uk*

Abstract

Bloodstain pattern analysis (BPA) is a discipline that is useful in both the investigative and evaluative phases of an investigation. The field of BPA is one that attracts attention from software developers and educational institutions. The purpose of this study was to understand the extent to which BPA is used in casework. 120 bloodstain analysts of varying expertise and training from around the world completed a survey addressing their experiences of using BPA in casework. Of these participants, 73.34% of the participants indicated that they did two cases or less per month on average. 77.5% of the participants indicated that area of origin (AO) calculations were not used as part of their casework. 71.67% of the respondents have never given evidence in court, with only 5.83% appearing in court less than two times a month. 18.33% of the participants indicated the use of software or technologies in casework, despite 38.33% having access to such specialised provisions. Given that 89.17% of the participants believe that such provisions will enhance the criminal investigation , there is a significant hurdle to the use of emerging technologies in BPA casework. As a result of these findings, there appears to be clear evidence that the focus of educational institutions and the investments into BPA research, should be reviewed and updated.

INTRODUCTION

The presence of blood in a crime scene is not an uncommon phenomenon. Blood can be located on several surfaces such as floors, ceilings, walls, furniture, weapons, clothing, and on the body of a person present at the scene [1] [2] [3]. Bloodstain pattern analysis (BPA) can be used to reconstruct the sequence of events of a blood-shedding incident and provide investigators with an insight into who was involved [1] [4] [5]. The size, shape, location, and distribution of bloodstains can provide valuable information of how blood was deposited on a surface [9]. Although most DNA conclusion use probabilistic statements to potentially link individuals that are present at a scene, other crucial questions can remain unanswered, to include the sequence of events [7] [8] [45]. The general science of BPA appears to be widely accepted and is advocated by the Academy Standards Board (ASB), provided guidelines by the Organization of Scientific Area Committees (OSAC) [52] and the Academy Standards Board (ASB) [45]. This methodology consists of the determination of directionality, movement, area of convergence (AOC) and area of origin (AO) of bloodstains, the identification and categorization of bloodstain patterns, and the relationship between patterns and relevant items [46]. BPA corroborates, refutes, or clarifies a statement that has been provided by an eyewitness,

Article submission history:
Received August 28, 2022
Received in revised form December 3, 2022
Accepted February 2, 2023

victim, or a suspect.

Since the National Research Council (NRC) highlighted recommendations for the accuracy and reliability in BPA [51], the accuracy and reliability of AO analysis of bloodstains has been thoroughly researched. The traditional stringing method [10], the tangent method [11], and the mathematical method from Varney et al. [12], allows for the calculation of the AOC and the AO [13]. This has been addressed through the use of software, which allows users to import point clouds and photographs for alignment, to present a virtual representation of the AO. Examples of such software are FARO ZONE 3D (FZ3D) [2] [14], Faro Scene [15], BackTrack [16], HemoSpat [29] [53], and HemoVision [34]. BPA software packages have been designed to support investigators in relation to speed and quality of analysis [17]. These software packages have been independently tested, compared, and validated through published peer-reviewed scientific articles. Researchers have felt the need for research to be conducted using these software packages for the accuracy and reliability of AO analysis [2], [15], [16], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38],[39]. However, these software packages have also been viewed skeptically for being potentially deceptive or lacking an objective mathematical foundation [40]. Vitiello et al. argues that the proposed approaches of these software packages attempt to replicate BPA investigators' tasks without an official mathematical representation of BPA, allowing an objective reconstruction of the crime [17]. In summary, the available approaches focus on different computational methods to perform BPA without attempting to model the whole BPA process through a mathematical representation [17]. Although AO analysis is an interesting area of BPA, the utilisation of AO analysis in casework must be explored. This paper will highlight specialist equipment that BPA analysts believe would be useful to have access to, and their thoughts on such equipment. Researchers are conducting AO analysis studies, software developers are investing in BPA tools for AO analysis, and training institutions are teaching AO analysis, but very little research has been conducted to explore the utilisation of AO analysis in casework, highlighting the value of the above. BPA training institutions teach the necessary skills involved in BPA (e.g., AO analysis) but not how to apply these skills within an acceptable methodological framework [41]. The challenges BPA analysts encounter on a day- to-day basis need to be addressed, and greater research must be conducted within these areas. This paper will highlight the challenges bloodstain analysts encounter on a daily basis.

BPA is recognised worldwide in both adversarial and inquisitorial courts. In most common law countries, such as England and the United States, the adversarial system is utilised. On the other hand, the inquisitorial system is used in many European countries and continental jurisdictions, such as France and Italy. Since the second half of the last century, the US criminal courts have used BPA [3]. The training of analysts, as well as the validity of BPA itself, has been questioned by some scientists and legal scholars, in the view that an unproven discipline gained a hold in the American justice system and flourished through state by state [51]. BPA was established when a small group of scientists and forensic investigators began testifying in cases, as experts in a new technique. As a result of this, many started to train police officers, crime-scene examiners, and investigators, many of whom also testified in court as well [54]. As a result of this, defendants have appealed the legitimacy of these experts' testimony, resulting in these cases being held in the state appeals courts. After one court ruled such testimony admissible, other states' courts emulated [55]. Once reviewing the accuracy or reliability of the technique used in BPA, judges had faith in their own – or the testifying experts' own – evaluation. Testimony has been accepted from forensic scientists with backgrounds in biology, physics, chemistry, serology, and pathology. It has also been accepted from law enforcement personnel such as evidence technicians, detectives, and crime scene investigators, who do not necessarily have a scientific background. It must be noted, these individuals – though not scientists – have attended and completed basic and advanced bloodstain interpretation. Coupled with casework experience at crime scenes, these attendees can attain expertise in the discipline and render credible testimony in courts of law [11]. To this date, there have been no peer-reviewed published papers on how often BPA evidence is presented in court, and how it would be presented. A recent paper by Bettison et al. questioned how BPA evidence is presented and interpretated in courts [45]. This paper will explore how often BPA is presented in courts, and the methods employed to present such findings. The overall aim of this study was to explore the utilisation of BPA in casework.

METHOD

A survey consisting of 25 questions was developed using Qualtrics Software and disseminated through personal connections and social media. These platforms attracted participants who are located in countries that use adversarial and inquisitorial justice systems. The survey was conducted between the 27th of January 2020 – 13th of January 2021. In total 120 participants completed the survey. It must be noted that all participants who completed the survey have the authorisation to complete BPA in their day-to-day casework. All Qualtrics responses were documented on an Excel spreadsheet, along with the thematical analysis, and was saved on an Encrypted SD Memory Card. A proportionate ethics form for this study was completed and granted by Staffordshire University. Partial responses and student responses were eliminated from the overall total and were not considered in the analysis stage of this study. Gender, age, and ethnicity were not required for this study. The questionnaire was themed around four sections; including, 1. Training and experience, 2. Their view and experience in using BPA in casework. 3. Their view and experience of using area of origin calculations in casework, and 4. Their view and experience of using the software in casework. As well as the indicated responses, the participants were also invited to provide free text responses. For qualitative data, a thematic analysis for free text responses was conducted using an Excel spreadsheet. Understanding the free-text responses was the first stage of the thematic analysis. Colour coding was used to represent a pattern. which represented a theme. Themes were then cross referenced against the original data.

RESULTS

The survey was published and attracted participants from many different countries. Figure 1 shows the number of participants who completed the survey. It is evident to state that

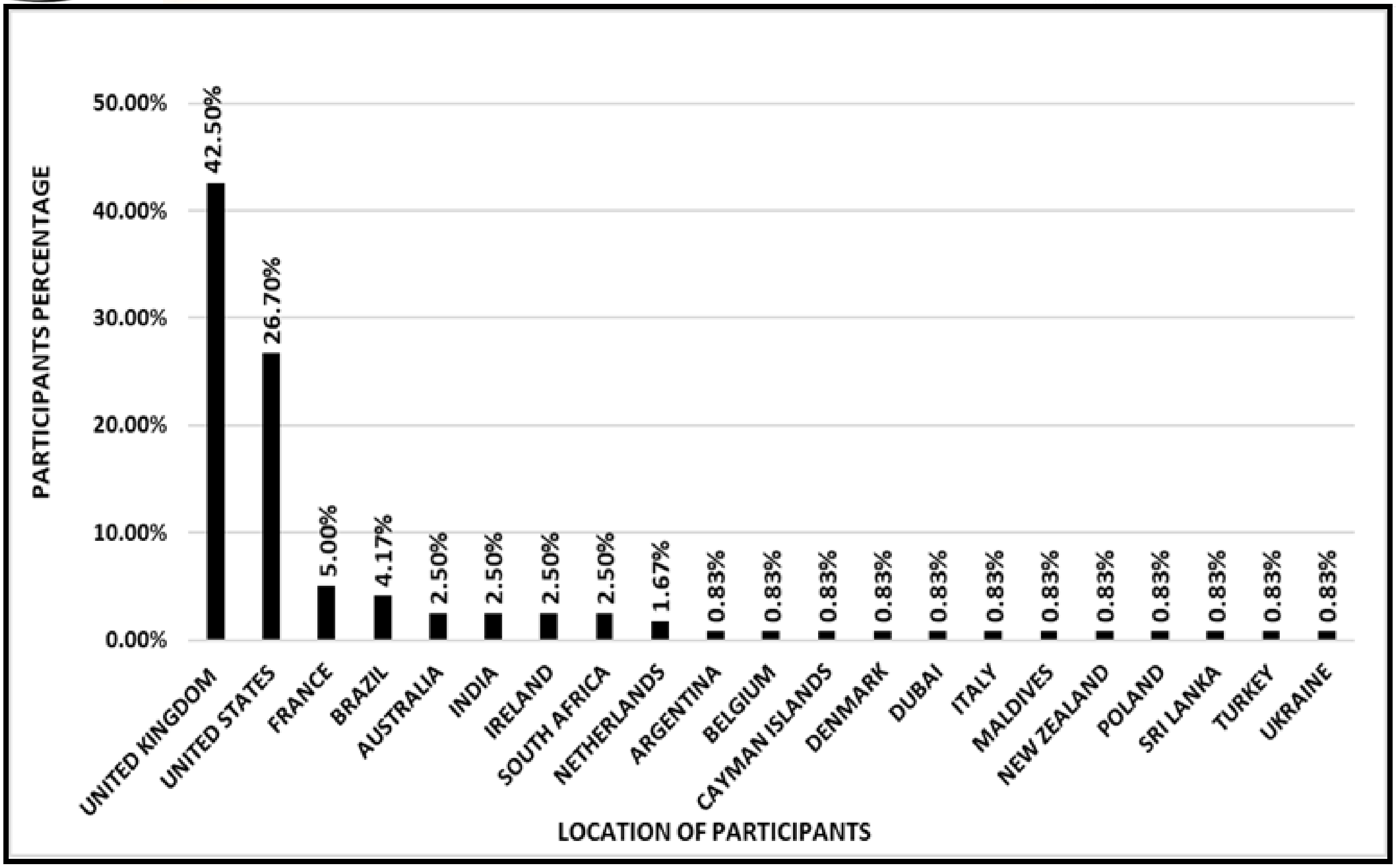

Figure 1- Illustrates where the participants are located worldwide

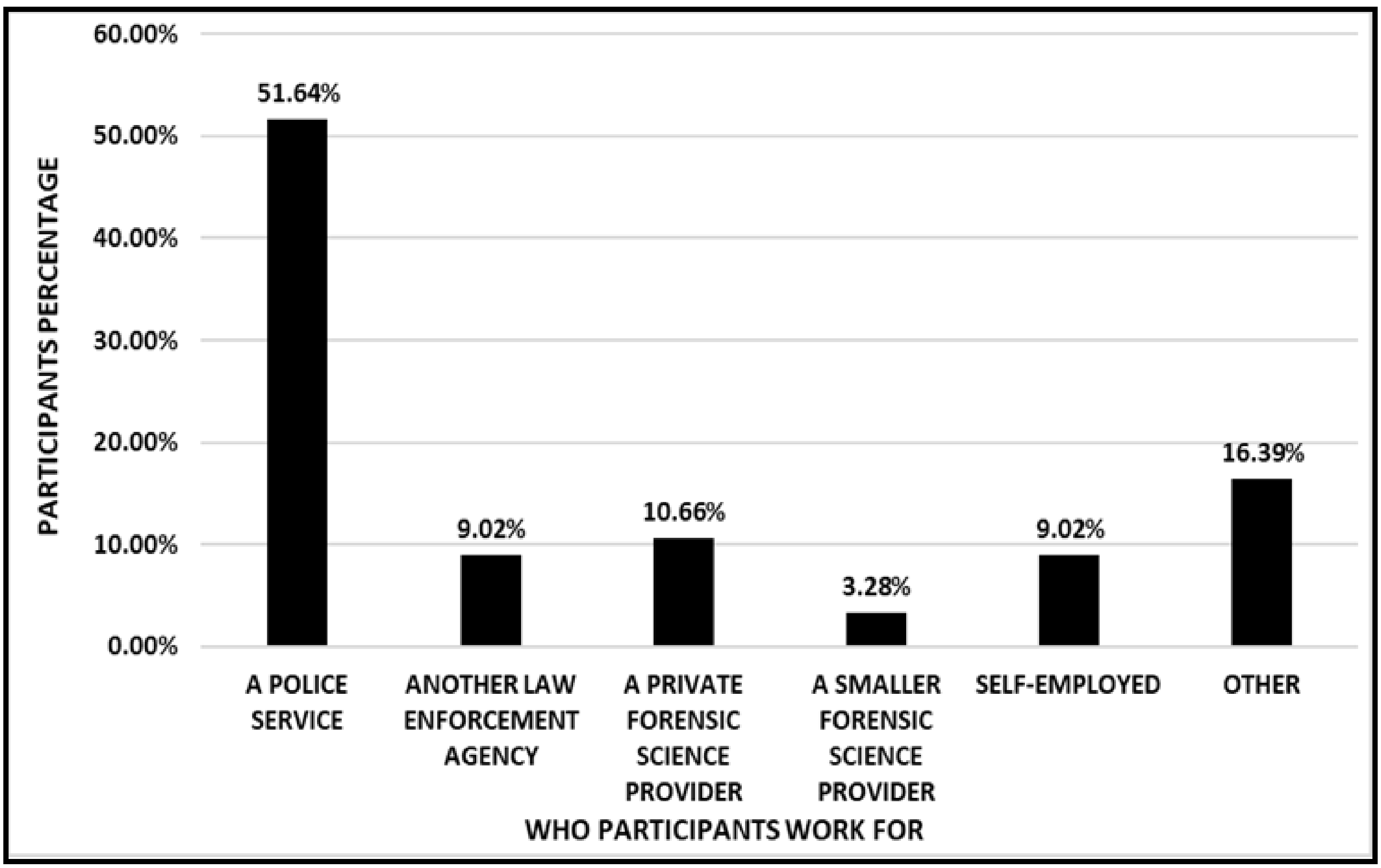

Figure 2- Illustrates who the participants were employed by

the majority of participants were from the United Kingdom (42.50%) and the United States (26.70%), with similar responses from other countries.

The majority of participants were employed by a police service (51.64%), and others worked for another law enforcement agency (9.02%), a private forensic science provider (10.66%), a smaller forensic science provider (3.28%), self-employed (9.02%) or other (16.39%). Other consisted of non-profit government laboratories and other public sector departments. This is depicted in Figure 2.

The majority of participants were crime scene examiners (45.00%), forensic examiners (16.67%), reporting officers (14.17%), or other (24.17%). Other roles consisted of forensic science laboratories (state or privately funded), self-employed forensic consultants, laboratory technicians, and independent experts. This is highlighted in Figure 3.

Participants had a varied level of BPA training, with the majority, 48.33% having completed advanced BPA training, 22.50% of participants having completed basic BPA training, 14.17%- had simple BPA awareness, 12.50% had crime scene only training, and only 2.50% had training for the analysis of blood on items only, as seen in Figure 4. Participants had varying levels of BPA experience, 28.33% had <5 years' experience, 16.67% had between 5-10 years' experience, 34.17% had between 10-20 years' experience, and 20.83% had >20 years' experience. It was established that 71.67% of participant's experience was all in the same department, and 28.33% of participants had experience in different departments.

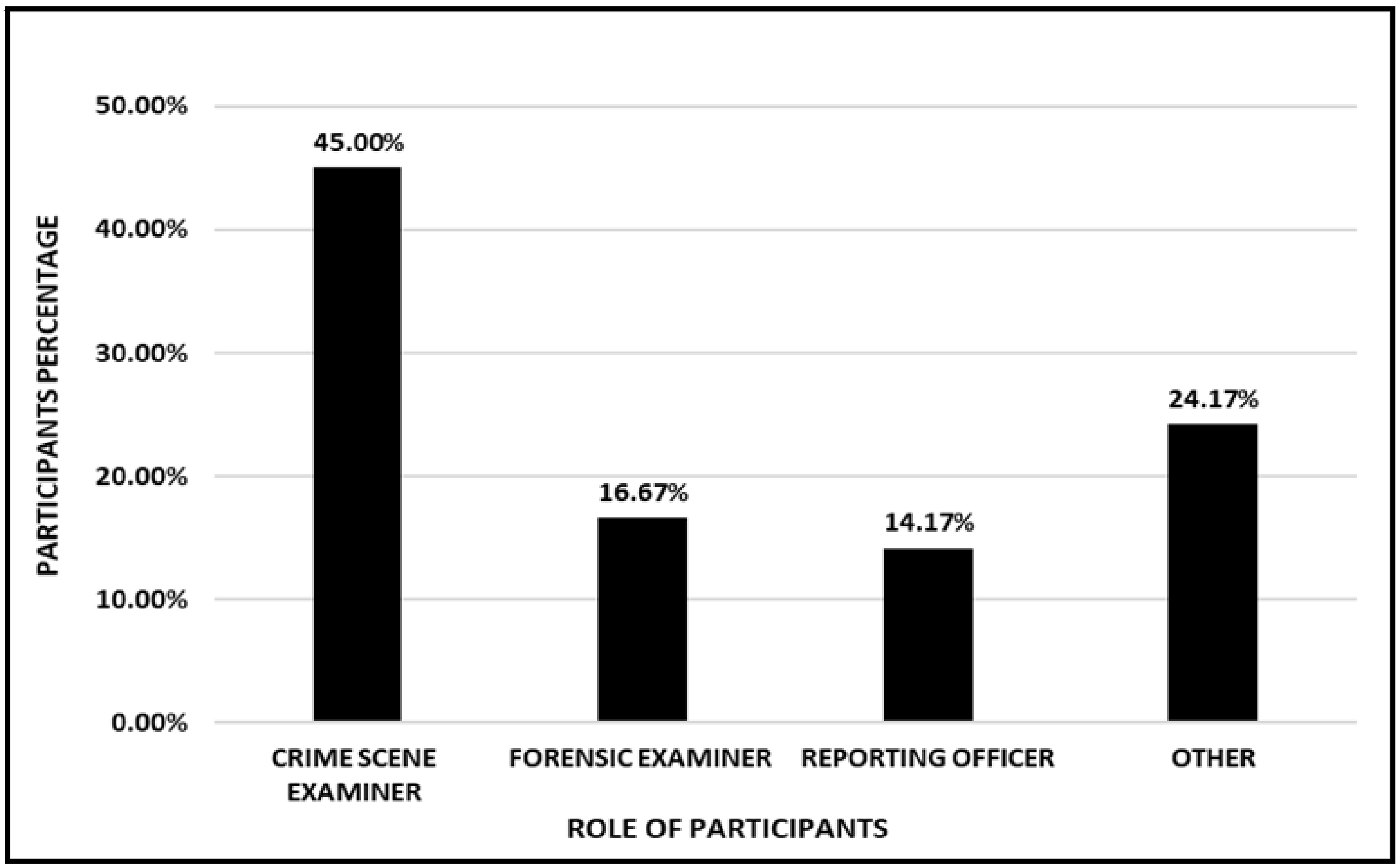

Figure 3- Illustrates the roles of the participants, these being crime scene examiners, forensic examiner, reporting officer and other

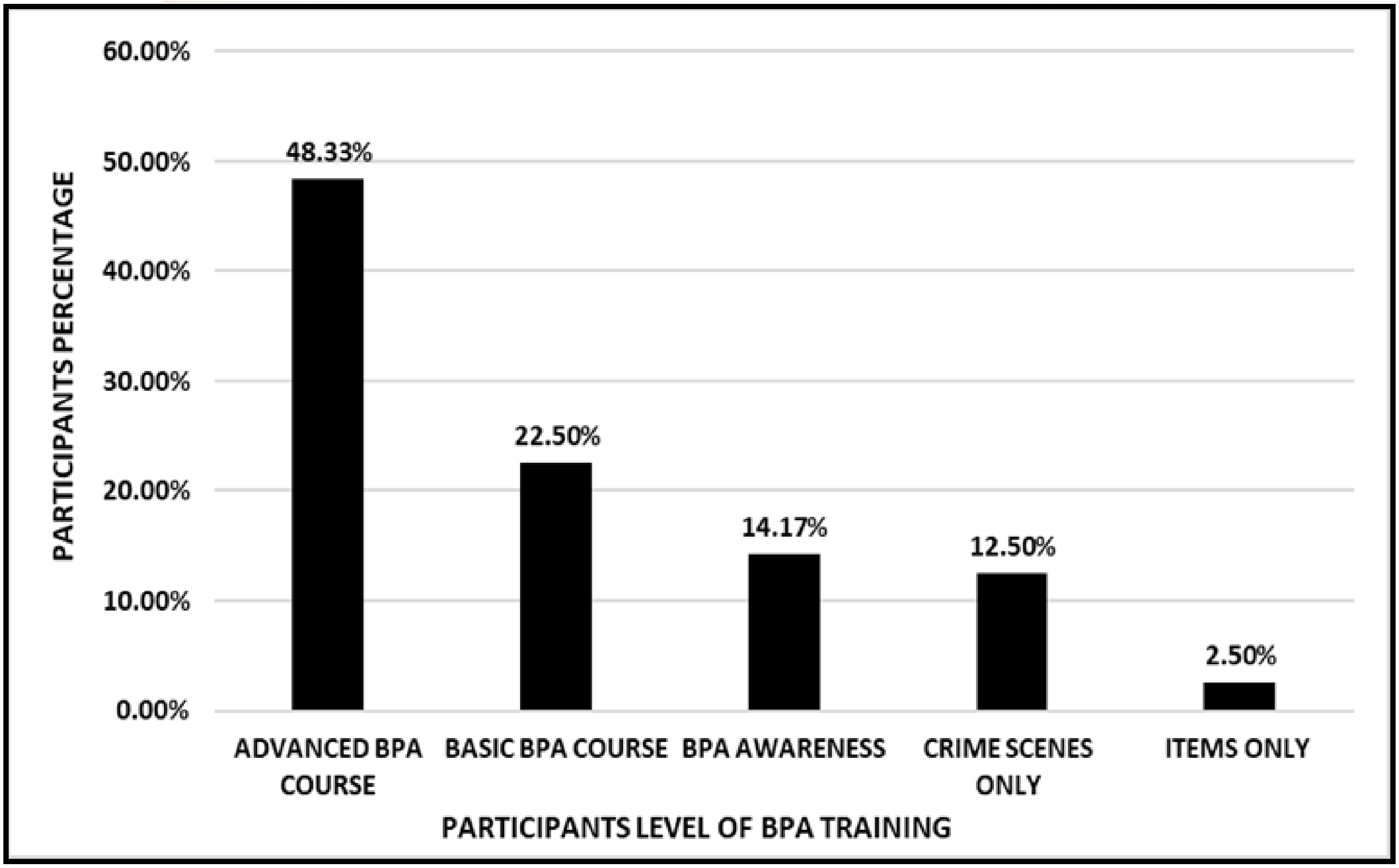

Figure 4 – Illustrates the level of BPA training of the participants

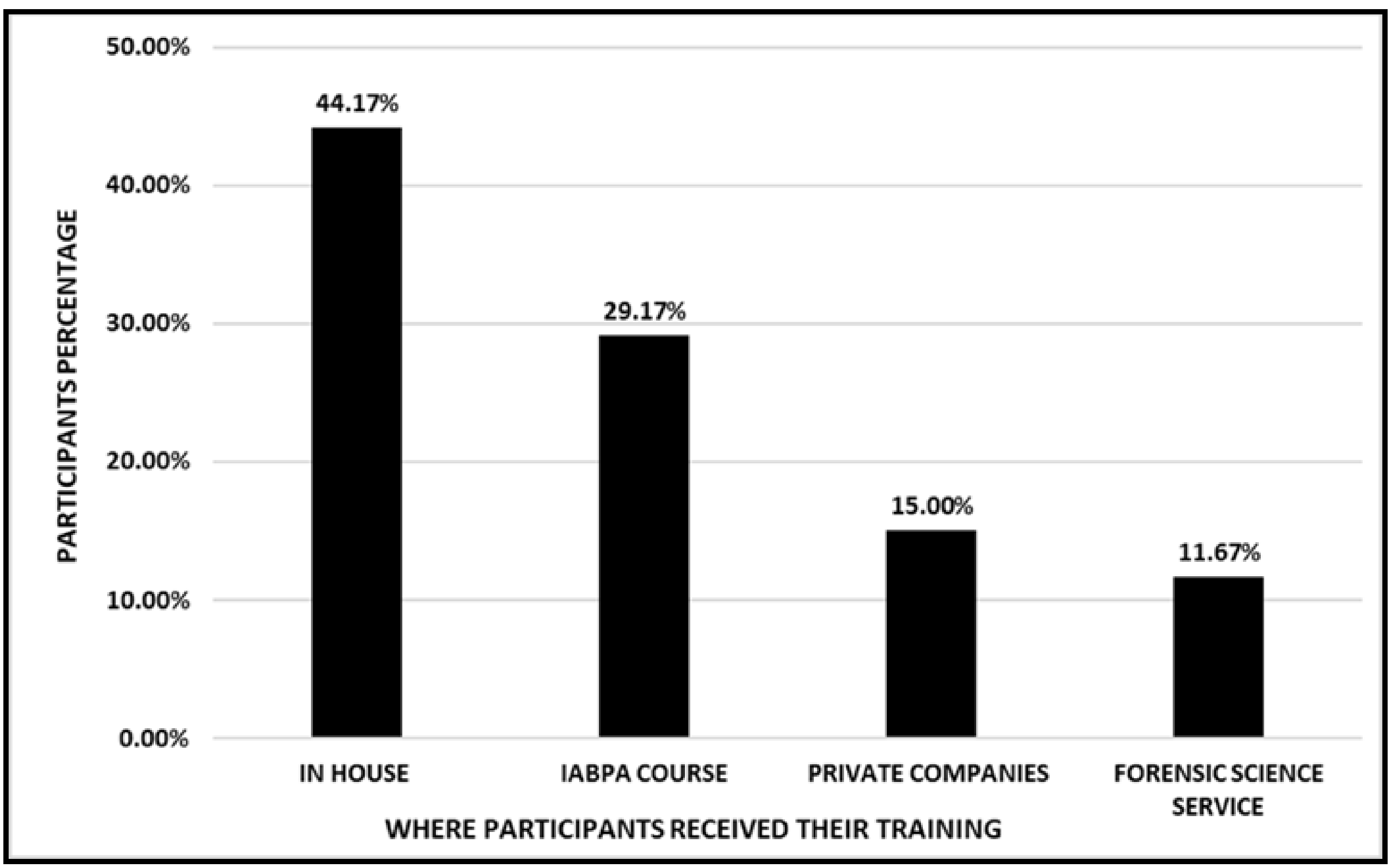

Figure 5 – Illustrates where participants received their BPA training

Of the participants who completed the survey, 44.17% of participants received their training in-house, 29.17% attended courses approved for membership into the *International Association of Bloodstain Pattern Analysts* (*IABPA*), 15% received their training at other private companies, and 11.67% received their training through the Forensic Science Service which was a government-owned company in the United Kingdom which provided forensic science services to police forces, seen in Figure 5.

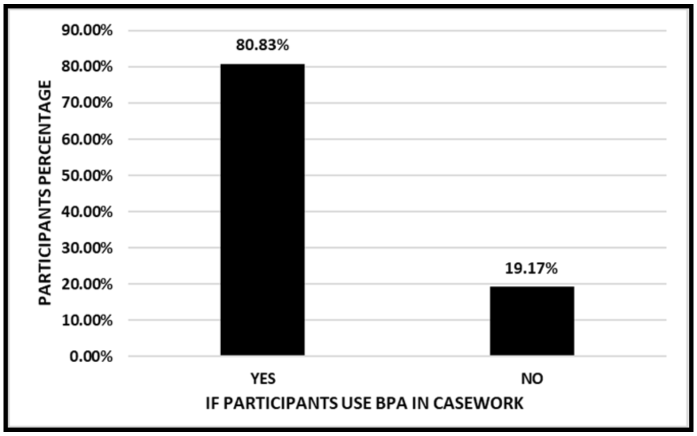

Figure 6 – Highlights if participants use BPA in casework

The majority of participants, 80.83% use BPA in casework. For those participants who use BPA in casework, they are asked how often they use BPA per month, 43.34%, use BPA once per month, with the remaining participants using BPA more frequently than others ranging from once to eight times per month. It is evident to state that although the majority of participants use BPA in casework, the monthly use of BPA in casework is low. This is highlighted in Figures 6 and 7.

Participants addressed the most common use of BPA in their experience. 29.17% of participants stated that BPA was used for the reconstruction of an incident, 14.17% stated BPA was used to provide information to the

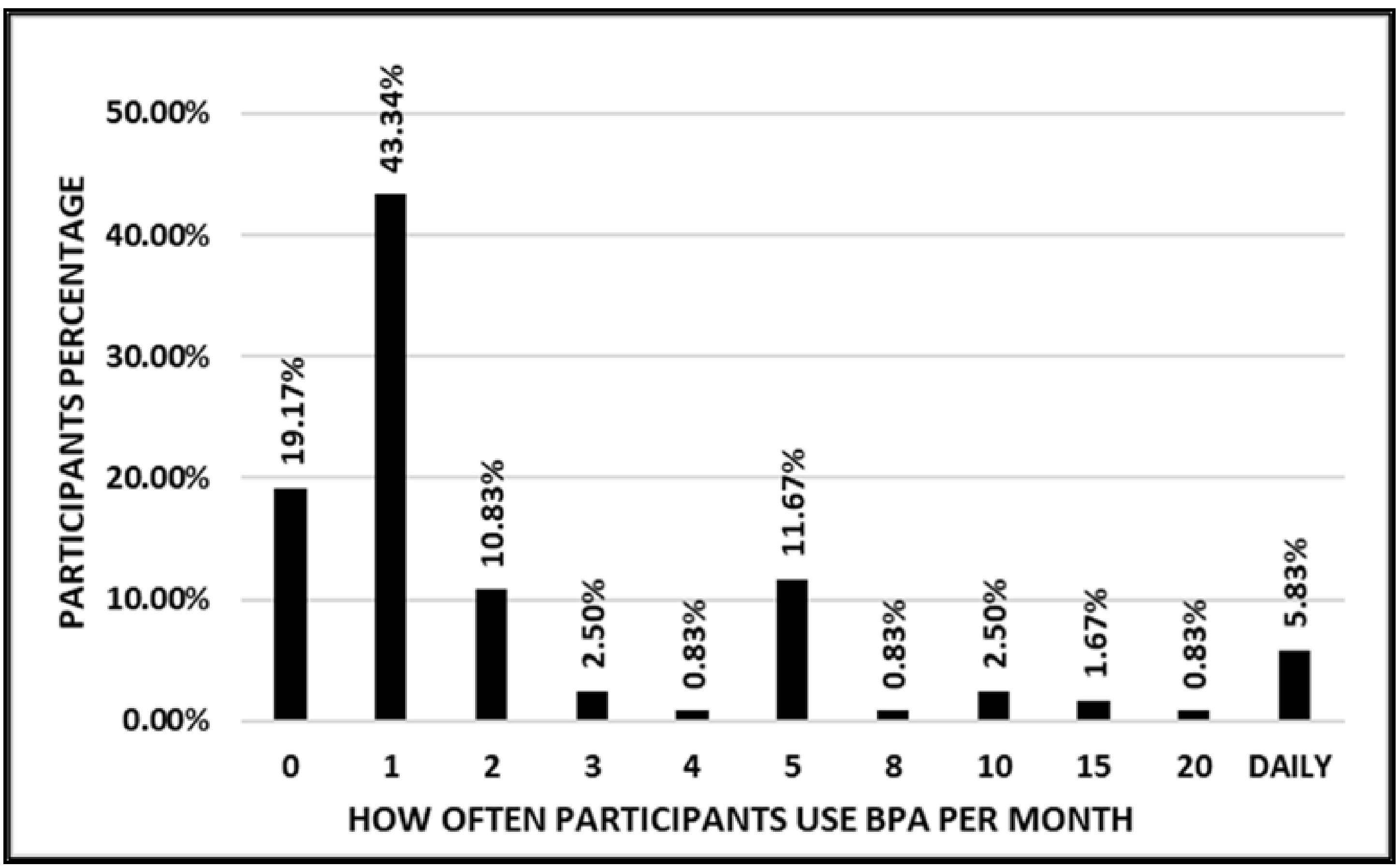

Figure 7 – Highlights how often participants use BPA in casework per month

investigator, 30.83% stated the evaluation of the bloodstain patterns given certain hypothesis, 14.17% stated BPA helped in the locating more significant stains for DNA analysis, and 11.66% stated all of the above.

Participants were required to highlight which aspect of BPA they use the most. 77.50% of participants use BPA for pattern classification, and 22.50% use BPA to calculate the AO. Pattern recognition consisted of contact stains vs impact stains, wipes vs swipes, impact spatter vs expirated blood, and identifying cast-off stains. Figure 8 illustrates how often participants are required to calculate the AO per month. It must be noted, these were whole numbers provided by participants. Those participants who are required to calculate the AO four-to-five times per month (3.34%) were from France and Argentina. If required to calculate the AO, 34% would use the Stringing method, 26.67% would use the Tangent method, 24.17% would use photography and non-analytical BPA software packages, 8.33% would use the naked eye, and 6.67% would use all of the above.

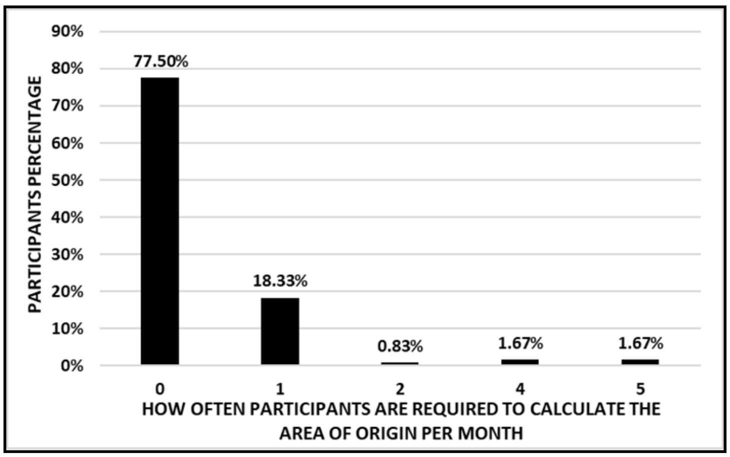

Figure 8 – How often participants are required to calculate the Area of Origin per month

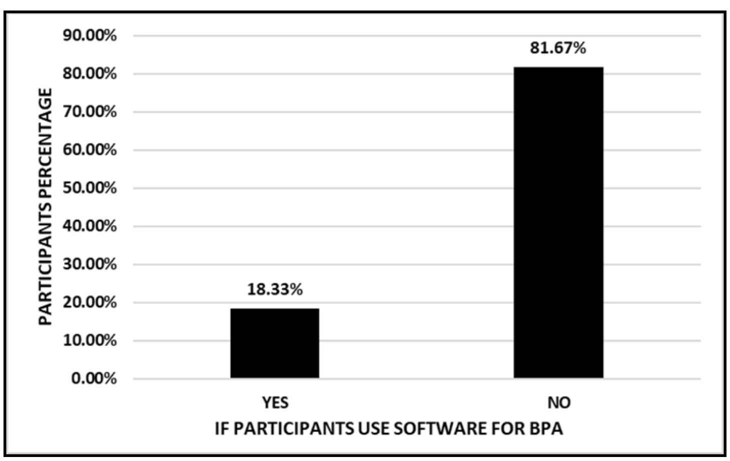

Figure 9- Highlights the if participants use software for BPA

As quoted previously, BPA software packages have been utilised for several BPA studies and addressed in many peer-reviewed articles. Participants were asked if they use software packages for BPA in casework, 18.33% do use BPA analytical software, and 81.67% do not use BPA analytical software packages in their bloodstain examinations (Figure 9). Those who do use software packages for BPA use MATLAB, FARO Zone 3D, FARO Scene, HemoSpat, 3D Vista virtual tour pro, IMS MAP360, Photoshop, CAD, Image J, and Sketchup, and Crime Zone. Participants were asked if they have access to laser scanners or other specialised crime scene documentation equipment, 38.33% stated they do have access, and 61.67% do not have access to such equipment. Of these participants, 38.33% of participants have access to the following scanners: FARO, Leica, and Spheron VR. Participants believe that having access to high powered portable forensic lasers and LED systems/torches would be useful at crime scenes, especially when documenting blood on dark surfaces.

Participants shared their opinion if they thought it would add value to the BPA investigation if they could use specialised crime scene documentation equipment, allowing them to record and identify bloodstain patterns. The majority of participants (89.17%) believe it

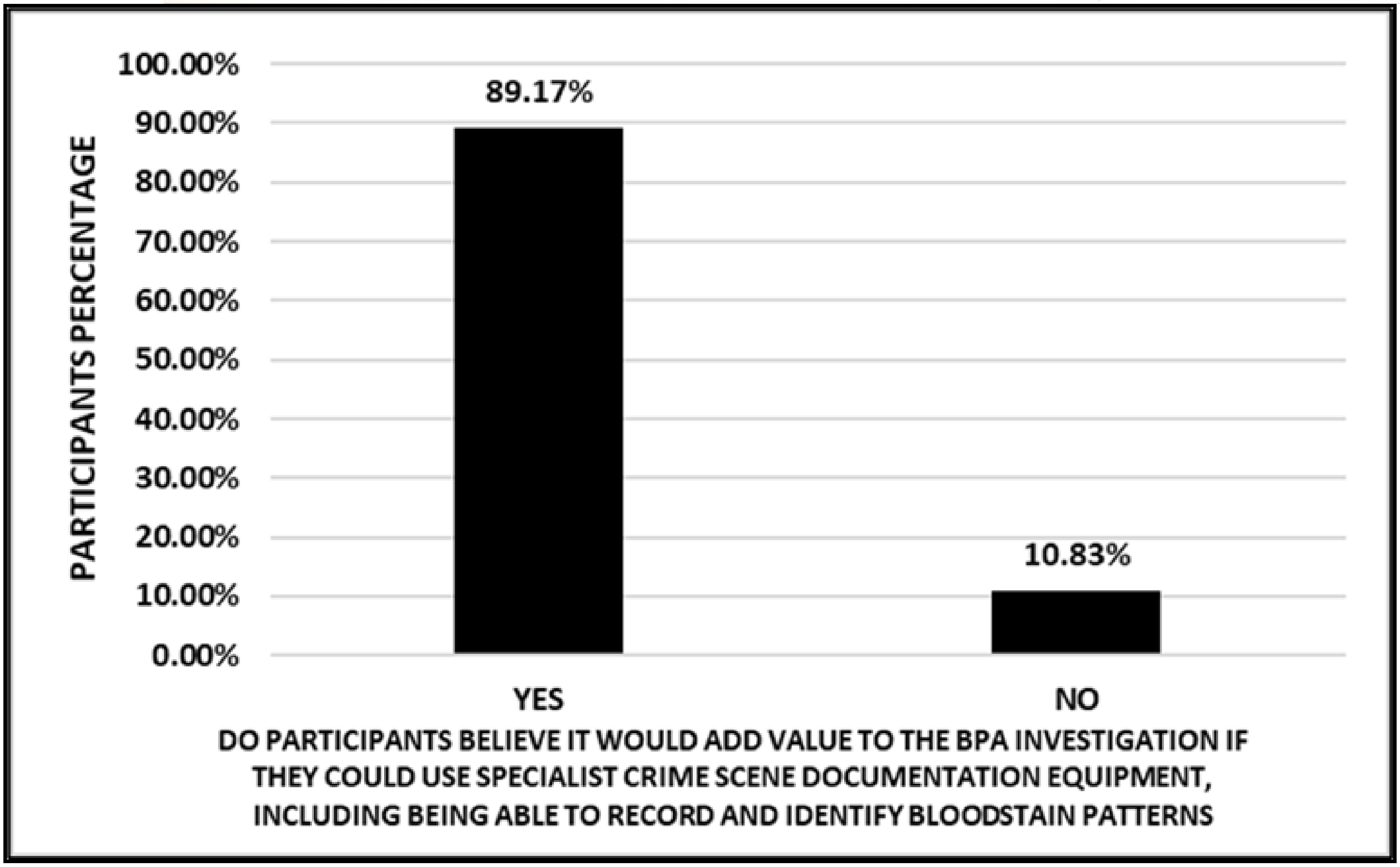

Figure 10 – the value of crime scene documentation equipment for BPA investigation

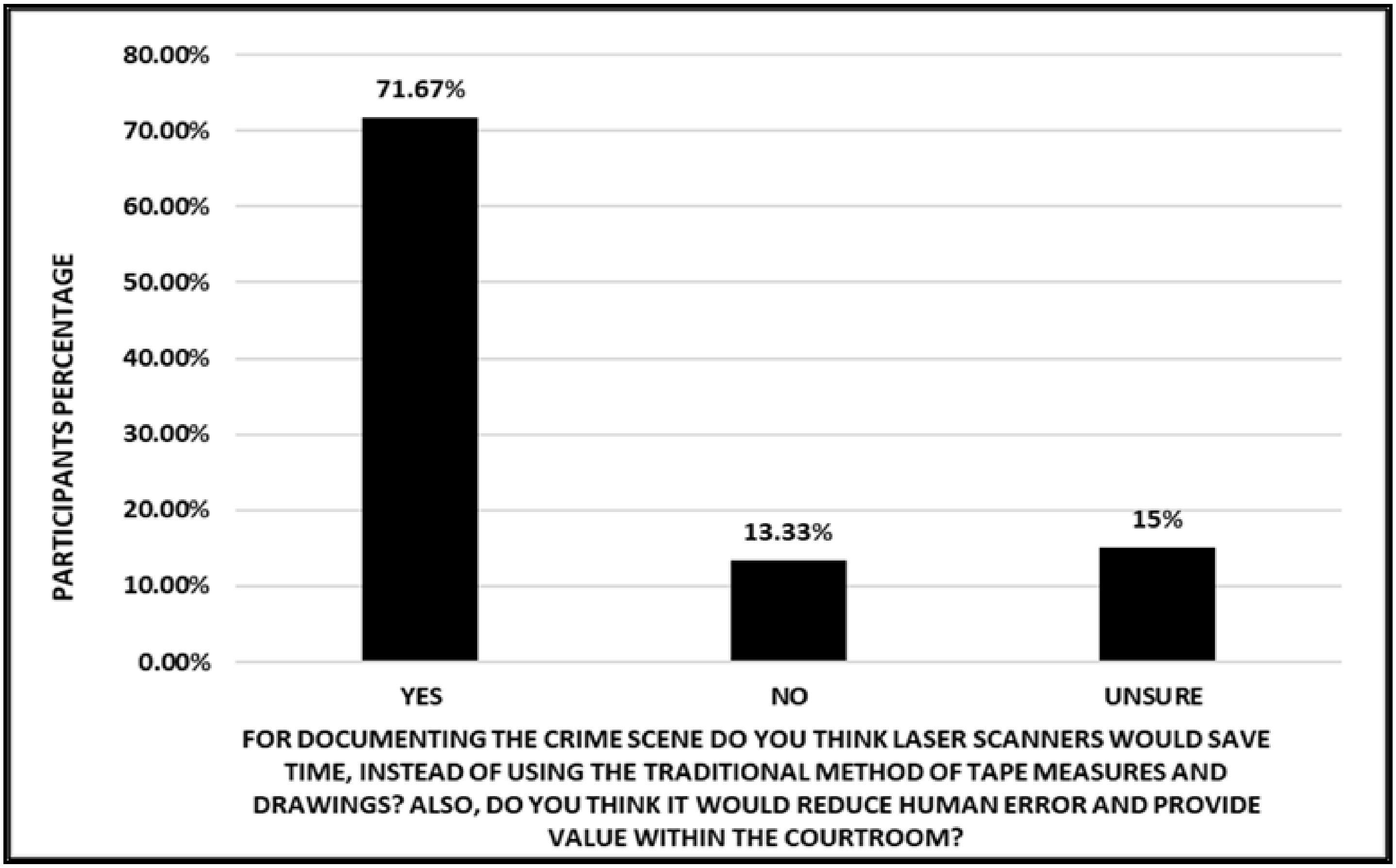

Figure 11 – the value of laser scanners at crime scenes

would add value to the BPA investigation and the remainder of participants (10.83%) believe it would not add any value. Participants stated their opinion on whether they believed laser scanners would save time, instead of using the traditional method of tape measures and drawings, and if laser scanners would reduce human error and provide value within the courtroom. The majority of participants, 71.67%, agreed it would, 13.33.% disagreed, and 15% were unsure. This has been depicted in Figures 10 and 11.

Participants highlighted how often they give BPA evidence in court. No one gives evidence weekly, 5.83% give evidence monthly, 22.50% give evidence yearly, and 71.67% never give

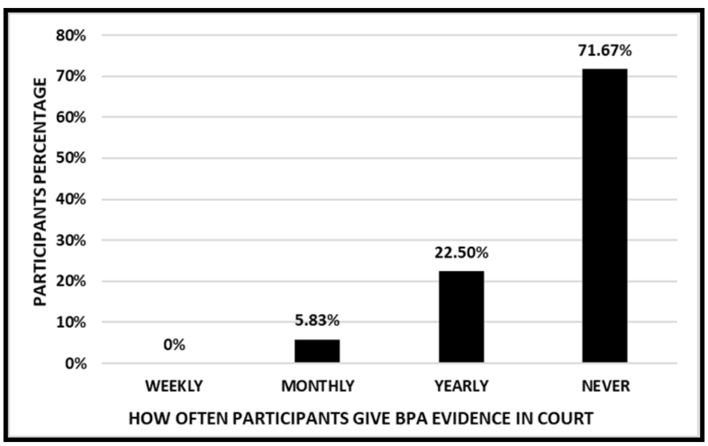

Figure 12 – Highlights how often participants give evidence in court relating to BPA.

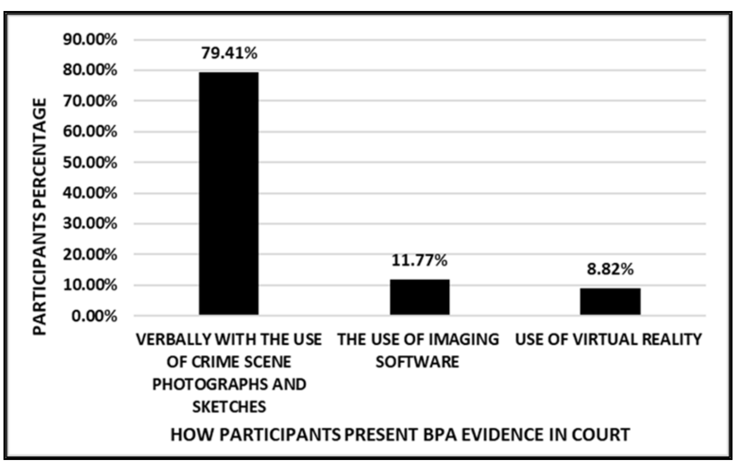

Figure 13 – Highlights for those participants who do give evidence in court relating to BPA, how they present their evidence within the courtroom

BPA evidence in court. For those participants who do give evidence in court, 79.41% give evidence verbally with the use of crime scene photographs and sketches, 11.77% use imaging software, and 8.82% use virtual reality (VR). This is depicted in Figures 12 and 13.

Participants described what they believe to be the biggest challenges in BPA in casework. Identifying what they cannot do, but if they could do, it would significantly enhance their capability as a bloodstain pattern analyst. Participants indicated that the number of reliable experts to assist at crime scenes is problematic. Crime scene investigators do not get the appropriate training due to time and cost, as it takes a significant amount of time to become an expert. The time at the crime scene is limited due to the volume of crime and the limited number of staff. Participants addressed the amount of unqualified BPA testimony, who do not have the appropriate training and experience, which restricts factual BPA testimony. Bloodstain pattern classification is problematic at crime scenes, such as discriminating impact spatter from expirated stains. Participants addressed the lack of high powered portable forensic lasers and LED systems/lights for those bloodstains on dark surfaces, such as jeans and leather chairs. The aging of blood is also a challenge at crime scenes. Software packages for bloodstain pattern analysis are valued, however, the cost of the software and software training is a disadvantage. Software packages are being updated frequently which requires further cost and training. Therefore, the amount of analysts who use software for analysis is limited.

DISCUSSION

The use of BPA in casework

The overall aim of this study was to explore the utilisation of BPA in casework. This was achieved through responses to a survey provided by 120 participants with the authorisation to complete BPA in their day-to-day roles. These participants were from a variety of countries, representing an international perspective with majority coming from the United Kingdom and the United States who use the adversarial justice system. The majority of the participants were crime scene examiners working for their local police forces, with a distribution of participants from other sectors, such as forensic science laboratories (state or privately funded), self-employed forensic consultants, laboratory technicians, and independent experts. The majority of participants had advanced BPA training. Participants had a range of experience from less than 5 years through to more than 20 years.

Table 1 reveals that a majority of participants (70.83%) had advanced and basic BPA training. Of these, 12.94% who had advanced BPA training had less than 5 years of experience and had completed the advanced BPA certification training. This demonstrates their employers or the individuals are striving to achieve a higher level of training. Statistics were similar for those who had advanced BPA training and had 5-10 years' experience (11.76%). It was expected there would be a dramatic increase for participants who completed the advanced BPA training with 10-20 years' experience (27.06%) and >20 years' experience in BPA (20.00%). A small percentage of participants (2.35%) had basic BPA training although having > 20 years' experience. After reviewing these two individual participants' responses, they quoted the following, "for more complex scenes we would just hire a BPA expert".

Participants received their training from a variety of sources, with the majority receiving their training through their employer with others receiving their training through independent trainers listed by the *IABPA*, or

Table 1 – illustrates participants level of training combined with their experience.

Training received combined with experience	Percentage of participants
Advanced Training with <5 years' experience.	**12.94%**
Advanced Training with 5-10 years' experience	**11.76%**
Advanced Training with 10-20 years' experience	**27.06%**
Advanced Training with >20 years' experience	**20.00%**
Basic Training with <5 years' experience	**8.24%**
Basic Training with 5-10 years' experience	**4.71%**
Basic Training with 10-20 years' experience	**12.94%**
Basic Training with >20 years' experience	**2.35%**

through an independent trainer. As such, there is a confidence that the participants represent a reasonable spectrum of BPA analysts. It is also important to gain an international perspective as one country's legal system may not allow for certain aspects of BPA to be carried out or render it inadmissible in a court of law.

The majority of participants, 80.83%, use BPA in casework, with the remaining stating they have the authorisation to do so. One of the key, and somewhat expected, findings was that the usage of BPA in various countries was low, with the majority of responders indicating that they only use BPA once or twice a month. While this was expected within the UK, it was also interesting to realise this was consistent in other countries, even in countries where the legal system is more inquisitorial than adversarial. The most common uses of BPA in participants' experience were relatively the same - the reconstruction of an incident, providing information to the investigator, evaluation of the bloodstain given certain hypothesis, locating more significant stains, or all of the above.

When participants were asked what they use their BPA skills for, the majority indicated BPA was used for pattern classification, such as transfer stains vs impact stains, or expiration pattern or an impact pattern. Other usages were to conduct AO analysis, however, as seen in figure 7 there is low usage of AO analysis by participants in casework. Although the low usage of AO analysis was expected, it may provide an evidence-based research strategy to reexamine educational priorities, where a significant focus appears to be on AO calculations. Whilst AO calculations are important, the findings suggest that other aspects of BPA may be more important, such as bloodstain pattern classification and the ability to differentiate between significant stain patterns. There has been limited research highlighting error rates, however, research has been conducted to highlight the rate of erroneous conclusions in bloodstain pattern classification and interpretation by practitioners [8] [47] [48] [49].

The use of BPA software and digital technologies in casework

Only 18.33% of the participants stated they used software packages for their casework. The majority of participants, 61.67%, do not have access to laser scanners and other digital technologies. For those participants who do have access to laser scanners and other digital technologies, they use FARO, Leica, and Spheron VR. The majority of participants, 89.17%, agreed that having access to specialised software and technologies, they would add value in BPA analysis. 71.67% of participants agreed that having laser scanners at a crime scene would save time and reduce human error. Participants addressed the need for enhanced high powered portable forensic lasers and LED systems/lights for BPA, especially when documenting blood on dark surfaces.

Whilst there seems to be a lot of effort and investment in developing software to support bloodstain pattern analysis, there seems to be little uptake of this. So, what is the stumbling block that stops such technologies from being used in casework, despite the desire and capability to do so? Possible reasons include operational requirements preclude them, the expense and time of using additional techniques was not justified, the techniques have not been validated or accredited for casework use and cannot be submitted to a court of law, and the technologies did not add any value to the case. Specialised software requires additional training, which can be time consuming and expensive. The technological requirements can also be excessive, such as the large point cloud files, as well as requiring reasonably high spec computers along with a graphics card, thus impacting upon the need to be cost-effective.

Use of BPA in court

Surprisingly, 71.67% of participants had never given evidence in court. Here it is necessary to clarify that, depending on the justice system, it is not always necessary to give evidence in court for the evidence to be accepted. In some jurisdictions, the bloodstain witness statements or reports were tendered in evidence in lieu of actual witness testimony. So, in reality, the number of cases where BPA is used in court is probably higher, but it is unknown as to what extent. Of those who have given evidence in court 28.33% would use presentation aids such as photographs and sketches. Bettison et al. stated it is possible that BPA evidence will continue to be heavily scrutinised by the courts. BPA needs more practitioners' input to explain the limitations and sources of error associated with the methods employed, and to provide quantifiable support from research for BPA being an area of specialised knowledge [45]. As this survey highlights the utilisation of BPA in casework, we have established the low use of AO analysis, and the challenges BPA analysts encounter on a day-to-day basis in casework.

CONCLUSION

In summary, while BPA is certainly a useful discipline, aspects of BPA need to be reviewed. Investments into AO analysis may be disproportionate, but investment into the broader discipline is required. The responses of the survey suggest that such research needs stronger practitioner input as there appears to be a disconnection between academia and BPA practitioners, and it is reasonable to state that researchers should be proactive in conducting research in areas relevant and valuable to the BPA discipline.

REFERENCES

1. Lee S. Seo Y. Moon B. Kim J. Goh J. Park N. Shin S. Study on development of forensic blood substitute: Focusing on bloodstain pattern analysis. Forensic Science International 2020; Available at: https://www.sciencedirect.com/science/article/pii/S0379073820303236?via%3Dihub (Accessed: 09/03/2023)
2. Griffiths G, Liscio E, Northfield D. Accuracy of Area of Origin Analysis on Textured, Wallpaper Surfaces. International Association of Bloodstain Pattern Analysts 2020; 35:1 -11 Available at: https://eprints.staffs.ac.uk/6541/1/Accuracy%20of%20Area%20of%20Origin%20Analysis%20on%20Textured%2C%20Wallpaper%20Surfaces%20JBPA%20Vol%2035%20No%201%20March%202020%20v1.cleaned.pdf (Accessed: 09/03/2023)
3. Liu, Y. Attinger D. Brabanter K. Automatic Classification of Bloodstain Patterns Caused by Gunshot and Blunt Impact at Various Distances. Journal of forensic sciences 2020; 65: 729 – 743. Available: https://onlinelibrary.wiley.com/doi/10.1111/1556-4029.14262 (Accessed: 09/03/2023)
4. Van den Berge M. Vries F. Van der Scheer M. Meijrink S. Determining how diluted bloodstains were derived: Inferring

distinctive characteristics and formulating a guideline. Forensic Science International 2019; 302: Available: https://www.sciencedirect.com/science/article/abs/pii/S0379073819303305?via%3Dihub (Accessed: 09/03/2023)

5. Peschel O. Kunz S. Rothschild M. Mutzel E. Bloodstain pattern analysis. Forensic Science, Medicine, and Pathology 2010; 7: 257-270. Available: https://link.springer.com/article/10.1007/s12024-010-9198-1 (Accessed: 09/03/2023)

6. Perepechina I. Crime stain as a forensic object: Some essential aspects of examination. Forensic Science International: Genetics Supplement Series 2017; 6: 531 – 533. Available: https://www.fsigeneticssup.com/article/S1875-1768(17)30289-5/fulltext (Accessed: 09/03/2023)

7. Laan N. De Bruin K. Slenter D. Wilhelm J. Jermy M. Bonn D. Bloodstain Pattern Analysis: implementation of a fluid dynamic model for position determination of victims. Scientific Reports 2015; 5: 1. Available: https://www.nature.com/articles/srep11461 (Accessed: 09/03/2023)

8. Taylor M. Laber T. Kish P. Owens G. Osbourne N. The Reliability of Pattern Classification in Bloodstain Pattern Analysis, Part 1: Bloodstain Patterns on Rigid Non-absorbent Surfaces† Journal of Forensic Sciences 2016; 61 (4): 922- 927. Available: https://onlinelibrary.wiley.com/doi/10.1111/1556-4029.13091 (Accessed: 09/03/2023)

9. Brodbeck S. Introduction to Bloodstain Pattern Analysis. Journal for Police Science and Practice 2012; 2: 51-57

10. Carter A. The Directional Analysis of Bloodstain Patterns Theory and Experimental Validation. Canadian Society of Forensic Science Journal 2001; 4: 173 – 189. Available: https://www.tandfonline.com/doi/abs/10.1080/00085030.2001.10757527 (Accessed: 09/03/2023)

11. James S. Kish P. Sutton P. Principles of Bloodstain Pattern Analysis. Theory and Practice 2005

12. Varney C. Gittes F. Locating the source of projectile fluid droplets. American Journal of Physics 2011; 79: Available: https://aapt.scitation.org/doi/10.1119/1.3591319 (Accessed: 09/03/2023)

13. Balthazard V. Piedelievre R. Desoille H. DeRobert L. Study of projected drops of blood. Ann Med Leg Criminol Police Sci Toxicol 19: 265 – 323

14. Tredinnick R. Smith S. Ponto K. A cost-benefit analysis of 3D scanning technology for crime scene investigation. Forensic Science International: Reports 2019; 1: Available: https://www.sciencedirect.com/science/article/pii/S2665910719300258 (Accessed: 09/03/2023)

15. Kwan N. Liscio E. Rogers T. 3D Bloodstain Pattern Analysis on Complex Surfaces using the FARO Focus Laser Scanner 2016; 32: 21-27. Available: https://iabpa.org/docs/December_2016_JBPA.pdf (Accessed: 09/03/2023)

16. Carter A. Eman J. Hawkes V. Illes M. Laturnus P. Lefevre G. Stewart C. Yamashita B. Validation of the BackTrack Suite of Programs for Bloodstain Pattern Analysis 2006; 2: 242- 254. PROQUEST. Available:

https://www.proquest.com/openview/187080c6574ce6dacb215fc8fe0678f8/1?pq-origsite=gscholar (Accessed: 09/03/2023)

17. Vitiello A. Nunzio C. Garofano L. Saliva M. Ricci P. Acampora G. Bloodstain pattern analysis as optimisation problem. Forensic Science International 2016; 266: 79-85. Available: https://www.sciencedirect.com/science/article/abs/pii/S0379073816302742?via%3Dihub (Accessed: 09/03/2023).

18. Le Q. Liscio E. FARO Zone 3D Area of Origin Tools with Handheld 3D Data. Original Article 2019; 23: 1- 10. Available: https://acsr.org/wp-content/uploads/2019/12/2019-FARO-Zone-3D-Area-of-Origin-Tools-with-Handheld-3D-Data-Le.pdf (Accessed: 09/03/2023)

19. Le Q. Liscio E. A comparative study between FARO Scene and FARO Zone 3D for area of origin analysis. Forensic science international 2019; 301: 166-173. Available: https://www.sciencedirect.com/science/article/abs/pii/S0379073819302130 (Accessed: 09/03/2023)

20. Hakim N. Liscio E. Calculating Point of Origin of Blood Spatter Using Laser Scanning Technology. Journal of Forensic Sciences 2015; 60: 409 – 417. Available: https://onlinelibrary.wiley.com/doi/10.1111/1556-4029.12639 (Accessed: 09/03/2023)

21. Lee R. Liscio E. The accuracy of laser scanning technology on the determination of bloodstain origin. Canadian Society of Forensic Science Journal 2016; 1: 38 – 51. Available: https://www.tandfonline.com/doi/abs/10.1080/00085030.2015.1110918?journalCode=tcsf20 (Accessed: 09/03/2023)

22. Esaias O. Noonan G. Everist S. Roberts M. Thompson C. Krosch M. Improved Area of Origin Estimation for Bloodstain Pattern Analysis Using 3D Scanning. Journal of forensic sciences 2019; 65: 722 – 728. Available: https://onlinelibrary.wiley.com/doi/10.1111/1556-4029.14250 (Accessed: 09/03/2023)

23. Connolly C. Illes M. Fraser J. Affect of impact angle variations on area of origin determination in bloodstain pattern analysis. Forensic Science International 2012, 223: 233-240. Available: https://www.sciencedirect.com/science/article/abs/pii/S037907381200446X (Accessed: 09/03/2023).

24. Develter W. Jenar E. Claes P. Vandermeulen D. Van de Voorde W. Thielemans D. Volders S. Blood pattern analysis; a novel approach for automated determination of the area of origin using an Active Bloodstain Shape Model (ABSM). Journal of Forensic Radiology and Imaging 2013, 1: 78. Available: https://www.sciencedirect.com/science/article/abs/pii/S2212478013000324 (Accessed: 09/03/2023)

25. Illes M. Boue M. Robust estimation for area of origin in bloodstain pattern analysis via directional analysis. Forensic Science International 2013, 226; 223-229. Available: https://www.sciencedirect.com/science/article/abs/pii/S0379073813000510 (Accessed: 09/03/2023)

26. De Bruin K. Improving the Point of Origin Determination in Bloodstain Pattern Analysis. Journal of Forensic Sciences 2011;

56: 1476-1482. Available: https://onlinelibrary.wiley.com/doi/10.1111/j.1556-4029.2011.01841.x (Accessed: 09/03/2023).

27. Liscio E. A Preliminary Validation for the FARO Zone 3D Area of Origin Tool. Original Article 2018; 22: 1-9. Available: https://acsr.org/wp-content/uploads/2018/08/2017-Preliminary-Validation-for-the-FARO-Zone-3D-Area-of-Origin-Tool-Liscio.pdf (Accessed: 09/03/2023)

28. Liscio E. Bozek P. Guryn H. Le Q. Observations and 3D Analysis of Controlled Cast-Off Stains. Journal of Forensic Sciences 2020. Available: https://onlinelibrary.wiley.com/doi/abs/10.1111/1556-4029.14301 (Accessed: 09/03/2023)

29. Maloney K. Killeen J. Maloney A. The Use of HemoSpat To Include Bloodstains Located on Nonorthogonal Surfaces in Area-of-Origin Calculations. Journal of Forensic Identification 2009; 5: 513. Available: https://www.researchgate.net/publication/285982869_The_Use_of_HemoSpat_To_Include_Bloodstains_Located_on_Nonorthogonal_Surfaces_in_Area-of-Origin_Calculations (Accessed: 09/03/2023)

30. Holowko E. Januszkiewicz K. Bolewicki P. Sitnik R. Michonski J. Application of multi-resolution 3D techniques in crime scene documentation with bloodstain pattern analysis. Forensic Science International 2016; 267: 218-227. Available: https://www.sciencedirect.com/science/article/abs/pii/S0379073816304030 (Accessed: 09/03/2023)

31. Orr A. Illes M. Beland J. Stotesbury T. Validation of Sherlock, a linear trajectory analysis program for use in bloodstain pattern analysis. Canadian Society of Forensic Science Journal 2019; 2: 78-94. Available: https://www.tandfonline.com/doi/abs/10.1080/00085030.2019.1577793?journalCode=tcsf20 (Accessed: 09/03/2023)

32. Polacco S. Illes M. Stotesbury T. The use of a forensic blood substitute for impact pattern area of origin estimation via three trajectory analysis programs. Canadian Society of Forensic Science Journal 2018; 2: 58–66. Available: https://www.tandfonline.com/doi/full/10.1080/00085030.2018.1463274 (Accessed: 09/03/2023)

33. Camana F. Determining the area of convergence in Bloodstain Pattern Analysis: A probabilistic approach. Forensic Science International; 231: 131-136. Available: https://www.sciencedirect.com/science/article/abs/pii/S0379073813002429 (Accessed: 09/03/2023)

34. Joris P. Develter W. Jenar E. Suetens P. Vandermeulen D. Van de Voorde W. Claes P. HemoVision: An automated and virtual approach to bloodstain pattern analysis. Forensic Science International 2015; 215: 116-123. Available: https://www.sciencedirect.com/science/article/abs/pii/S0379073815001243 (Accessed: 09/03/2023)

35. Attinger D. Comiskey P. Yarin A. De Brabanter K. Determining the region of origin of blood spatter patterns considering fluid dynamics and statistical uncertainties. Forensic Science International 2019. 298: 323-331. Available: https://www.sciencedirect.com/science/article/abs/pii/S0379073818307928 (Accessed:

09/03/2023)

36. Behrooz N. Hulse-Smith L. Chandra S. An Evaluation of the Underlying Mechanisms of Bloodstain Pattern Analysis Error. Journal of Forensic Sciences 2011; 5. Available: https://onlinelibrary.wiley.com/doi/10.1111/j.1556-4029.2011.01835.x (Accessed: 09/03/2023)

37. Stotesbury T. Illes M. Vreugdenhill A. An Impact Velocity Device Design for Blood Spatter Pattern Generation with Considerations for High-Speed Video Analysis. Journal of Forensic Sciences 2015; 61. Available: https://onlinelibrary-wiley-com.ezproxy.staffs.ac.uk/doi/10.1111/1556-4029.12975 (Accessed: 09/03/2023)

38. Matisoff M. Barksdale L. Mathematical & Statistical Analysis of BLOODSTAIN PATTERN EVIDENCE Part 1. The Forensic Examiner 2012; 21: 26-33. Available: https://www.proquest.com/docview/1239519411 (Accessed: 09/03/2023)

39. Buck U. Kneubuehl B. Nather S. Albertini N. Schmidt L. Thali M. 3D bloodstain pattern analysis: Ballistic reconstruction of the trajectories of blood drops and determination of the centres of origin of the bloodstains. Forensic science international 2011; 1-3: 22-28. Available: https://www.sciencedirect.com/science/article/abs/pii/S0379073810002926 (Accessed: 09/03/2023)

40. Sparer A. Serp B. Schwarz L. Windbeger U. Storability of porcine blood in forensics: How far should we go? Forensic science international 2020; 311. Available: https://www.sciencedirect.com/science/article/abs/pii/S0379073820301304?via%3Dihub (Accessed: 09/03/2023)

41. Arthur R. Cockerton S. De Bruin K. Taylor M. A novel, element-based approach for the objective classification of bloodstain patterns. Forensic Science International 2015; 257: 220- 228. Available: https://www.sciencedirect.com/science/article/abs/pii/S0379073815003722 (Accessed: 09/03/2023)

42. The Federal Bureau of Investigations Scientific Working Group on Bloodstain Pattern Analysis: Guidelines for the Minimum Educational and Training Requirements for Bloodstain Pattern Analysts. Forensic Science Communications 2008; 10: 1. Available: https://www.nist.gov/system/files/documents/2020/05/19/bpa_guidelines_for_report_writing_in_bloodstain_pattern_analysis_OSAC%20PROPOSED.pdf (Accessed: 09/03/2023)

43. Castro T. Chapter Seven - Forensic Interpretation of Bloodstains on Fabrics. Forensic Textile Science 2017; 1: 127 – 167. Available: https://www.sciencedirect.com/science/article/pii/B9780081018729000078 (Accessed: 09/03/2023)

44. Smith L. How an Unproven Forensic Science Became a Courtroom Staple. The New York Times Magazine 2018. Available: https://www.nytimes.com/interactive/2018/05/31/magazine/bloodstain- pattern-analysis-timeline.html (Accessed: 14/12/2020)

45. Bettison A. Krosch M. Chaseling J. Wright K. Bloodstain pattern analysis: Does experience equate to expertise? Journal of Forensic Sciences 2021. Available: https://onlinelibrary.wiley.com/doi/10.1111/1556-4029.14661 (Accessed: 09/03/2023)

46. Gardner RM, Griffin T. The foundations for the discipline of bloodstain pattern analysis – a response to the report by the National Academy of Sciences. Journal of Forensic Ident. 2010;60(4):477–94. Available: https://www.researchgate.net/publication/294448427_The_foundations_for_the_discipline_of_bloodstain_pattern_analysis_-_A_response_to_the_report_by_the_National_Academy_of_Sciences (Accessed: 09/03/2023)

47. Raymond T. Crime Scene Reconstruction from Bloodstains 2009;2(29): 69-78

48. Taylor M. Laber T. Kish P. Owens G, Osborne N. The reliability of pattern classification in bloodstain pattern analysis, part 2: bloodstain patterns on fabric surfaces. Journal of Forensic Science. 2016; 61(6): 1461 – 6. Available: https://onlinelibrary.wiley.com/doi/10.1111/1556-4029.13091 (Accessed: 09/03/2023)

49. Laber T, Kish P, Taylor M, Owens G, Osborne N, Curran J. Reliability assessment of current methods in bloodstain pattern analysis. Final report for US National Institute of Justice. 2014. Available: https://www.ncjrs.gov/pdffiles1/nij/grants/247180.pdf (Accessed: 09/03/2023)

50. FARO. FARO Zone 3D Software – Forensic Scene Reconstruction for Any Experience Level. 2020. Available: https://faro.app.box.com/s/hex3v888l41h5txghm3zeffyyu6wwxup/file/667924184963 (Accessed: 09/03/2023)

51. Strengthening Forensic Science in the United States: A Path Forward | Office of Justice Programs. (n.d.). Available: https://www.ojp.gov/ncjrs/virtual-library/abstracts/strengthening-forensic-science-united-states-path-forward (Accessed: 09/03/2023)

52. OSAC. (2019). Department of State's Overseas Security Advisory Council. Available at: Osac.gov. https://www.osac.gov/ (Accessed: 09/03/2023)

53. Santoro, A. (2019). Leica Map360: Bloodstain Pattern Analysis White Paper (Leica, Ed.) [Review of Leica Map360: Bloodstain Pattern Analysis White Paper]. Leica Geosystems. (Accessed: 09/03/2023)

54. Firm, C. L. (2018, June 18). Should Bloodstain Pattern Analysis Be Used in the Courtroom? Chambers Law Firm. Available: https://www.chamberslawfirmca.com/bloodstain-pattern-analysis-used-courtroom/ (Accessed: 09/03/2023)

55. Scarraher. (2018, July 10). The Evolution of Blood-Stain Pattern Analysis Verdicts in the Courtroom - Center for Statistics and Applications in Forensic Evidence. Center for Statistics and Applications in Forensic Evidence. Available: https://forensicstats.org/blog/2018/07/10/the-evolution-of-blood-stain-pattern-analysis-verdicts-in-the-courtroom/ (Accessed: 09/03/2023)