RESEARCH PAPER | Engineering | Volume : 5 | Issue : 1 | Jan 2015 | ISSN - 2249-555X

Hammer Transfer Stains in Coherence with BPA

KEYWORDS: Bloodstain Pattern Analysis, Hammer Transfer Stains, Physics, Reconstruction, Target Surface, Hammer head hit

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ABSTRACT *This paper is particularly aimed at summarizing the research work undertaken by the authors in the light of the other relevant work conducted in the domain of Bloodstain Pattern Analysis. Bloodstain Pattern Analysis is characterized by overlap from various other fields of science such as Mathematics, Physics, Forensic Medicine, Computer Science, Fluid Mechanics etc. Owing to the large spread of the domain and the large amount of uncertainty involved in the study and interpretation of bloodstain patterns, proper positioning of research work often becomes a challenge for researchers concerned. By way of this research paper , the authors aim at seamlessly amalgamating their research work on hammer transfer stains that involves basic concepts and understanding of physics with the research work undertaken in bloodstain pattern analysis having visible overlaps in the domain of fluid mechanics, physics, mathematics and particularly forensic science .*

1. Introduction

The legal dictionary defines Forensic Science as the "application of scientific knowledge and methodology to legal problems and criminal investigations" [1]. In interpretation of physical evidence within the legal system, nearly every area of science has reasonable contribution [1]. Physical evidence on the other hand can be broadly classified into two basic types, namely Associative and Reconstructive evidence based on its use in the reconstruction of a crime scene. This paper particularly deals with a particularly type of reconstructive pattern evidence that is commonly referred to as Bloodstain Pattern Analysis.

The Federal Bureau of Investigation Uniform Crime Reporting program defines violent crime as those offenses which involve force or threat of force [2]. The Uniform Crime Reporting (UCR) program prescribes that violent crime is primarily composed of 4 different offenses, murder and non-negligent manslaughter, forcible rape, robbery, and aggravated assault [2]. As per the report by Donna Leinwand Leger published on October 24, 2013, after 2 decades of decline of violent crime probably violent crime is again on the rise in the United States[3].England, Wales recorded similar rise in violent crime in 2013[4]. Apart from developed countries, developing countries such as India also recorded a significant rise in crime over the last two years[5]. By way of case study and experience, it can safely be concluded that violent criminal acts in most cases are accompanied by large scale bloodletting events. This very fact highlights the need for study of bloodstain patterns at a crime scene in order to evidentially support the probable events that might have occurred at the crime scene. In the words of Jon J Nordby, "bloodstain pattern analysis involves the scientific investigation/ study of static consequences resulting from dynamic blood-shedding events"[6]. The distribution of bloodstain patterns, the size and shape of the individual stains on a victim, a suspect, on the walls, the ceiling, the doorway, or on any other object help analysts reconstruct probable blood-letting events that had led to the formation of the particular stains[6]. Like most other areas of Forensic Science, bloodstain pattern evidence interpretation is characterized by the overlap from various other fields of science such as physics, computer science, medical science etc. For example, fluid mechanics particularly explains the forces that lead to the formation of a particular bloodstain pattern. Forensic Medical practitioners particularly work towards drawing the correlation between the bloodstain patterns formed and the wound formed on the body or head of the victim concerned. Computer scientists have worked out methods to automatize the process of calculation of the area of origin for a bloodstain pattern. The manual Stringing method that was used for calculation of the area of origin (in 3D) or the point of convergence(in 2D) for a bloodstain impact spatter often led to contamination of relevant evidence at a crime scene. Computer based automation of this process help analysts get over such drawbacks. While Mathematical models developed have helped investigators make a near accurate estimation of the area of origin, computer science helps at automatizing the mathematical estimation of the area of origin in a 3 dimensional space with reduced human effort.

Such evidence is useful in the court of law in order to draw evidentially supported conclusions about the murder weapon that might have been used , the number of blows struck, theposition of the perpetrator, victim and bystander(if any) etc. Bloodstain evidence not only helps sequence events in a crime scene, it also helps prove or disprove eyewitness testimony, suspect statements etc.

This paper is particularly aimed at reviewing work in different domains that have been undertaken towards investigating bloodstains patterns in a crime scene along with a brief presentation of the work the authors have so far undertaken. By way of this paper, the authors intend to present their work in coherence with the research work already undertaken in bloodstain pattern analysis.

Section 1 (Introduction) introduces the art of bloodstain pattern analysis to the readers. Section 2(Literature Review) highlights the relevant research work on bloodstain patterns that has already been undertaken in various domains. Section 3(ResearchWork) provides a brief summary of the research work that has been undertaken by the authors. Section 4(Future Work) elucidates the research work that

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the authors intend to undertake in the near future and how this work particularly is particularly relevant within the present scenario.

2. Literature Review

The bloodstain pattern terminology list introduced by the International Association of Bloodstain Pattern Analysts (IABPA) is widely accepted and followed by investigators worldwide[7]. Jon J Nordby[6] , E. Bernstein[8], H.M. Latham[9][10], J. Liesegang[11] have in their work used the scientific reasoning that governs the formation and hence study of bloodstain patterns at a crime scene.The interpretation or study of bloodstain patterns at a crime scene is particularly based on the apostle that blood is a non-Newtonian fluid and behaves similarly under identical physical mechanisms and conditions. T.W. Adair[12], C.D. Adam[13], G Ahmed[14], J.W. Anderson[15], D. Attinger[16] , V. Balthazard et al.[17], D. Brutin[18], A. Emes[19], J. Finsterer et al.[20], W.C. Fischer[21][22], H.L. Goldsmith et al.[23], H.N Harkins et al.[24] in their respective work particularly looked at the fluid mechanics that control the formation of bloodstain patterns at a crime scene. Hulse-Smith et al.[25] worked on impact dynamics and the factors that influence the formation of a blood drop. In their work, they presented equations that explicitly relate drop diameter and impact velocity to measurements of stain diameter and number of spines[25].Larkin et al in their work looked at how stain size and angle of impact correlate with reference to the surface of impact[26] . The study undertaken highlights that spines in particular cannot be used as a factor in a specific equation as they are highly influenced by the impact surface texture, hardness etc[26]. The work by N. Kabaliuk et al. analyzed how blood drop size emanating from hand held objects varied[27]. The primary blood drop size was found to range from 4.15 ± 0.11 mm up to 6.15 ± 0.15 mmdepending on the edge dimensions of the object edge dripping blood[27]. The smaller numbers were recorded by sharper bloody ended objects[27]. While the number of accompanying droplets were found to increase with object size, no significant correlation between the number of accompanying droplets and surface texture was observed[27]. While Blood Dynamics-I by Pizzola et. al. particularly documented the dynamics involved when blood impacts a stationary target surface[28], Blood Dynamics-II by the same authors concentrated on the study of blood dynamics when it impacts a moving target surface[29].

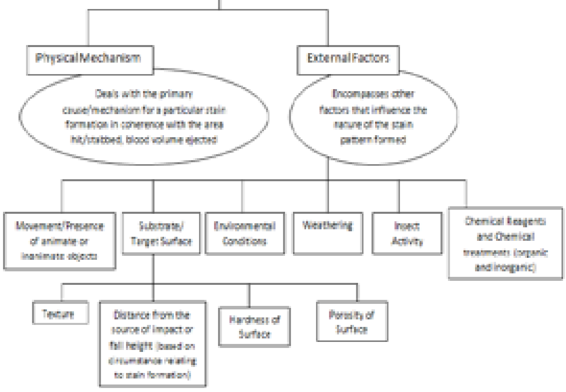

Figure1: A graphical representation of the broad classification of the factors that affect the formation of a bloodstain pattern at a crime scene

Bloodstain patterns in their turn can further be classified under different heads based on their mechanism of formation, over all pattern, distribution etc. Bevel and Gardener in their book on Bloodstain Pattern Analysis – an Introduction to Crime Scene Reconstruction 3rd edition presented a taxonomy based classification of bloodstain patterns[30]. James et al. also developed a bloodstain pattern classification system basedon the physical mechanisms that govern the formation of different bloodstain patterns[31]. As per Ristenbatt III, the taxonomic classification of stain patterns by Bevel and Gardener in "nonsensical" at certain points owing to subjective descriptors[32]. The bloodstain classification system put forward by James et al. is widely accepted and hence widely followed by bloodstain pattern analysts.

There are basically two broad aspects that affect the formation of bloodstain patterns in a crime scene(refer Figure 1). They are the physical mechanism involved and the external factors such as the texture, absorption ability of the target surface on which blood falls,environmental conditions etc.

Of the different types of bloodstains patterns such as drip trails, impact patterns, expiration stains, blood flow pattern, saturation stains etc., the authors were particularly interested in the review of work done with particular focus on the impact patterns, expiratory bloodstain patterns and transfer stain patterns. The different bloodstain patterns are differentiated and hence named as impact, expiration or transfer stain pattern based on the physical mechanism of formation. The IABPA defines 'Impact Pattern' as a bloodstain pattern resulting from an object striking liquid blood. Boonkhong et al.[33], Brinkmann et al.[34], Buck et al[35], Carter et al.[36][37], K. Clark[38], Conolly et al.[39], M Illes[40][41][42], M. Boue[41][42], Knock et al.[43], Maloney et. al.[44], Pizzola et al.[45], M.J. Sweet[46], Bruin et. al.[47] and J.K. Wells[48] significantly contributed to the study of Impact Stain Patterns on angled surfaces, calculation of the area of origin (3D), determination of the angle of impact , determination of the directionality of impact stain patterns, drawing up the trajectory of blood spatter owing to high velocity impact in a 3D space etc. Expiration stain pattern is defined as "a bloodstain pattern resulting from blood forced by airflow out of the nose, mouth, or a wound" by the IABPA. K Clark in his work suggested ways for differentiating between impact spatter patterns or expiration stain patterns both of which may be created as a result of high velocity impact and often look similar to a layman[38]. However, expiration stain will contain amylase, tissue cells, mucous strands that might particularly be absentin other high velocity impact spatter that hasn't been formed as a result of expiration[38]. G.S. Carter[49], D.V. Christman[50], Denison et al[51], Donaldson et al.[52], James et al.[53] and Power et al.[54] worked on the study and identification of expiration stains by using oral microbial DNA analysis as a marker or by utilizing salivary bacteria detection using PCR based methods as a marker .

Transfer stains are produced when a bloody hand, a bloody toe or simply a bloody boot touches a surface. Formally put, a transfer stain refers to a stain pattern formed when a blood bearing surface comes in contact with another surface. Barksdale, Sims and Vo worked on knife impression transfer stain patterns and how these patterns could particularly be matched to a particular suspected knife[55].While J. Nutt[56] worked on the enhancement and analysis of latent prints in blood, Cresap worked on bloody bare plastic footprints and how they could be used

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at predicting the foot size of an individual concerned[57]. T.W. Adair reviewed the different methodologies used for recording two dimensional bloody shoeprints in a crime scene[58]. He recommended that Alginate could particularly be used as an effective casting product for recording for recording bloody shoe impressions on dark colored surfaces that are particularly not suitable for basic photography owing to dark colored background[58].

As had been previously mentioned,external factors such as the texture, absorption capabilities of the target surface, insect artifacts do affect the formation of bloodstain pattern. This section of the paper particularly deals with how the target surface affects the formation of the bloodstain patterns. The authors have not particularly emphasized on the effect of insect artifacts that affect or alter the formation of bloodstain patterns. McQuisten[59] and Perkins[60] worked on the photographic enhancement on stain patterns on dark colored fabric and documentation of bloodstain patterns on clothing using infrared photography, respectively. Slemko studied transfer, passive and impact spatter stains created on fabrics (of varying texture, having different absorption capabilities, chemically treated, washed etc)[61]. By way of his work he highlighted the difficulty of estimating directionality and impact angle for stain patterns formed on fabric[61]. F.S. S. A[62] and Tronnberg et al.[63] particularly worked on the recognition and interpretation of expiration stain on fabric. B. White looked at the effect of drop volume, fall height and impact angle on the dimension of the stain formed on fabric[64]. M. Benecke et al. documented the paradoxical effects of surface structure and drop height on the formation of bloodstain patterns[65].Chandra et al.[66] and Josserand et al[67], worked on the impact on stain formation when a droplet strikes a dry, solid surface. Laber et al. looked at the effect of substrate on the drying time of a bloodstain pattern[68].

Bloodstain patterns are particularly used for reconstruction of crime scene. An important aspect of crime scene reconstruction deals withsequencing of events that had occurred at the crime scene. N.M. Hurley and J.O. Pex dealt with sequencing of bloody shoe impressions based on blood spatter and blood droplet drying times[69].Huss et al. developed an interpretation methodology to distinguish between the impressions left by a bloody finger, impression left when a finger comes in contact with a bloody surface, and the impression left when blood drips over a latent fingerprint left on an object[70].

It is indeed difficult to automatize the entire process / methodology of bloodstain pattern analysis owing to the large amount of uncertainty involved. Contribution of A.L. Carter[71][72][73] towards validation of the BackTrack software (which is a semi automated bloodstain pattern analysis software) and use of computers for bloodstain patterns is particularly commendable. Illes et al. used the BackTrack suite of programs for analyzing stain patterns developed from downward moving stains[74]. Jack March developed a computer based research design to investigate the uncertainty involved in theoretical as also practical estimation of the area of origin of an impact spatter[75]. Hemospat[76] and BackTrack[77] software are widely used for semi-automated analysis of bloodstain pattern images obtained from a crime scene. However an experienced bloodstain pattern analyst is particularly required to make sense of the results obtained from these toolkits within a legal setting. The book named 'Scientific and legal application of bloodstain pattern interpretation' by Stuart H. James is particularly aimed at acquainting Forensic practitioners and law enforcement professionals with the documentation and presentation methodology of bloodstain pattern evidence within a legal setting[78].

Often the science involved in bloodstain pattern evidence has been questioned on the pretext that stain interpretation done by analysts is often subjective and largely dependent on the experience of the analyst concerned[79][80].

3. Research work undertaken

With the FBI charts reporting that more number of people each year get killed by blunt force trauma as compared to the number of individuals killed by rifle or shot gun[81], the authors decided to particularly analyze the event of hammer head hit where the hammer has been used as a murder weapon. Based on extensive case study[82][83][84][85][86][87][88][89], the authors can safely conclude that the household claw, ball-peen hammer has in the past often been used as a murder weapon owing to its easy availability and ease of use.

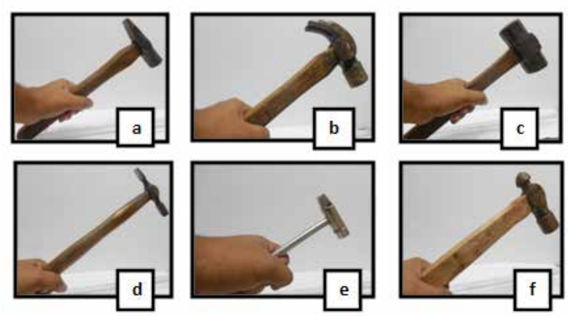

Figure 2: Isometric view of the 6 different hammers that were used in the study (a) Brick Hammer, (b) Claw Hammer, (c) Sledge Hammer, (d) Cross and Straight Peen Hammer, (e) Special Hammer, (f) Ball- Peen Hammer [Images taken with Nikon Coolpix L610]

To design the event of hammer head hit, the authors procured 6 most commonly available hammers (refer Figure 2) from the city marketplace and used these hammers to hit a hollow coconut shell with pig blood drenched hair to resemble the head of an average human(refer Figure 3).

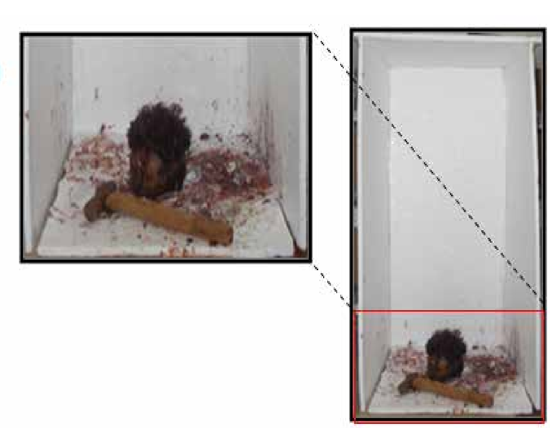

Figure 3: Experimental setup mimicking the event of hammer head hit. The hair wig that was used in the study was soaked in 20 ml. blood.[Image taken with Nikon Coolpix S3100]

The authors used pig blood as it closely resembles human blood rheology[90][91]. The height of the perpetrator or

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the victim were not taken into account as the authors at that juncture were particularly interested in documenting the hammer transfer stains formed when a hammer had been used for 10 head hits and then dropped from a height of 40, 60 and 80 cms respectively(refer Table 1). The authors also documented the case when after 10 head hits the hammer fell into a 30 ml blood pool , was picked up and again dropped from a height of 40, 60 and 80 cms respectively(refer Table 1).

Table 1: A Tabular Representation of the Hammer Transfer Stains obtained from a Ball-Peen Hammer, when the hammer was used to hit the human head simulation 10 consecutive times and then dropped from a height of 40, 60 and 80 cms onto a smooth/ plain, non-absorbent, non-porous surface (paper) [i.e. Images in the third row of the table labeled as HD#imagenumber]. The Table also contains images of Hammer Transfer Stains when the same Ball-Peen Hammer was allowed to hit the human head simulation consecutively for 10 times, dropped into a 30 ml. blood pool and then dropped onto a smooth/ plain, non-absorbent, non-porous surface (paper) from a height of 40, 60 and 80 cms respectively [i.e. Images in the fifth row of the table labeled as HW#imagenumber] . [All images were taken with Nikon Coolpix L610]

Ball Peen Hammer Transfer Stains

[Ball Peen Hammer Head Weight -500 gms, Handle Weight -100gms]

After 10 consecutive head hits, the ball-peen hammer was allowed to fall from a height of 40 cms.

HD1

After 10 consecutive head hits, the ball-peen hammer was dropped into a 30 ml blood pool, was picked up, and then allowed to fall from a height of 40 cms.

HW1

After 10 consecutive head hits, the ball-peen hammer was allowed to fall from a height of 60 cms.

HD2

After 10 consecutive head hits, the ball-peen hammer was dropped into a 30 ml blood pool, was picked up, and then allowed to fall from a height of 60 cms.

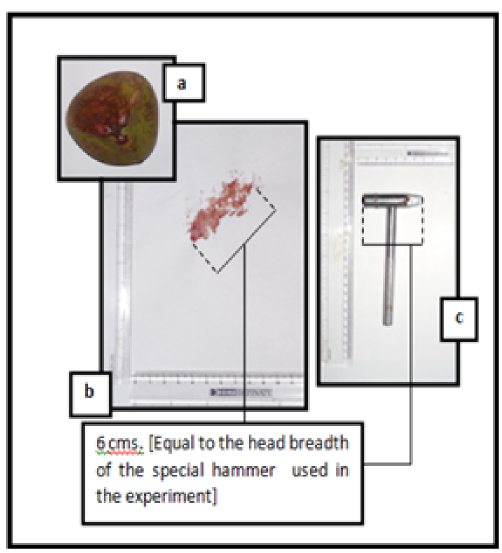
HW2

After 10 consecutive head hits, the ball-peen hammer was allowed to fall from a height of 80 cms.

HD3

After 10 consecutive head hits, the ball-peen hammer was dropped into a 30 ml blood pool, was picked up, and then allowed to fall from a height of 80 cms.

HW3



The images were compared for the same hammer. A non porous paper surface was used to record the transfer stains. In course of the experiment the authors also created samples to testify that other blunt ended objectsfor example the end of a hollow coconut shell could also produce hammer like transfer stains(refer Figure 4). Again, when a particular surface, for example, a floor tile slab or a flooring marble slab was struck with a particular velocity using the bloody edge of a hammer that was initially used for 10 consecutive head hits, the crack formation on the surface was largely controlled by the hardness of the surface measured using Mohs scale and the force of hit. Rod Cross's article on the falling physics of a top heavy elongated object like hammer partly explains the sort of hammer transfer stain one could expect to see when a bloody hammer is dropped from a height of 40, 60 and 80 cms respectively[92]. Mass Distribution, fall height, hardness of substrate, velocity of hit, surface area of hammer exposed to blood, blood molecules attached to hammer, angle of inclination at which hammer falls, edge of hammer that touches the target surface first particularly control the formation of hammer transfer stains in a crime scene. But given a tool transfer stain and absence of a probable murder weapon from the scene it often becomes challenging for an analyst to predict the tool that had left the particular transfer stain from the analysis of the transfer stain alone. In such circumstances, wound analysis, study of other bloodstain patterns at the scene, absence or presence of possible objects from the scene etc. help the analyst at drawing up probable conclusions. However, transfer stains from sharp and blunt ended objects under most circumstances can be clearly distinguished and hence help to narrow down the tool investigation process.

In lines, with the work undertaken by Eduard Piotrowski[93], where he killed live rabbits by hammer head hit in order to record how movement of a live subject affected the impact spatter formed, the other also have taken into consideration the head movements apparent when an individual suffers hammer head hit .

Though hammer head hit under most circumstances leads to profuse bleeding, the authors are also aware of the fact that depending on the different muscular structure and arterial layout in the human head[94] as also the non-uniform velocity of hit, all areas would not bleed equally when struck with a hammer.

Given that blood is a non-Newtonian fluid, atmospheric conditions such as temperature as also relative humidity was recorded on the day the experiments were conducted. All experiments were conducted within controlled laboratory settings.

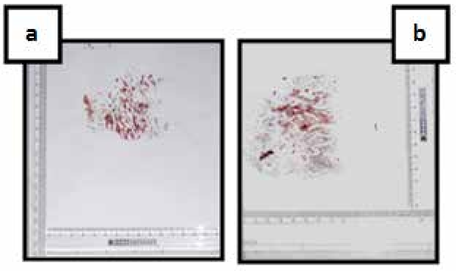


Figure 5: (a) After 10 consecutive head hits, the claw hammer was dropped from a height of 40 cms. and was hence superimposed by a half bloody shoeprint.(b) After 10 consecutive head hits, the claw hammer was dropped from a height of 40 cms. and was hence superimposed by a half bloody shoeprint.[Images taken with Nikon Coolpix L610]

It would be worthy to mention that superimposed transfer stains are often difficult to analyze and hence interpret. Superimposed stains are formed when stain patterns formed due to two or more separate (similar or different) mechanisms overlap. These types of stains are often referred to as complex bloodstain patterns. Most crime scenes are messy and analysts under most circumstances can expect to come across such complex bloodstain patterns. Figure 5 represents some of the superimposed transfer stains that the authors created within the laboratory setting, in order to highlight to the readers the difficulty associated with the interpretation of complex stain patterns in a crime scene.

4. Conclusion and Future Work

The authors have worked on creation of hammer transfer stains or rather blunt ended tool transfer stains in a crime scene and how these transfer stains could particularly be used in the sequencing of events at a particular crime scene. Using concepts of physics in their work the authors have particularly attempted at understanding the transfer stain formation pattern that one could expect to see given he/she has knowledge of certain variables such as drop height, hardness of substrate/target surface, angle of inclination of hammer at the time of fall, edge of hammer that touches the target surface first, mass distribution of hammer, dimensions of hammer, blood molecules attached to hammer surface. Thus in a crime scene an analyst could attempt at backtracking the probable events that might have lead to the formation of a particular blunt ended, elongated tool transfer stain based on the reference database developed by the authors in accordance with other relevant circumstantial evidence present at the crime scene.

The research so far undertaken by the authors is a mere precursor of the work that the authors intend to undertake in the long run. The authors intend to develop a database of stain patterns relevant to the event of a hammer/blunt ended object head hit and thereby use the database as the basis for developing a semi supervised tool that could probabilistically predict the position as also involvement of a particular individual in a crime scene based on the bloodstain on his clothing and in other parts of the crime scene where the crime had taken place.

To sum it all up, bloodstain pattern analysis is not in itself subjective, and can in parts(if not fully) be outlined by carefully controlled empirical, scientific studies.

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