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# he Vision in "Blind" Justice: Expert Perception, **Judgment, and Visual Cognition in Forensic Pattern Recognition**

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Abstract Many forensic disciplines require experts to judge whether two complex patterns are sufficiently similar to conclude that both originate from the same source. Studies in this area have revealed that there are a number of factors that affect perception and judgment and that decisions are subjective and susceptible to extraneous influences (such as emotional context, expectation, and motivation). Some studies have shown that the same expert examining the same prints but within different contexts, may reach different and contradictory decisions. However, such effects are not always present; some examiners seem more susceptible to such influences than do others-especially when the pattern matching is "hard to call" and when the forensic experts are not aware that they are being observed in an experimental study. Studying forensic examiners can contribute to our understanding of expertise and decision making, as well as have implications for forensic science and other areas of expertise.

Keywords: Forensic science, Pattern recognition, Expert perception, Statistical analysis, Review.

Many forensic identifications are based on matching a visual pattern left at a crime scene and one from a suspect. However, a large body of forensic trace evidence (such as shoe prints, firearms, tool marks, bloodstains, hair, finger and palm prints, bite marks, handwriting, ear prints, tire marks, etc.) lacks instrumental analysis. In these types of evidence, the "instruments" are, to a large extent, the human expert examiners themselves, who make judgments on the similarity of visual patterns (Cole, 2001; Haber & Haber, 2008; Mnookin, 2008). Such dependence on specialized human visual perception and judgment in expertise (Busey & Vanderkolk, 2005; Gauthier, Williams, Tarr, & Tanaka, 1998) is common in a wide range of domain experts, from radiologists

to military fighter pilots (Berlin & Hendrix, 1998; Dror, Kosslyn, & Waag, 1993).

Fingerprint identification is among the most widely used forensic techniques. It is cognitively challenging because no two fingerprint impressions, even from the same source finger, are ever identical; along with intersource differences, there are also intrasource variations. Due to the elasticity of the skin, the pressure applied, the material on which the prints are left, the method of lifting the prints, and a variety of other factors, visual differences are always introduced, even in the best and most ideal cases. And in the real world of forensics, things are far from ideal; the marks left at a crime scene (the latent prints) usually are partial and distorted and include noise.

Thus, the role of expert fingerprint examiners is complex: They do not simply determine whether two images are "identical" but determine whether different images are sufficiently similar to conclude that they originate from the same source. This can be very challenging, because some intersource differences are extremely small, thus producing look-alike prints that are very similar but, nevertheless, originate from different sources (people). Performance levels are reduced, difficulty is increased, and potential problems of false positives arise as distractors become more similar to the target (Ashworth & Dror, 2000; Vokey, Tangen, & Cole, 2009). With the growing use of searchable databases, the potential for such error drastically increases, because it is more likely that one will

find a look-alike nonmatch (Cole, 2005; Dror & Mnookin, 2010; Dror, Péron, Hind, & Charlton, 2005).

This is clearly an interesting area in visual cognition, combining issues in perceptual expertise, judgment, and decision making. It is particularly interesting because fingerprint experts have long been touted as infallible (Federal Bureau of Investigation, 1985). On the rare occasions in which errors are found, individual examiners are blamed, attributing the error to incompetence, negligence, or fraud, insisting that, in the hands of competent experts, errors are "virtually impossible" (Ashbaugh, 1994; Cole, 1998, 2005). Incompetence or deliberately made false expert identifications are of no interest to cognitive science. However, expert judgments that are sincere but nevertheless incorrect are a different story (Giannelli, 1997, 2006). Bias and other cognitive influences unconsciously affect hard-working, honest, and dedicated forensic experts, thus creeping in without the experts' awareness. This is a difficult and interesting problem, with generalizability across domains.

Errors committed by wellintentioned experts are more problematic and dangerous for at least three reasons. (1) Cognitive biases affect all examiners, not just "bad apples" (Thompson, 2008), and thus have a potential to impact forensic judgments across the board and to be relatively widespread. (2) Erroneous judgments of forensic experts are all the more persuasive in the legal context because the examiners believe them themselves. Even more than an honestly mistaken eyewitness, an honestly mistaken expert is the least culpable and thus, potentially, the most dangerous kind of witness that can testify in a legal proceeding. (3) Many individual examinersand more worrisome, many forensic professional bodies (both in the U.S. and in Europe)-have been reluctant and resistant to acknowledge, accept, and take proper action to counter these biases. Risinger, Saks, Thompson, and Rosenthal (2002) contended that forensic science, as a practice, has historically dismissed cognitive bias by conceptualizing it as an ethical issue, to be overcome by moral discipline, rather than as an inherent cognitive issue, to be managed by bias-minimizing actions. This is especially of concern because evidentiary independence can be corrupted; Hasel and Kassin (2009) illustrated how forensic evidence and confession to crimes can be interlinked and interdependent.

A recent National Academy of Sciences report on forensic science (National Academy of Sciences, 2009) concluded that

a body of research is required to establish the limits and measures of performance and to address the impact of sources of variability and potential bias. Such research is sorely needed, but it seems to be lacking in most of the forensic disciplines that rely on subjective assessments of matching characteristics. These disciplines need to develop rigorous protocols to guide these subjective interpretations and pursue equally rigorous research and evaluation programs. The development of such research programs can benefit significantly from other areas, notably from the large body of research on the evaluation of observer performance in diagnostic medicine and from the findings of cognitive psychology on the potential for bias and error in human observers. (p. 8)

In this article, we review the current knowledge of and research into forensic decision making and highlight the interesting cognitive issues to be researched, with an emphasis on latent fingerprint identification. Such research will have

important implications not only for forensic disciplines, but also for other domains that rely on expert visual perception and interpretation. This area provides a great opportunity to research perception and cognitive processing of complex visual patterns, expertise, and decision making. It is hoped that research in this area will follow in the footsteps of the research on eyewitness testimony and face recognition, which has provided a better understanding of memory and facial information processing and has influenced and motivated reform in policing and the criminal justice system.

## **Criminal Case Studies**

An analysis of publicly exposed cases of fingerprint misidentification showed that cognitive bias probably contributed to such errors (Cole, 2005). One reason for this conclusion was that more than half of the errors, rather than being exposed through reanalysis by a second expert, had been corroborated by additional analysts, sometimes as many as three. One possible explanation for this finding is that the "verifying" examiners might have been biased by the awareness of their colleague's conclusion. Even more suggestive, however, were four cases (18% of the total cases examined) in which even experts hired by the defense had corroborated what was later determined to be an erroneous identification. This suggests that cognitive bias was more powerful than the combination of the actual data and whatever motivation the experts might have had to interpret the evidence in a manner favorable to their own clients (Cole, 2005).

One such case was the Brandon Mayfield case, in which a Muslim attorney in Oregon was arrested and held for 2 weeks as a material witness in the 2004 Madrid terrorist bombing, on the basis of an erroneous match between his fingerprint and one found at the crime scene. This high-profile identification error undermined the claim that only "incompetent" practitioners make errors, because it involved the prestigious FBI latent fingerprint laboratory. The case is particularly suggestive because, not only did the initial FBI examiner make an erroneous attribution, but at least two additional FBI examiners assigned to check that examiner's work corroborated and verified the erroneous identification. And, after that, a highly regarded independent examiner appointed by the court to examine the evidence on behalf of Mayfield's defense also concluded that Mayfield was the source of the print. After Mayfield had spent 2 weeks in jail, the Spanish National Police matched the fingerprint to an Algerian national, Ouhnane Daoud. Subsequently, the FBI released Mayfield, apologized, and gave him \$2,000,000 in a compensation settlement.

Of course, one possible reason that so many different experts reproduced the same error might be attributed to the stimuli themselvesfor example, the prints were extremely similar. A report by the U.S. Justice Department's Office of the Inspector General (OIG) posits such an explanation, claiming that the similarity of Mayfield's and Daoud's friction ridge skin (the skin that produces finger, palm, and sole prints) was "an extremely unusual event" (Fine, 2006). However, the Madrid bomber print was searched against several large databases of prints, using automated fingerprint identification systems (AFISs). An AFIS produces a list of candidates that is then examined by a human

expert. But since the AFIS examines millions of prints, it is not a surprise that similar look-alike prints are found by the mere scope of the search (Cole, 2005; Dror & Mnookin, 2010; Dror et al., 2005). The similarity makes it easier for cognitive biases to take over and affect the identification decisions. As the bottom-up data become more challenging (e.g., because of coincidental similarity or other reasons, such as low quality and/or quantity of the data), topdown cognitive influences have more leeway to influence the identification process. In scenarios such as this, computer searches combined with cognitive bias may prove to be a pernicious mix.

The Mayfield case shows that second, third, and even defense experts may be influenced by the knowledge that another examiner has already concluded that two fingerprints come from the same source. Thus, subsequent examinations may be biased by the initial examination. An internal FBI report concluded that this was, indeed, the case and recommended that verifications be performed "blind" in "designated cases" (whatever those are; Stacey, 2004).

But as important, if not more important, is that the initial examination may also be biased. As the OIG report details, the FBI examiners reached their erroneous conclusions despite seemingly clear (with the benefit of hindsight bias, of course; Berlin, 2000; Harley, Carlsen, & Loftus, 2004) discrepancies between the crime scene print and Mayfield's. This happened because the expert examiners posited ad hoc explanations for the discrepancies (e.g., the discrepancies were "noise" because they derived from another fingerprint that was laid down previously on the same surface by

another individual). In other words, they explained away and dismissed the discrepancies (which otherwise would not have permitted an identification). The reason they did not see the data for what they were was that they were already convinced that Mayfield was the source of the print, and this biased their perception and judgment of the actual data.

There are other interesting cases of erroneous judgment. Take, for example, the case of detective Shirley McKie from Scotland. In this case, a print left at a murder scene was identified as that of Shirley McKie, and after this identification was further verified by other experts, she was arrested. However, she contested the identification all along, and indeed many leading international fingerprint experts have categorically rejected that it is her print. Eventually, she received an apology for the erroneous identification and was awarded £750,000 in a compensation settlement (Association of Chief Police Officers in Scotland, 2000: Justice 1 Committee, Scottish Parliament, 2007; McKie & Russell, 2007). What is interesting about this case is that the print continues to be disputed. The issues of cognitive bias and psychological influences have been raised by both sides as a contributing factor to the errors of their opponents.

# **Research Studies**

There has been just a handful of research studies into forensic decision making, most of which have been conducted only in the past few years (an exception is a study on microscopic hair comparison [Miller, 1987]). The few existing studies provide a mixed picture, with conflicting findings as to whether bias affects forensic experts or not (see, e.g., Hall & Player, 2008, who claimed that bias has no effect on forensic experts' decisions; for a rebuttal, see Dror, 2009; Saks, 2009). Latent print identification has been the main focus of forensic decisionmaking studies, because it has provided a stimulus-rich opportunity for research and because it is reputed to be among the most accurate and objective of the forensic disciplines.

If expert latent fingerprint examiners can be biased, then so, presumably, can firearm and toolmark examiners, shoe print examiners, bite mark examiners, document examiners, ear print examiners, and all the other forensic experts who heavily rely on human perception and judgment. In fact, one of the reasons researchers chose to investigate this forensic discipline was because of its long-standing reputation for accuracy and objectivity (Leo, 2001). If bias is present in this domain, we can quite confidently assume that it is present to the same degree, if not more so, in the other, less established domains. Even the robust and newer forensic domain of DNA profiling is susceptible to biased interpretation (Thompson, 2006).

Research studies into forensic decision making have varied along a number of dimensions. For example, some have defined error only as false alarms (incorrect identifications) and have not regarded misses (incorrect exclusions or insufficiency) as error, whereas other studies have regarded both as error. Some studies have been conducted by cognitive psychologists and academics (e.g., Vokey et al., 2009), whereas others have been conducted by the forensic examiners themselves (e.g., Hall & Player, 2008; see Risinger & Saks, 2003, for the dangers and pitfalls of conducting law-enforcement-sponsored research). In addition, practitioner-led research

is potentially problematic in that there may be conflict of interest, pressures, and "role ambiguity," all deriving from the fact that the practitioners are both researchers and participants (Cole, 2008).

Another important difference in the research studies has been the use of different participant groups. Some studies have used general university students (mainly psychology), and some have specifically used trained forensic students. Other studies have used actual forensic experts; however, some studies used experts during covert data collection while the experts were doing routine casework and were not aware they were being studied, whereas some studies used experts who knew they were being tested. We review the literature by participant group because it captures two important elements in studying forensic expert decision making; the first is level of expertise (general students, forensic students, and experts), and the second is ecological validity (testing experts in experiments vs. covertly collecting data during real casework).

Studies in which students (general university students) were used. A recent study utilizing signal detection theory (SDT) reported three experiments whose aim was to examine the extent to which people can correctly determine the source of fingerprints (Vokey et al., 2009). The results of psychophysics testing showed that participants (nonexpert, not even forensic students) could perform at levels characterized by Vokey et al. as "quite well"; however, performance varied as a function of similarity and the specific finger in question. The early call for the application of SDT to the study of forensics (Phillips, Saks, & Peterson, 2001) had never been systematically followed up until the Vokey et al.

study.

To study whether emotional context can affect judgment on fingerprints, Dror et al. (2005) presented pairs of prints to psychology student participants, who were required to decide whether or not the two prints originated from the same source. The participants (N = 27) received 96 pairs of prints (48) of them were clearly from the same source or clearly not from the same source, and 48 were ambiguous). Before presenting the fingerprints, some participants were briefed about the background of the case. Half of the briefed participants were given a low-emotional context (i.e., the prints were lifted off stolen property), whereas the other briefed participants were given a high-emotional context (i.e., the prints were lifted off a weapon used in a brutal and unprovoked attack). Horrific photos from crime scenes were used to support the high-emotional context experimental condition.

The results showed that when the stimuli were clear, the emotional context had no impact on the participants' deciding that the prints were from the same source (or not from the same source). However, when the prints were ambiguous, an identification was more likely to be made when they were presented in the high-emotional condition. Furthermore, for the ambiguous prints, in the control group that did not include any background information, 47% of the prints were judged to be from the same source. When the same prints were presented in the lowemotional context, 49% were judged to be from the same source, whereas in the high-emotional context, 58% were judged to be from the same source (for details, see Dror et al., 2005).

Studies in which forensic

science students were used. In two experiments, Schiffer and Champod (2007) evaluated how forensic science students conduct pattern analysis. During the initial stage, the examiner is supposed to examine and note only important features and characteristics of the pattern of the print, prior to any comparison with another print pattern. This is commonly referred to as the analysis stage in what latent print examiners call the ACE– V methodology (A, analysis; C, comparison; E, evaluation; and V, verification).

In the first experiment, performance was examined before and after training in fingerprint identification (Schiffer & Champod, 2007). The finding showed that, posttraining, participants noticed more characteristics (minutiae) and there was higher consensus among the participants. In their second experiment, Schiffer and Champod investigated whether the amount of minutiae detected would be influenced when the comparison print was present and whether low- and high-emotional-context backgrounds (petty burglary vs. terrorism) would influence the analysis stage. They found that neither had an effect on the analysis of the prints.

Studies in which forensic experts who knew that they were being tested were used. An error rate of 1.041% was observed with experienced latent print examiners (Wertheim, Langenburg, & Moenssens, 2006). However, almost all the errors (1.007% of the 1.041% total error) were classified by the authors as clerical mistakes, and only 0.034% of errors were classified as and attributed to erroneous identification judgments. Cole (2006) questioned the classification of the clerical errors, and Vokey et al. (2009) characterized this study as "quite flawed," because

"among other things, it lacked distractor test prints, so false positives could not be assessed" (p. 1024).

In another study, 43 expert examiners were given a set of six comparisons (Langenburg, Champod, & Wertheim, 2009). The participants were randomly assigned to one of three experimental conditions: a control group; a low-context group, which received, along with the prints, the conclusion reached by another examiner; and a high-context group, which received, along with the prints, the conclusion reached by an internationally respected and recognized expert. The study examined whether the contexts would affect the examiners' decisions. They also included a second control group of novices. The findings showed that the context did bias all the participants but that its effects were more noticeable for the novices than for the experts. Furthermore, the experts were more affected in the direction of inconclusive and exclusion, and less in the direction of identification.

A study of 70 fingerprint experts examined emotional effects (Hall & Player, 2008). Some participants were told that the fingerprints were related to forgery (the low-emotional-context condition), whereas other participants were told that they were related to murder (the highemotional-context condition). The authors concluded that the emotional context did not have an effect on the final decisions reached by the examiners. However, many of the participants in the study did not even read the context scenario and, thus, could not have been affected by it (13 participants, 19% of the entire participant pool); nevertheless, the data from these participants were included in analyzing the effect of the scenario context (see Dror, 2009; Saks, 2009). Furthermore, although Hall and Player concluded that there

was no effect of emotional context in their study, the experts taking part in the study reported that "the severity of the case had an effect on their analysis" (Hall & Player, 2008, p. 38). This contextual effect is further established and reflected by the fact that the magnitude of the effect was a function of the level of the emotional context: 52% of the examiners in the high-emotional-context condition said that they were affected by the context, but only 6% of the examiners in the low-emotional-context condition said that the context affected them.

Emotional and motivational factors have also been examined in a qualitative study (Charlton, Fraser-Mackenzie, & Dror, 2010). In this study, the emotions of the examiners vulthemselves and their motivations were explored. The findings showed general positive emotional effects associated with matching fingerprints and fear of making errors, and specific satisfaction related to catching criminals, which was most notable in solving high-profile, serious, or longrunning cases.

Studies in which covert data collection of forensic experts working real cases was used. Collecting experimental data from experts is important in terms of ecological validity. However, even in field collection, data can be problematic, because the behavior of people is often affected under experimental conditions, or even when they are just observed. This is further and significantly exacerbated when the topic of study is expert performance. In such studies, experts are motivated to do well, and thus their attention and performance are not reflective of their routine performance during ordinary dayto-day work. Furthermore, the study of error is an especially problematic and sensitive issue to investigate, and any data collection must, therefore, not reveal the purpose of the study. Thus, for ecological validity, this line of experiments was done covertly, collecting data from fingerprint experts during their routine day-today work.

Only two empirical field studies of this sort have been conducted (Dror & Charlton, 2006; Dror, Charlton, & Péron, 2006; see Dror & Rosenthal, 2008, for their meta-analysis). The first study used the Mayfield case to provide a context that suggested that two similar prints were not from the same source. Five experienced expert latent print examiners, who at the time of the study had not seen the actual Mayfield prints, were used in the data collection. These experts were presented with a pair of prints that allegedly were those of Mayfield and the latent print of the Madrid bomber (thus giving them strong contextual cues that, although these prints looked alike, they were, in fact, from different sources). The fingerprint examiners were asked to analyze the prints and to focus on the actual prints while ignoring the context (that the prints were from the Mayfield case). However, rather than the Mayfield prints being presented, unbeknownst to the experts, they were actually presented with a pair of prints that they themselves had previously examined years ago in real criminal cases and had determined to be from the same source—that is, an identification. The materials were exactly the same as those they had analyzed in the past, except that the context was repackaged so as to suggest that the prints were not from the same source.

In this study, 4 of the 5 expert examiners contradicted their original conclusions. Three of them changed from identification to exclusion consistent with the contextually biasing information. One of them changed from identification to inconclusive. Only 1 stuck to the original response (Dror & Charlton, 2006). Thus, most of the expert fingerprint examiners made decisions on the basis of the context, rather than on the basis of the actual information contained in the print. The experimental manipulation in this study enabled the researchers to scientifically assess within-expert performance. Thus, comparing experts with themselves under different conditions allows researchers to isolate variables, using the experts as their own control, and avoiding between-experts individual differences (Byrne & Eysenck, 1993).

A follow-up study (Dror & Charlton, 2006) with a different and larger sample replicated and expanded the previous study. The next study used 48 pairs of fingerprints and showed that expert fingerprint examiners could be biased in both directions (toward individualization as well as toward exclusion). Furthermore, this study established that bias can be induced by more ordinary contextual information (such as "the suspect confessed to the crime" or "the suspect has an alibi"); for discussions on the presumption of evidentiary independence and the contamination of one form of evidence by another, see Castelle and Loftus (2001), Hasel and Kassin (2009), and Loftus and Cole (2004). Finally, this study also demonstrated that although bias is more likely to occur with difficult and similar prints, it can also occur in less challenging cases. Dror and Rosenthal (2008) combined the data collected from Dror and Charlton (2006) and Dror et al. (2006) and subjected it to meta-analysis, so as to quantify the reliability and biasability of fingerprint experts' decision making.

## **Summary and Conclusions**

Many disciplines in forensic science rely on examining partial and distorted trace evidence left at a crime scene. These visual patterns-be they tire marks, shoe prints, or bite marks (to name just a few)—are compared with target patterns from potential suspects. A number of studies have examined how well forensic experts from the established and most commonly used discipline of fingerprinting examine different visual patterns. Fingerprint identification relies on the ability of human examiners to make correct visual judgments. For the most part, matching fingerprints that are complete and of high clarity may well be a straightforward pattern-matching task. However, it can become quite complex and interesting when the comparison is made to a partial and distorted print (e.g., latent prints collected from a crime scene). In such cases, patterns do not match easily, and the expert examiner needs to determine whether they are sufficiently similar to conclude that both print patterns originated from the same source

Research shows that various factors affect the perception and comparison of fingerprint patterns and that judgments and decisions are subjective and susceptible to influences. Across studies, it seems that extraneous information, such as emotional context, expectation, and motivation, affects decision making. In fact, studies have shown that the same expert examiners, examining the same prints but within different contexts, may reach different and contradictory decisions. However, some examiners seem more susceptible to such influences than do others. Furthermore, all examiners are influenced more by context and other extraneous information when the pattern matching is objectively "hard to call" and when they are not aware that they are taking part in an experimental study.

It is clear that experts in forensic identification have special abilities and cognitive processes specializing in pattern recognition but that these processes are also vulthemselves to error (Busey & Dror, in press; Dror, in press). Forensic pattern recognition comprises issues in visual cognition, expertise, and decision making-par excellence, subject matters within the domain of cognitive science. Nevertheless, there has been only a handful of studies in this area, most of which have taken place only in the past few years. These studies have only begun to unravel the perceptual and cognitive processes involved in forensic pattern recognition. This area calls for additional research that will benefit the understanding of expert performance, as well as provide scientific insights into the real world of forensic identification.

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# Study On Pre-litigation Identification as an ADR Method

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**Abstract** China's current law allows the parties to take the pre-litigation identification as a kind of ADR mode to solve civil disputes. Pre-litigation identification is alternative, selective and accurate with the characteristics and mechanism of the ADR. In judicial practice, pre-litigation identification promotes reconciliation, people's mediation and pretrial mediation to realize the alternative dispute resolution, and contribute to the just settlement of the dispute, and to save litigation resources. In reality, pre-litigation identification also exist certain problems and defects, and need further regulation in order to achieve the purpose and the value of the ADR.

Keywords: Forensic science, Pre-litigation identification, ADR, Self identification, Pretrial mediation.

At present, the settlement of dispute involves more and more with the judicial identification activities. Scientific and authoritative method is one of the three core elements of social diverse dispute settlement mechanism. On the one hand, we should establish and perfect the diversified dispute settlement mechanism; on the other hand, we should learn to change the major political, economic and social problems into legal problems (and not the contrary). Especially, what we intend to do at last is that we would change the legal problems into technical problems. Depending on the objective judicial authentication, making use of scientific and technological means, it will be fair, objective and effective to mediate and resolve various disputes.

# 1 The concept and properties of pre-litigation identification activities

1.1 Related concepts of identification

Some administrations define the judicial authentication clearly as "judicial appraisal refers to that the expert uses science and technology or expertise knowledge to identify and judge specific problems involving the lawsuit case and provide expert opinions for the judging activities." If there is no legal definition, the concepts of identification activity are quite broad, which relates to whether the identification of activities before judicial proceedings are applicable to judicial regulations and have judicial effect. Some scholars believe that, judicial appraisal should be identified in the proceedings, and should also include the identification before proceedings. Identification by a party before proceedings should be entrusted if another party (including the identification in pre-litigation and litigation) has no objections, and can be adopted by the court.

Pre-litigation identification generally refers to situation that the public security and judicial organs have not yet placed the case on file, then the litigant of the case entrusts appraisal institutions or the investigation organs to identify the special problems in the case; or the people's court has accepted the case, but by the law, the parties early has already entrust the institution for the special cases in the identification before the proceeding. The execution of the pre-litigation, commissioned external body, and pre-litigation identification results play different roles in the proceedings. Also the identification expenses are different. According to the role court plays before the lawsuit, some scholars divide the pretrial identification into three categories: court -dominant, court-leading, and court-promoting models, which center on the relationship between court and the identification activity.

From the client's perspective, pre-litigation identification is "self identification" commissioned by the clients themselves. The expert then makes use of the technology to the detect, judge, and evaluate the problems and disputes that arise in their daily life, providing the scientific proof for the solvement.

# 1.2 Substituting property of pre-litigation

The pre-litigation identification has the various characteristics of the alternative dispute resolution (ADR) or the dispute mechanism. ADR refers to the dispute settlement method through the modest dialogue held by the intermediary who has no interests in either parties. First of all, identification before litigation is characterized with the property of substitute, which can substitute the trial of the court. Before the proceedings, if the dispute between the parties is solved before entering the next procedure, this is the substitution effect for court trial. Identification of activity in reality often can not directly settle disputes, in most cases, according to the expert opinion of reconciliation and mediation before litigation, both parties can come to compromise by themselves instead of by the trial.

Secondly, pre litigation identification has selectivity, the parties have the right to choose the way of dispute settlement. The parties involved in the identification have access to the selections: mainly including whether for identification, accreditation bodies to apply for, whether to apply for withdrawal and re identification problems. Objectively they also may have the choice of evidence materials they have occupied. It is common for the court to provide a list of authentication institution that may solve the problem by applying a special identification, and then it is one party that makes a choice of appraisal institution. If the other party does not agree, it can be determined by negotiation or options of drawing by lot. Appraisal law expert and scholars also confirmed this point, agreeing on selection right of the appraisal body prior to the judging. In selecting the authentication institutions and

identification of human and nature to solve the issue, the direct interest cut between the identification appraiser and identification results should be imposed, ensuring the objectivity. Law on the identification of the avoidance system has been implemented for some years, and regulations are also around the identification in abnormal contact with appraisal agencies and personnel and the specification. It is a problem particularly prominent in medical accident identification activities, or medical dispute. How to avoid the identification of favoritism in the identification activities must be considered, not only for the interests of the parties, but also for the objectivity of the identification activities.

Finally, as a quasi-judicial method, the pre-litigation identification means certain legal effect. It formed a kind of the alternative dispute resolution methods. If the pre-litigation identification is reviewed by the court, it will have the force of law. On the one hand, the judicial authentication activities should be a method of judicial or quasi judicial. As mentioned before, a pre-litigation identification activities is still a kind of the judicial authentication activities. Thus, it must be a kind of the quasi judicial methods. On the other hand, prelitigation identification activities are carried out by both parties entrust or both sides commissioned. The expert opinion formed as a consultation between the two sides to approve or provide the pre-litigation mediation fact basis, so it has certain legal effect in both the formal and the substantive aspects.

In fact, the majority of the court of our consensus recognizes the identification conclusion as evidence in the lawsuit practice. The identification qualification and the testimony confirms the probative force. Also, identification have the force of law without that circumstances.

# 2 ADR mode and the value of pretrial identification activities

# 2.1 Value of the identification activities

When the reform wave sweeps the old judicial expert system, the cause of our judicial expertise is led to a new era. The direction of the reform bring about the thinking of the value of judicial evidence, which is of great significance to the clear identification of the nature of justice and promotion of the improvement of judicial system and the proceedings, and to solution to the difficulties it faces. Judicial activities are an activity of litigation. Its scientific nature makes it different from the general litigation activity; therefore judicial expert evidence has dual attributes, which is scientific and legal.

Judicial fairness is of primary value in judicial expert activities, which aim to symbolize and pursue justice and fairness. Scientific attribute of the judicial decision of the judicial expert activities makes the value of justice connotation different from ordinary litigation activities, and it should also include scientific concept of justice. Scientific justice, procedural justice and entities justice are three levels of the value of judicial justice. They are mutually conflicted and balanced. Fairness in the judiciary means that the different entities who take part in judicial expert activities have equal right to choose in different levels. The judges, the parties and expert have certain mutual restraints on each other in terms of the rights of choice.

Judicial efficiency is the inevitable contents in the judicial value, which is to minimize the cost in time, economy and ethical activities is another pursuit of judicial expert service. Characteristics and experience of two Schools of different national judicial system tell us that the fairness and efficiency of judicial expert activity are sometimes conflicting. How to ensure the fairness and efficiency of judiciary expert activity is the objective of judiciary activities. The most obvious problems are multi-headed and repeated expert evidence as well as extension of the time limit for lawsuits affecting the efficient identification of the outstanding problems. It should be solved through legislation to regulate the system.

At present, China is undergoing the judicial system reform. The drawbacks of judicial expert system are of the main reasons for the disorder. To solve the real problems fundamentally in the reform of the judicial expert system and management system, it is necessary to construct a new order system in purpose of fairness and efficiency, to protect the neutrality, independence, objectiveness, and science of judicial expert evidence. Scientific value is just the manifestation of reasonable allocation of resources and establishment of nonprofit are the requirement of efficiency of the judicial expert activity.

# 2.2 ADR model of identification of activities

The common feature of pretrial litigation, outer litigation and by- themselves identification is that the parties or their attorneys are commissioned side of the identification, and the purpose of identification is to specialize the judgment on a case or dispute, coming to an authorized result, which serves a party to claim their rights. When the party can claim his own substantive or procedural right without the action of proceedings, it would accord with ADR features. Usually there are three modes of pre-trail identification. There are several kinds of subjects in judicial expert activities. Fairness in

the judiciary means that the different entities who take part in judicial expert activities have equal right to choose in different levels. The judges, the parties and expert have certain mutual restraints on each other in terms of the rights of choice.

One is the service mode of reconciliation. In practice, there are oral or written agreement of both parties by the themselves, which takes the expert opinion as the basis of dispute settlement, and they carry related identification materials to appraisal institutions for identification jointly or under the witness of unilateral entrusted appraisal. Ultimately on basis of the authentication opinions the doubts are dispelled, the debtor pay off all the debt and they go no further into the judicial procedure. In the appraisal institution the author works, there are also practice cases of reconciliations according to the identification result by the two sides under the supervision of the law firms, the news media and the neighborhood offices and other institutions. This also belongs to the pre-litigation identification service ADR model, which can solve the settlement more quickly and save the labor power of the court.

The second one is mediation model outside the proceedings. Litigation mediation refers to the mediation activity hosted by people's mediation commission, under the supervise of the national laws and regulations, and social morality standard, to persuade and prompt them who have civil disputes for mediation, to forgive each other, aiming for the equal consultation, reaching an agreement voluntarily, eliminating disputes. "People's Mediation Law" of the people's Republic of China stipulates the twentieth " they can invite the personnel or staff with specialized knowledge, specific experience or relevant social organizations to participate in the

mediation", which standardizes and safeguards the approach of promoting people's mediation through the cowork of authentication institutions, the person with special knowledge, which also symbolizes the positive effects of the pre-trial litigation in the ADR model the identification. The exercise of the mediation outside the proceedings makes many ordinary civil disputes solved more quickly, without waiting for the proceedings. At the same time, it also puts new requirement for the related agencies, such as the method for the mediation, or whether it will make later disputes among them The third one is the prelitigation mediation mode service. It refers to the lawsuit mediation before proceedings by the court judges or the jury or the mediator or them coordinately. Supreme People's Court promulgated the "several problems about civil mediation work of the people's Court of", of which the third term says People's court may invite the specialized knowledge to assist the mediation work. The court mediation should be followed in accordance with the facts, distinguishing right from wrong principle. The facts concluded by court in civil cases mediation may become the proof to the parties involved in the mediation and may go into the judicial authentication procedure, which constitutes the pretrial judicial mediation ADR mode service. Always, those facts are more convincing in the procedures.

## 2.3 Active ADR value

2.3.1 Conducive to the realization of justice in resolving the dispute

Justice connotation is different from ordinary litigation activities, instead it should include science and concept of justice. Scientific justice, procedural justice and entity justice are three levels of the value of justice, which have mutual relationship between the conflict and the balance. How to handle the three relations is conducive to the identification of judicial reform objectives and direction.

Through the pre-litigation mediation or settlement of the cases, a compromise is achieved, saving the proceedings. It can better embody the justice of procedure and substance. Mediation is more in line with the "essence of justice", emphasizing active participation of the parties in the mediation, through voluntary negotiation of the parties rather than judge adjudicates according to law to settle the dispute. Litigation process is very clear, easy to understand and accept to the parties. the pre-trial expert opinions issued by institutions can also reduce lawsuit conflicts, because only the parties themselves are clearly aware of dispute truth, they can choose the most suitable measures to solve the disputes beneficiary to their own interests. Therefore, the processing results of their voluntary choice should be said to be not only in accordance with their best interests demand, but also the closest to the pursuit of substantive justice.

The priority of pre-litigation Identification is to the pursue the justice, which is the inherent requirement of judicial authentication activities, which not only reflects that the judicial identification activities in essence, is the pursuit of objective justice and procedure, also that it is the scientific requirements of the identification research. Identification of judicial activity is both scientific and legal action, whose concept also can be divided into the two levels: the science and the law. The identification justice pursue should include scientific justice, procedural justice and substantive justice. The core of procedure justice in judicial expertise is service judge, or justice to the judge, which is in fact the service on the substantive justice. In this goal under the guidance of the implementation, the specific legislation of system identification

should be made clear in direction, namely justice. Therefore, pretrial identification takes the objectivity and impartiality as the standard, helping solve legal dispute reasonably as the goal, pursuing substantive justice as the result. The premise of the pursuit for substantive justice is perfect procedural justice, according with the requirement of procedure justice. Identification shall be subject to the general principles and values of judicial authentication. As we know, the pursuit of justice includes three aspects: scientific, procedural and substantive justice, which correspond to the facts: the scientific facts, legal facts and the objective facts. There are conflicts in value among them, the solution of which is find a balance among the three, to maintain the scientific and procedural justice value, at the same time to seek truth and justice to resolve disputes, reduce and weaken the confrontation between the parties, to achieve reasonable and lawful reconciliation and mediation, conducive to social harmony and stability. In a word, the justice is always in the first place in the proceeding or before the proceedings.

2.3.2 Saving the lawsuit resources

Depending on the right of the disposition and the mediation, diversified dispute resolution pattern has more important significance, which is called the more radical new adversary system. the prelitigation identification emphasizes the importance of friendly negotiation and compromise between the parties and promotes mutual understanding and friendly cooperation, although sometimes it is not easy.

The contradiction between limited resource and some countries and regions "litigation explosion" is one of the origins of ADR research. Reasonable distribution of litigation resources requires that the cases can be bypassed into the proceedings. The pre-trial identification can provide the scientific proof for the settlement. When pretrial judicial authentication activities pursue judicial justice and efficiency, it obtains effective justice, which is the target of the activities, and also is the direction of the reform of the system.

For example, "the Huangjing death case" in 2003 was identified many times until 2006. The result and the process arouses a lot of doubts among the public, including whether there is a need to identify for many times, whether the identification result provided are convincing when there are other controversial issues.

# 3 Negative facets of the ADR model

The identification efficiency is helpful to realize the justice of identification. The value of efficiency is symbolized in that pretrial judicial expertise can resolve disputes not only for the identification of justice, but also save national judicial resources. Only in a certain period of time effective identification activities is finished, can rights and interests of the parties be safeguarded legitimately. If it lasts a long time, it will consume a lot of social resources. In order to make more scientific and effective identification, technological means are increasingly adopted in the judicial authentication. To pursue the efficiency and the justice are two essentiality of the identification activity. To establish a balance between the two in the system, on priority of the justice, there should be efficiency in identification activities. If the identification activity is exercised on the just and justice, it is also more in line with the principle of efficiency, which is the inevitable direction of scientific, rational development of identification activities. Identification and pre-litigation mediation before proceedings are more in line with the requirements of effective action,



and have the characteristics of being simple, efficient, economic, and can reduce the burdens of parties, but also can save the judicial resources.

# 3.1 Defects and disputes settlement mechanism of pretrial identification activities

The defects and problems of prelitigation identification activities the reliability of expert opinion. Some scholars believe that in the pre-litigation identification and self identification activities, the experts of the identification sometimes make the partial appraisal conclusion. for economic benefits to the client's request. Although this view is not the statistical verification, but at least it is represented by some parties' concerns and doubts about the pretrial expert opinion reliability. The reason usually includes two aspects: first, one party, for personal interests, intentionally provide incomplete

identification materials. On the other, the identification is practiced under the influence of the clients' requirement, giving a subjective result maybe. The parties in order to protect their own rights, put forward the requirements of identification, and its sidedness exists. Factors affecting the expert opinions exist in many aspects, including two aspects: the objectivity of the materials submitted and the relationship of the appraiser and the clients. When there are some relationships between them, it is normal and lawful for the appraiser to avoid the identification and also the detailed regulations should be made and clarified in this aspect so as to make sure every identification results are objective and effective. What is true in many countries is that it still lacks the supervision to this invisible process. Maybe sometimes, supervision of related agencies is

necessary in this process.

# 3.2 The existence of risk of duplicate identification

From the objective point of view, in the judicial practice, the parties often commission the authoritative agency for the prelitigation identification as the proof for the personal interest. However, not all the identification results can be the evidence. In reality, it may not be accepted and recognized by both parties, even by some expert due to various reasons. Even sometimes, it may aggravate the dispute between parties. So not all the pre-litigation identification can go to the way of ADR. On the contrary, a part of the dispute into the procedure involves special problems caused repeated expertise identification, which is not only a waste of litigation and identification resources, but also makes the identification for two

times. It arouses us to think about about questions such as whether the duplicate identification should be avoided, or applicable supplementary identification or repetitive identification procedures should be made. When people talk about these problems, they would remind immediately that who can decide this process, that is whether to identify again or not. The regulation about this has still the space for discussion. In the future, the more precise and exact rules should be made towards this so that there will be little or no waste of the human power for the process and identification.

The multi-headed and the repeated Expert evidence result to lawsuit resources waste, affecting lawsuit efficiency. At the same time, it brings the waning of the authority of the expert evidence and the disorder of its operation. However, in certain case, repeated expert evidence also has its existence significance and value. The attitude we must take is to limit the operating conditions leading to repeated expert evidence. Based on the discussion of the advantages and disadvantages, this article proposes some operating conditions and the improving methods. With the increasing reform of Expert Evidence system in our country, this paper provides the practical and the theoretical support for this solution to this problem.

# 3.3 No binding of effect of the pre-litigation

Based on the identification before litigation, parties reach a verbal or written agreement. Some are achieved under the guidance and witness of the law firms, government agencies or relatives. To resolve disputes through settlement way based on expert opinion is one of values of the identification of ADR. But in such mediations, there are no constraints and no law to refer to. If the parties do not recognized the authentication opinions, they still can turn to proceedings. At the same time, the special problems on the identification of the entrusted matters. It somehow complex in practice. Sometimes one of the parties has false confession, fluky psychology, and intentionally delays time for identification, so a part of such cases is doomed to be unable to solve the case successfully or quickly. In many areas, there are a lot of the cases waiting to be solved and judged for those reasons. It may make us consider how this can be resolved. It always depends on the voluntary cooperation of the parties. It there are some stipulations on this, it can be more effective. Of course people's awareness should be improved.

#### 3.4 Touchstone of false evidence

Today, many have dropped the social good faith and false action is not to be ignored in the current civil procedure. False litigation can obtain illegal interests or the illegal purpose, which is one of the causes of false litigation and false evidence. On the pre-litigation identification, behavior can bring great benefits by forging false evidence with only a little cost, such as the economic contract, IOU(receipt for a loan), wills. and this kind of evidence may be identified as the genuine by the identification expert before litigation. Behavior entrust identification by pre-litigation identification way. If it is lucky enough for them to get the desired demand of expert opinion, they may enter the proceedings for malicious litigation. Even not through identification, such people usually will not be punished. Without relevant regulations, identification in a way could become a hotbed of false evidence touchstone and malicious litigation. Therefore, what should be done is worthy of out thinking. Perhaps, the public education of law and rules of the identification can make people know more about the roles of identification it should

play. The improvement of people's awareness of the law is constructive to the implementation of the identification in daily reconciliation work and in judging process. Moreover, when people always have the evil access to the process, the society will go in chaos. So more should be done in this aspect.

# 3.5 Causing problems of material damage in identification

When people know that the identification results can lead the lost of their interests. There is a risk that they may try to change or damage the identification materials. In prelitigation identification process, the commissioners may utilize the technology to forge or destruct samples, so that the other party can not be identified in litigation. Because the identification before litigation, the principal knows the appraisal conclusion would be to their disadvantage. When entering the proceedings in the other proposed identification, there will be no identification of material or unable to be identified. The identification of material caused by technical reasons cannot make a two identification, which is widespread existence in forensic, trace evidence, document identification etc.. It is difficult for this to be solved because the proof should be provided by them, while without the genuine proof, the identification can not be carried out and with false proof, the result should not be adopted. It is a paradox. At present, what the institution tries to do is to distinguish the genuine ones and tries to distill as more evidence as possible.

# 4 The dispute settlement mechanism of identification before litigation

4.1. Pre-litigation identification startup conditions

The Supreme People's court

"several regulations about the civil action evidence" the twentyeighth stipulation: "to the appraisal conclusion by one party entrusting the relevant departments to make, the other party has evidence to refute and apply for re-identification, the people's court shall permit." Our current law does not prohibit parties to hire appraisal main body, and only rules in what circumstances it shall appoint or employ identification subject, and stipulates that all the identification for proceeding services in the areas of litigation are judicial identification. So do not prohibit parties in the prosecution for pretrial identification. But, that does not mean that the identification cannot set the start condition before litigation. From the procedure, the pretrial identification as the principal body shall review the qualification and ability of responsibility, from the substantive review perspective, prelitigation identification should also set different scope and standards according to the identification requirements. For example, in order to prevent the client from the copy forgery, handwriting identification may request that the handed samples must be original ones. No matter which party initiated the appraisal process, whether it is the way of identification, and the appraisal conclusion is impartiality, objectivity and admissibility, it has no inevitable link among them. Therefore, we can see that the before the proceedings, not only the appraisal agencies, but also the law department, should set up the startup mechanism, ensuring the just and objective start of the proceeding process.

# 4.2 Improving the withdrawal system

The NPC Standing Committee "on judicial expertise management decision" provisions "stipules that appraiser should avoid in accordance with the legal provisions. If there are following circumstances, they should choose to avoid. (1) authenticator is a party to the case, or a close relative of the party; (2) identification of the close relatives have an interest in the case; (3) the identification of people served as the case of the witnesses, the defender, agent. (4) the other may affect the accurate identification. The appraiser involved in pre-litigation identification into the proceedings may belong to the circumstance that "possibly influence the accurate identification of situations" and apply for the avoidance system. But at present, there is no exact regulation about the relationship between the appraiser and the clients. Of course, accordingly, there is no provision about the avoidance system. When to avoid and how to avoid are quite obscured. For example, there are cases that the appraiser, judge and the client are all relatives. It is easy for them to make a connection of the false judgment, for there are no exact rules and punishment for such behavior. It will be waiting for more sophisticated improvement.

# 4.3. The investigation system establishment of pretrial identification

Different from the legal liability of false evidence, it lacks supervision and accountability for those producing and providing false evidence before the lawsuit. On the other hand, the parties choose to destroy evidence when aware of the disadvantageous proof, which is a difficult situation to the identification before litigation. It is not illegal and incapable of being solved at present. If we do not regulate, prelitigation identification will be a double-edged sword. On one hand, it contributes to the implementation of alternative dispute resolution, on the other hand it has become false litigation and twist. At present, it is not through the judicial authentication institutions to conjure up methods

to solve this problem, but through the system of report, demanding the foundation of identification mechanism in the pre-litigation by the government and law department. In Identification process, if the false evidence is found, identification evidence shall be submitted to the judicial administration organs for the record. When required by the judicial administrative organs to the court for the evidence preservation, responsibility of the parties should be called to account. What is present today is that many false and forged materials are discarded by the identification institutions, no further steps are taken because there are no rules for this behaviors and no department can exercise law tools to curb this phenomenon.

# 4.4 strengthening pre-litigation identification industry regulation

An important factor to improve the pretrial judicial identification dispute resolution ability is to improve the reliability and credibility of prelitigation identification. To avoid the partial judgment against the science and facts due to the close relationship between identification institution or the appraiser and the clients for the personal interests. Judicial and administrative industry should adopt the means of self-government in combination. Trust management mechanism should be built up through self-regulation to establish the identification trust, which is to a certain extent constraint on the appraiser in "human favor" "material identification", such as Nanjing forensic association, making each appraiser a credit file, and hook with the identification qualification, urging people to rigorously obey appraisal credit style for the service in dispute resolution. When the mechanism is improved and strengthened, the more objective and effective results can be achieved.

4.5 Regulating rights to choose

#### of judicial identification subjects

There are many kinds of participants in the identification. The fairness of identification for different subjects involved in judicial authentication activities means equal rights to choose in different degrees, and the choosing rights of judges, the parties and the identifiers are restrained by each other. The choosing rights of these different subjects include: choose to apply for judicial authentication, select a judicial authentication institution, adopt the identification results or not, choose what scientific method, demand judicial authenticators to appear in court to be cross-examined and selection of part-time job, and so on. Various subjects involved in the identification work mainly include the party, the judicial authority, the identifier and the identification institution.

They respectively have different freedom choice in identification process, which can be reflected in the start-up phase of identification. Also there exist various choices in the process of scientific operation and process of conclusion formation in the identification, even in crossexamining, adopting, applying and excluding the identification results, there are still the free rights to choose. Another important embodiment of rights of litigant in the identification of activities is the free choice of identification institution, but the options in this area should be limited.

The rights of judicial personnel in the identification activities include the right for choosing institutions, and approve of the expert opinions or not. The judge is in fact the referee during the litigation and identification, so he has absolute rights and determining force in the selection and identification of opinions. The judicial identifiers have the rights to choose the methods for identification, because identifiers, as technical experts, master specialized knowledge, and have their own experience and skills in the use of the technique to solve the identification problem. At the same time, for the similar authentication case commissioned, there may be several ways to test different possible results, which may require the choice, that is, in the inspection process, appraisal may be faced with a variety of ways and has to select one or several from to solve special problems. Some experts, due to various reasons, have part-time jobs in other institutions. There is already related part-time law that has given a clear definition. A judge may not work as the expert or engaged in the identification activities in two or more than two appraisal institutions at the same time. China's "general principles of judicial identification procedures" have clearly defined it clearly. This provision is conducive to standardizing the market order of identification, clarifying duties of the identification institutions and identification staff, and ensuring the vocational responsibilities of identification personnel.

# **5** Conclusion

Pre-litigation identification is alternative, selective and accurate with the characteristics and mechanism of the ADR. In judicial practice, pre-litigation identification promotes reconciliation, people's mediation and pretrial mediation to realize the alternative dispute resolution, and contribute to the just settlement of the dispute, and to save litigation resources. The construction of judicial identification law is an important goal of the construction of appraisal system, also is the important link of the course of law in our country. The judicial appraisal system in our country should be in our country the old judicial identification characteristics and cultural basis,

combined with the modern concept of the rule of law, taking the justice and efficiency value goal, establish a scientific and perfect the judicial identification system. China's legislation of judicial expertise should be combined with China's relevant legal system modification chance, in the gradual perfection of the existing law on the basis of building a unified, complete judicial identification of department law.

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# fficacy of Test of Memory Malingering Trial 1, Trial 2, the Retention Trial, and the Albany **Consistency Index in a Criterion Group Forensic Neuropsychological Sample**

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Abstract The Test of Memory Malingering is one of the most popular and heavily researched validity tests available for use in neuropsychological evaluations. Recent research has suggested, however, that the original indices and cutoffs may require modifications to increase sensitivity rates. Some of these modifications lack cross-validation and no study has examined all indices in a single sample. This study compares Trial 1, Trial 2, the Retention Trial, and the newly created Albany Consistency Index in a criterion group forensic neuropsychological sample. Findings lend support for the newly created indices and cutoff scores. Implications and cautionary statements are provided and discussed.

Keywords: Test of Memory Malingering, TOMM, Albany consistency index, Forensic neuropsychology, Validity.

# Introduction

According to a survey of neuropsychologists' beliefs and practices, the Test of Memory Malingering (TOMM; Tombaugh, 1996) is the most frequently used performance validity test (PVT; Sharland & Gfeller, 2007). This is not surprising given that the measure is heavily researched and multiple studies have found patients' scores to be unaffected by age, education, pain, psychiatric conditions, and all but the most severe neurocognitive conditions (Ashendorf, Constantinou, & McCaffrey, 2004; Gunner, Miele, Lynch, & McCaffrey, 2012; Iverson, Le Page, Koehler, Shojania, & Badii, 2007; Tombaugh, 1996, 1997, 2003). Despite clinicians' favorable attitudes toward the measure and the abundance of research supporting its use, it has recently been suggested that the TOMM cutoffs and indices

may require modifications to maximize sensitivity rates (Greve, Binder, & Binachini, 2009; Greve, Ord, Curtis, Bianchini, & Brennan, 2008; Gunner et al., 2012).

To increase sensitivity, some authors have altered the TOMM Trial 2 and Retention Trial cutoff scores. When maintaining specificity at 90%—the desired minimum level of specificity for validity testing (Boone, 2007)-it was determined that a cutoff of  $\leq 48$  for both Trial 2 and the retention trial could be applied to some clinical samples (Greve, Bianchini, & Doane, 2006). Specifically, when this new cutoff was used in place of the traditional TOMM cutoff in a mild traumatic brain injury (TBI) sample grouped by Malingered Neurocognitive Dysfunction (MND) criteria (Slick, Sherman, & Iverson, 1999), sensitivity rates increased from 40% to 70% on Trial 2 and from 57% to 60% on the Retention

Trial (Greve, Bianchini, & Doane, 2006). Additionally, when the new cutoff replaced the traditional cutoff in a toxic exposure sample grouped by MND criteria (Greve, Bianchini, Black, et al., 2006), sensitivity rates increased from 55% to 61% on Trial 2 and from 52% to 68% on the Retention Trial, with specificity remaining above 90% on both trials.

Although the  $\leq$ 48 cutoff showed promise in the mild TBI and toxic exposure samples, specificity suffered when the cutoff was applied to a moderate-to-severe TBI sample differentiated by MND criteria (Greve, Bianchini, & Doane, 2006). In the credibly performing moderateto-severe TBI sample, a cutoff of  $\leq 46$ was required to maintain adequate specificity rates on Trial 2 and the Retention Trial (91% specificity was observed on both trials). When this cutoff was compared with the traditional TOMM cutoffs in the noncredible moderate-to-severe TBI sample, sensitivity increased from 46% to 55% on Trial 2 and from 46% to 64% on the Retention Trial.

In addition to modifying the traditional TOMM cutoff scores, some authors have attempted to increase sensitivity by utilizing Trial 1 as a validity measure. Using MND criteria to derive groups, Greve, Bianchini, and Doane (2006) found that a Trial 1 cutoff score of  $\leq 43$ resulted in a sensitivity rate of 73% and a specificity rate of 91% in a mild TBI sample. The authors indicated, however, that this Trial 1 cutoff score would not be appropriate for their moderate-to-severe TBI sample if 90% specificity was desired. For the moderate-to-severe TBI sample, a cutoff score of  $\leq$ 38 produced the best sensitivity (46%) while maintaining adequate specificity (91%). Overall, the authors concluded that Trial 1 can be an accurate indicator of negative response bias.

Others have found similarly promising results when utilizing Trial 1 in mixed clinical samples. For example, O'Bryant, Engel, Kleiner, Vasterling, and Black (2007) evaluated Trial 1 cutoffs in a mixed neuropsychological outpatient sample divided by definite MND and non-MND criteria. Using a cutoff of  $\leq 40$ , the authors found sensitivity and specificity rates of 79% and 90%, respectively. These rates are strikingly similar to rates reported in a study that reviewed and combined multiple TOMMTrial 1 findings (Denning, 2012). When 18 independent studies utilizing diverse clinical and forensic groups were pooled using weighted averages, an average cutoff of ≤40 yielded mean sensitivity and specificity rates of 77% and 92%, respectively.

Finally, in the most recent attempt to increase sensitivity rates, Gunner and colleagues (2012) developed a consistency index for the TOMM, called the Albany Consistency Index (ACI). For a complete description of the computation of the ACI, the reader is referred to the original article. In brief, the index consists of summing the number of items that are inconsistently responded to across Trial 1, Trial 2, and the Retention Trial. For example, an item that is correctly answered on two TOMM trials (e.g., Trial 1 and Trial 2) but incorrectly answered on a third trial (e.g., the Retention Trial) is classified as an inconsistent item response. When comparing groups of patients classified as providing optimal or suboptimal effort, derived from Word Memory Test (WMT; Green, 2003) performances, the traditional TOMM Trial 2 cutoff score resulted in sensitivity and specificity rates of 33% and 96%, respectively. The ACI, however, yielded sensitivity and specificity rates of 71% and 100%, respectively, when using a cutoff of  $\geq 10$  inconsistent responses.

As can be seen, studies have shown that both adjustments of traditional TOMM cutoff scores and the addition of new indices may increase the measure's sensitivity to neurocognitive malingering. However, this body of literature is relatively small and it is lacking in studies that examine all TOMM indices in a single forensic sample. The purpose of the present study was to examine the utility of TOMM Trial 1, Trial 2, the Retention Trial, and the ACI in an outpatient forensic neuropsychological sample grouped by MND criteria.

## Method

## **Participants**

This is an archival study of 69 consecutive forensic cases (i.e., compensation seeking, litigation, or disability), some of which were utilized in a previous study (Schroeder, Baade, et al., 2012). All

patients were referred to a university medical center neuropsychology clinic, directed by a board-certified neuropsychologist, for forensic evaluations. The majority of patients presented with complaints related to TBIs. Specifically, 34 patients had histories consistent with mild TBIs, as defined by the American Congress of Rehabilitation Medicine's Mild Traumatic Brain Injury Committee (Committee on Mild Traumatic Brain Injury, 1993). Of these patients, 26 had uncomplicated mild TBIs (i.e., lack of acute intracranial pathology on neuroimaging), whereas 8 had complicated mild TBIs (i.e., positive findings of acute intracranial pathology of neuroimaging). In addition to patients with mild TBIs, patients with moderate-to-severe TBIs were included in this study (n =7). The remaining patient diagnoses were major depressive disorder (n = 5), frontotemporal dementia (n = 5), cerebrovascular accident (n = 3), hypoxic brain injury (n = 3), posttraumatic stress disorder (n = 3), mild cognitive impairment (n =2), psychotic disorder (not actively psychotic at the time of testing; n = 2), mental retardation (n = 2), Huntington's disease (n = 1), nonepileptic seizures (n = 1), and chronic pain (n = 1). Because patients with mental retardation and dementia have neurocognitive impairments that can potentially result in false-positive errors on some validity measures, patients with these diagnoses were excluded from the final analyses. As a result, the final study sample was comprised of 62 patients.

All of the 62 patients included for final analyses were differentiated by MND criteria, as described in the "Procedures" section. Overall, 36 patients (58%) did not meet criteria for any degree of MND, 24 patients (39%) were categorized as meeting criteria for probable MND, and two patients (3%) were categorized as meeting criteria for definite MND. Thus, 42% of the forensic cases, which are primarily TBI-related, met criteria for neurocognitive malingering: a rate that is similar to base rates reported in the literature (e.g., Larrabee, 2003; Mittenberg, Patton, Canyock, & Condit, 2002). Table 1 shows demographic information for the groups "passing" and "failing" MND criteria.

# Procedures

All patients included in this study underwent comprehensive forensic neuropsychological evaluations consisting of record reviews, a clinical diagnostic interview, neurocognitive testing, psychological/personality testing, and validity testing. Although there were slight variations in the tests administered across the neuropsychological batteries, as dictated by clinical need, each patient received a similar core set of tests. All tests were administered according to standardized instructions by neuropsychology post-doctoral fellows, neuropsychology predoctoral interns, or trained neuropsychology technicians working under the supervision of a boardcertified neuropsychologist.

As outlined in the MND criteria (Slick et al., 1999), patients were differentiated into appropriate criterion groups using both behavioral criteria of negative response bias and the results of validity testing. There were three behavioral criteria of negative response bias utilized in this study. The first criterion was a pattern or severity of neuropsychological dysfunction not consistent with the neuropsychological condition. The second criterion was having markedly inconsistent performances across neuropsychological testing. The third criterion was having implausible self-reported symptoms on clinical interview. All of these behavioral criteria of negative response bias contributed to MND classification, however, for this study, at least one validity measure also had to be failed in order to meet MND criteria.

The validity measures and cutoffs used for the classification of MND criteria are detailed in Table 2. It should be noted that not all patients were administered the exact same validity measures. Specifically, the Validity Indicator Profile (Frederick, 1997) was only given to a select number of patients based on clinical necessity. Additionally, clinic policy dictated transition to the newer versions of the Wechsler Adult Intelligence Scale (WAIS) and Wechsler Memory Scale (WMS) upon their releases. Because this study utilizes data from clinical forensic patients, some of the included patients were administered the WAIS-Third Edition (WAIS-III; Wechsler, 1997a), whereas others were administered the WAIS-Fourth Edition (WAISIV; Wechsler, 2008) (Wechsler, 2008). Similarly, some patients were administered the WMS-Third Edition (WMS-III; Wechsler, 1997b) while others were administered the WMS-Fourth Edition (WMS-IV; Wechsler, 2009). Thus, depending on the test edition utilized, the appropriate WAIS and WMS embedded validity measures were employed.

It should also be noted that for this study, the WMT was examined for possible genuine memory impairment profile (GMIP; Green 2003) when one or more of the initial three WMT trials were failed. Although Green (2003) has noted that the initial three WMT trials are insensitive to all but the most extreme forms of cognitive dysfunction, Greve, Ord, Curtis,

Table 1. Demographic information by the classification group

Group	Age	Education	Gender (% male)	Race (% Caucasian)
Pass MND Criteria	40.83 (14.70)	12.89 (2.35)	56	92
Fail MND Criteria	44.08 (11.26)	12.68 (1.93)	65	85

Note: MND Criteria 1/4 Malingered Neuropsychological Dysfunction Criteria.

Table 2. Validity measures and cutoff scores

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Test	Cutoff score	Study
1. WAIS-III Processing Speed Index	St score ≤65	Curtis, Greve, and Bianchini (2009)
2. WAIS-III/WAIS-IV Reliable Digit Span	Reliable Digit Span score ≤6	Schroeder, Twumasi-Ankrah, Baade, and Marshall (2012)
3. Finger Tapping average dominant finger	Men ≤35, Women ≤28	Arnold and colleagues (2005)
4. WMS-III Auditory Immediate Index	St score ≤80	Ord, Greve, and Bianchini (2008)
5. WMS-IV Verbal Paired Associates-II Recognition	Raw score ≤27	Pearson (2009)
6. WMS-IV VR-II Recognition	Raw score ≤3	Pearson (2009)
7. Minnesota Multiphasic Personality Inventory (MMPI)-2 F or MMPI-2 Fp	T-score ≥80	Greve and colleagues (2008)
8. MMPI-2 Symptom Validity Scale	Raw score .27	Greve and colleagues (2008)
9. Word Memory Test	≤82.5%; No GMIP	Green (2003)
10. Validity Indicator Profile	Failure of either subtest	Frederick (1997)

Note: WAIS<sup>1</sup>/4 Wechsler Adult Intelligence Scale; WMS <sup>1</sup>/4 Wechsler Memory Scale; VR <sup>1</sup>/4 Visual Reproduction; GMIP <sup>1</sup>/4 genuine memory impairment profile. Some patients were administered the WAIS-III, whereas others were administered the WAIS-IV. Similarly, some patients were administered the WMS-III, whereas others were administered the WMS-IV. No patient received both versions of the WAIS or WMS. Thus, depending on the test edition utilized, the appropriate WAIS and WMS embedded validity measures were employed.

Bianchini, and Brennan (2008) have indicated that the initial three trials can result in relatively high falsepositive error rates when applied to a TBI sample differentiated by MND criteria. Because the current study sample includes multiple patients with TBIs and it utilizes MND criteria, a more conservative approach of evaluating initial WMT failures in the context of a GMIP was utilized for this study.

Because multiple, diverse validity measures were used in this study, it is not surprising that sensitivity rates vary between many of the measures. Although it is exceedingly important to use validity measures that have high sensitivity rates, those with lower sensitivity rates may still have value when combined with the highly sensitive measures. For example, some patients feign global cognitive deficits, but others feign deficits in specific cognitive domains-typically the domains in which they report having cognitive difficulties (Boone, 2007). Thus, if a validity measure that generally has low sensitivity rates appears to be testing the cognitive domain that is being feigned, it might yield a more accurate outcome than a validity measure that has higher sensitivity rates but appears to be testing a cognitive domain that is not being feigned. An additional value of having multiple diverse validity measures is that a patient's effort/response bias can greatly fluctuate over the course of a neuropsychological evaluation

(Boone, 2009; Heilbronner et al., 2009; Schroeder & Marshall, 2011). A patient might start the evaluation by providing good and credible effort (and passing validity measures) but later lose motivation toward testing (and fail validity measures). Again, although one validity measure might be more sensitive than another, having multiple diverse validity measures could increase the overall true-positive hit rate (Larrabee, 2008). Indeed, this is a primary reason that all of the aforementioned validity measures were included in the current study.

Once patients were classified as passing or failing MND criteria, statistical analyses were performed. Mean scores and ranks for the TOMM indices were computed for groups passing and failing MND criteria. Statistics comparing and contrasting sensitivity, specificity, and overall hit rates for each of the TOMM indices were also calculated. Finally, correlations within TOMM indices and between TOMM scores and visual memory test scores were conducted.

# Results

Table 3 shows mean scores and ranks for each TOMM index by the groups passing and failing MND criteria. As can be seen, the group passing MND criteria produced significantly better scores on all TOMM indices, p < 0.01.

Next, a receiver operating characteristic (ROC) curve was

generated for each index. As can be seen in Fig. 1, all TOMM indices provided good to excellent discriminative ability. The ACI achieved the highest area under the curve value (AUC = 0.926, 95% CI = 0.865 - 0.987), followed by Trial 1 (AUC = 0.900, 95% CI = 0.827-0.972), the Retention Trial (AUC = 0.879, 95% CI = 0.779-0.978),then Trial 2 (AUC = 0.869, 95%CI = 0.765 - 0.972). These results indicate that the ACI has the greatest classification ability when considering the combined effects of sensitivity and specificity for each measure.

Table 4 shows sensitivity and specificity rates for various cutoff scores on TOMM Trial 1, Trial 2, the Retention Trial, and the ACI when the sample is differentiated by MND criteria. Please note that Gunner and colleagues (2012) score the ACI as the number of inconsistent responses obtained (e.g., 10 inconsistent responses). To improve the readability of Table 4, the ACI was scored in the opposite direction (i.e., number of consistent responses attained). Thus, higher scores represent better performances on all four of the TOMM indices. As can be seen by examining the table, when specificity is set at 89% or greater, the ACI yielded the highest sensitivity rate (81%) of any index. When specificity is set at 90% or greater, various Trial 2 and Retention Trial cutoffs yielded the highest sensitivity rates (77%). When specificity is set at 95% or greater, a cutoff score of  $\leq 47$  on the

Table 3. Group perforn	nances on TOMM indices
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Index	Group	Mean score (SD)	Mean rank	Mann–Whitney U	p-value
TOMM Trial 1	Pass MND	47.17 (3.86)	41.89	94.00	< .01
	Fail MND	35.92 (9.47)	17.12		
TOMM Trial 2	Pass MND	49.86 (0.68)	41.08	123.00	< .01
	Fail MND	41.96 (8.88)	18.23		
TOMM Retention	Pass MND	49.69 (0.95)	41.35	113.50	< .01
	Fail MND	39.88 (10.99)	17.87		
ACI	Pass MND	46.89 (4.48)	42.57	69.50	< .01
	Fail MND	30.15 (11.90)	16.17		

Notes: TOMM ¼ Test of Memory Malingering; MND ¼ Malingered Neuropsychological Dysfunction Criteria; ACI ¼ Albany Consistency Index. The TOMM Trial 1, Trial 2, and Retention mean scores are the mean number of items correct. The ACI mean score is the mean number of consistent responses.

Retention Trial yielded the highest sensitivity rate (73%). Thus, although the ACI has the greatest classification ability when considering the average effects of sensitivity and specificity, scores on other TOMMindices may be more accurate than the ACI at specific cutoff points.

Kappa statistics were computed to determine reliability between the MND criteria and TOMM Trial 1, Trial 2, the Retention Trial, and the ACI cutoffs. The cutoff for Trial 1 was set at 40 or fewer correct items (Denning, 2012), the cutoff for the ACI was set at 40 or fewer consistent item responses (Gunner et al., 2012), and the cutoffs for Trial 2 and the Retention Trial were the traditional cutoffs provided in the TOMM manual (Tombaugh, 1996). Results of these analyses indicate that the levels of concordance (Landis & Koch, 1977) between the TOMM Trial 1, Trial 2, and the Retention Trial and our MND groups were moderate with an absolute value of 0.41, 0.41, and 0.45, respectively. The level of concordance with the ACI was substantial at an absolute value of 0.62.

Next, Pearson's product-moment correlational analyses were performed to investigate possible relationships between TOMM scores and scores on true memory tests. As previously noted, some examinees were administered the WMS-III, whereas the remaining consecutively referred forensic examinees were administered the WMS-IV. As a result of this test transition, the use of either battery alone for correlational analysis would



Cutoff	Tria	al 1	Tri	al 2	Rete	ntion	Α	ACI		
Cuton	Sens.	Spec.	Sens.	Spec.	Sens.	Spec.	Sens.	Spec.		
< 20	< 8	100	0	100	8	100	23	100		
20	8	100	0	100	12	100	23	100		
25	12	100	8	100	19	100	35	100		
30	39	100	15	100	23	100	50	100		
35	54	100	27	100	27	100	65	97		
36	54	97	27	100	27	100	65	97		
37	54	97	27	100	27	100	65	92		
38	54	92	31	100	27	100	65	92		
39	54	92	31	100	39	100	73	89		
40	54	89	35	100	39	100	77	89		
41	54	89	35	100	42	100	81	89		
42	65	89	42	100	46	100	81	89		
43	73	86	46	100	46	100	85	81		
44	73	78	46	100	50	100	89	75		
45	85	75	50	97	58	97	89	75		
46	89	72	50	97	58	97	89	72		
47	96	64	62	97	73	97	96	64		
48	100	53	65	97	77	92	100	53		
49	100	42	77	94	81	86	100	42		
50	100	0	100	0	100	0	100	0		

Table 3. Group performances on TOMM indices

Notes: Sens. = Sensitivity; Spec. = Specificity; ACI = Albany Consistency Index. The Trial 1, Trial 2, and Retention Trial scores are the number of correct items. The ACI score is the number of consistent responses.

have resulted in an extremely small sample size. Consequently, the WMS-III and WMS-IV Visual Reproduction 2 (VR 2) and VR 2 scaled scores were coded independently and then combined, which allowed for a larger sample size to offset the aforementioned limitation (this is further described in the "Discussion" section). Results indicated that among the group passing MND criteria, none of the TOMM index scores correlated with either VR 1 or VR 2. However, in the group identified as failing MND criteria, TOMM Retention was found to correlate significantly with VR 1 (r = 0.72, p < 0.01).

Finally, correlational analyses demonstrated significant relationships between each of the four TOMM indices (p , 0.001), with values of 0.84 or higher. The authors had initially intended to use binomial logistic regression for further examination of TOMM indices; however, the strong relationship between these variables and the likelihood of multicollinearity among predictors precluded this analysis.

# Discussion

The TOMM is one of the most popular and heavily researched PVTs available for use in neuropsychological evaluations. Nonetheless, recent research has suggested that modifications of the original indices and cutoff scores could increase sensitivity rates (Greve et al., 2008, 2009). Consequently, new cutoff scores for Trial 2 and the Retention Trial have been suggested, the utilization of Trial 1 as a PVT has been proposed, and a consistency index has been created. Some of these modifications lack cross-validation: however, no study has examined all indices in the same forensic sample. This study was undertaken to examine the efficacy of Trial 1, Trial 2, the Retention Trial, and the ACI in a

sample of forensic neuropsychological patients differentiated by MND criteria.

All indices included in this study significantly differentiated the groups of patients passing and failing MND criteria. The index achieving the greatest average classification ability was the ACI (AUC = 0.926). This was followed by Trial 1 (AUC = 0.900), the Retention Trial (AUC = 0.879), and then Trial 2 (AUC = 0.869). Although Trial 1 yielded the second largest AUC, the authors suggest caution in its clinical application. This is because individuals obtaining low scores on Trial 1 are likely to obtain low scores on all other indices as well (thus, there is a high sensitivity rate), but false-positive errors may occur among those who demonstrate genuinely poor learning with adequate performance on Trial 2 and the Retention Trial. This is demonstrated by the lower specificity of Trial 1, which does not approach the levels of specificity obtained by Trial 2 or the Retention Trial until 11 items are missed, at which point the sensitivity drops to 54% (compared with 77% on Trial 2 and the Retention Trial when at least 90% specificity is maintained).

Kappa statistics were computed in order to determine the agreement between each TOMM index and MND criteria when controlling for chance. This was deemed important as chance identification may result in either false-negative or false-positive errors, and because the other analyses do not take this confound into consideration. Classification of groups determined via TOMM Trial 1, Trial 2, and the Retention Trial all achieved moderate overall agreement with classification of groups via MND criteria, while the ACI achieved substantial agreement. These findings provide support for the use of each TOMM index, especially the ACI, in differentiating individuals providing credible versus noncredible performances.

Finally, correlational analyses of TOMM scores from the group passing MND criteria provided evidence of divergent validity between all of the TOMM indices and true visual memory tests (VR 1 or VR 2). This is a function of the TOMM's exceedingly low ceiling in terms of its measurement of true memory abilities; thus, the lack of a correlation is expected. Conversely, the Retention Trial significantly correlated with visual memory test performances among the group performing noncredibly. This was also expected, as it was thought that patients who suppressed their TOMMscores were likely to suppress their scores on true memory tests as well.

This article contributes to the literature by comparing, contrasting, and providing data on the new TOMM indices and cutoff scores. However, further cross-validation is recommended. Few studies have evaluated TOMM Trial 1 scores when differentiating patients by MND criteria. Across studies that have used MND-based criteria (Denning, 2012; Greve, Bianchini, & Doane, 2006; O'Bryant et al., 2007), when 90% specificity rates were derived, sensitivity rates ranged from 46% to 79% depending on the clinical sample-the current sensitivity rates fall within this range as well (54%). This is a large range, and continued research should assist in determining more precise cutoffs and sensitivity rates for specific clinical groups.

A similar suggestion is offered for findings related to the ACI. Both the present study and the study by Gunner and colleagues (2012) indicated that the ACI is superior to the other TOMM indices in its ability to discriminate between groups of patients providing credible and noncredible performances. These are the only published studies on the ACI, and different criteria for classification of credible performances were employed (i.e., MND criteria vs. WMT scores). Thus, further crossvalidation is recommended for this index as well.

A potential limitation of the current study is that some patients received the WMS-III during their forensic evaluations, whereas others received the WMS-IV. When conducting the correlational analyses, the authors combined VR scaled scores from both WMS batteries. The authors fully realize that many changes were made between the third and fourth versions of the WMS, rendering their simultaneous use methodologically tenuous. However, it is also realized that these two batteries measure the same construct driven by the same theory of memory. In addition, the tests chosen for analyses were VR 1 and VR 2, which retain the same set of stimuli from the WMS-III to the WMS-IV. Although the two versions of this test employ different raw scoring criteria, both sets of scores are linearly transformed to normalized scaled scores, which was the metric used for our analyses. Thus, it was decided to evaluate the scores individually and when combined, as the combination offers greater insight into the convergent and divergent validity of each TOMM index.

Another potential limitation of the study is that failure of two or more validity measures was not necessarily required for classification of probable MND (one validity measure failure and the presence of behavioral negative response bias was considered adequate). It could be argued that requiring failure of two or more validity measures would result in a more conservative criterion group. The authors contend, however, that the use of behavioral criteria combined with a validity measure failure is methodologically similar to requiring two validity measure failures. This has been supported by

research showing that the probability of identifying negative response bias via a combination of behavioral criteria and a single validity measure failure was comparable to the probability of identifying negative response bias via two validity measure failures (Marshall et al., 2010). Nevertheless, the current authors reviewed the data of those patients characterized as meeting probable MND in this study. Of the 24 patients who met criteria for probable MND, the number of validity measure failures ranged from 1 to 7 (mean  $\frac{1}{4}$ 3.54), and all but three patients failed at least two validity measures. Those three patients failed one validity measure (two failed the WMT; one failed the MMPI-2 measures) and met criteria for behavioral negative response bias. Overall, rates of probable MND would have changed only slightly if failure of two or more validity measures were required as the criterion. Given this information and the increase in generalizability to clinical decision-making (Bush et al., 2005) and to other studies that utilize MND criteria, the authors retained the original classification criteria in this study.

Additional limitations of the current study deserve mention. First, the vast majority of our sample was comprised of Caucasian patients (89%). Although this sample is representative of the patients seen in our Kansas-based practice, the extent to which these results will generalize to samples of different racial and cultural backgrounds is unknown. Another potential limitation is that our sample was largely comprised of patients with mild TBIs. Further cross-validation with additional clinical groups is therefore advised. Finally, future research should utilize even larger study samples to allow for increased confidence and power.

## Conclusions

Notwithstanding the noted limitations, this is the first study to evaluate all of the new TOMM indices and cutoffs in a single criterion group neuropsychological sample. Evidence was provided for convergent and divergent validity for all TOMM indices, which increases confidence for the clinical utility of both the new and traditional indices. Although each index well differentiated patients passing and failing MND criteria, the ACI was found to be the superior index. Because research on the new TOMM indices is still limited. however, further cross-validation is recommended.

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# dentification of Dyes on Single Textile Fibres by **HPLC-DAD-MS**

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Abstract An HPLC-DAD-MS method is described to analyse textile dyes in different dye classes (reactive, basic, acid, direct, disperse). The described method is sensitive enough to analyse single fibres with a length of a few mm or less, which makes it suitable for forensic analyses. The current paper describes the information content of the acquired data and as well as the results of a validation study, in which the repeatability, specificity and limit of detection of the method were assessed by repeated measurements of nine different dyes in the mentioned dye classes. The mass accuracy (deviation generally < 2 ppm) and absorbance spectra were found to be highly stable in several easurements over a period of 8 weeks. Deviation in retention times were observed and attributed to small experimental effects and a pre-column blockage. The results show that dye analysis is possible for most fibres with a minimum length of one or a few mm.

Keywords: Forensic science, Dyes, Fibres, HPLC-DAD-MS.

## Introduction

Many textiles tend to shed fibres. Only a mild contact with such a textile suffices to cause transfer of textile material to a receptor. If transferred material ('traces') can be attributed to a certain donor, it may establish a relation between a suspect and a crime scene or a victim. The easy transfer of material thereby makes investigation of transferred fibres a powerful forensic tool.

However, textiles are generally mass produced. A match found between a reference material of known origin and questioned textile traces does not imply that the reference material is the source of the investigated fibre trace: there will most likely be other possible sources that also could have transferred matching fibre traces. The evidential value of a match is the strength of the indication that the reference material is indeed the source of the textile trace. The evidential value is

determined by the extent to which fibres from different sources can be discriminated and is thus directly related to the analytical methods used in their analysis. A very discriminative method will lead to a high evidential value, while the evidential achievable by a less-discriminative method will be poor. Useful reviews of studies on the discrimination of different textile fibres using routine techniques (microscopy, optical spectrometry<sup>[1]</sup>) are provided by Siegel<sup>[2]</sup> and Grieve<sup>[3]</sup>. Newer studies are reviewed by Palmer<sup>[4]</sup>.

The various studies show that the evidential value of a match involving synthetic fibres is generally much higher than the evidential value of a match involving cotton. This is due to the fact that cotton is used in many textiles and, being a natural product, is rather inhomogeneous. The morphology of cotton fibres from different sources cannot generally be distinguished and discrimination by routine techniques is mainly based on

colour.

Obviously, optimisation of the evidential value is very beneficial, especially for cotton fibres. It is expected that the elucidation of the chemical nature of the fibre dyes that induce the textile colour improves the achievable evidential value for different reasons. Firstly, it enables the discrimination of dyes that have an equal or very similar colour, but are chemically different. A similarity of colour of different dyes can occur by chance, but also by subtle tuning of dye chemicals by dye manufacturers to make a specific chromophore suitable for alternative application methods and fibre types or to circumvent patent issues. Secondly, it would be the preferred method for fibres that are dyed unevenly as an uneven dyeing often hinders microscopic and spectrometric colour comparison. A chemical identification would identify the same (mixture of) dyes in various fibres, albeit in different amounts or ratios and

thereby provides a more robust and objective answer to the question whether a specific fibre trace may have originated from a questioned textile.

There are many studies that aim to improve identification of textile dyes. Published studies focus on

- Absorbance microspectrometry (UV/Vis), which provides a rough classification of dyes, but is not specific enough for a detailed chemical identification<sup>[8]</sup>;

- Raman spectrometry, which has been introduced in several laboratories in the past decade. Raman spectrometry has been used to study the chemical nature of dye molecules<sup>[9–11]</sup>. It has several advantages, such as a general high sensitivity and chemical specificity for dye molecules and an easy, quick and non-destructive analysis procedure. However, Raman spectrometric analyses are often hindered by fluorescence and may be limited in the discrimination of a mixture of dyes;

- Direct mass spectrometry, as proposed by Tuinman et al.<sup>[12]</sup>

- Chromatographic techniques. Thin layer chromatography (TLC), as used routinely in a number of forensic fibre laboratories, enables separation of dyes, but only yields limited chemical identification. HPLC<sup>[5,13]</sup>, CE<sup>[14–17]</sup>, and UPLC<sup>[18]</sup> have been proposed for their higher resolution and sensitivity. Moreover, these techniques can be connected to a mass spectrometer<sup>[19,20]</sup> to provide a high chemical specificity.

Nevertheless, none of the proposed techniques has proven powerful enough to routinely identify fibre dyes. In our opinion, this is due to two main challenges:

The first main challenge is the small sample size: often, only one or a few fibre traces are available for analysis. To be relevant for forensic analyses, it should be possible to analyse samples as small as 5 mm<sup>[5]</sup> or 10 mm<sup>[6]</sup>. Such small samples contain

between 2 and 200 ng of dye<sup>[5,7]</sup>. In addition, dyes are often present as a mixture.

A second challenge is the wide chemical variety between different classes of dyes. This is especially challenging for chromatographic approaches, where dyes need to be isolated from the fibre material before analysis. Isolation procedures are complex and may vary for different classes of dyes. In his standard text on TLC, Wiggins mentions 15 different solvent mixtures that are needed for the classification and separation of different dye types<sup>[21]</sup>. The analyst has to follow a classification scheme to decide which method is most likely to lead to a good separation. Later studies, summarised by Griffin and Speers<sup>[13]</sup>, mostly report on the analysis of dyes from a single class. A more versatile method proposed by Speers et al.<sup>[22]</sup> enabled analysis of dyes in three separate classes (basic, acid, disperse), thereby improving the versatility of the technique. However, dyes for cotton are excluded. This is a serious omission, as cotton is the textile most frequently encountered<sup>[23-24]</sup> and a relatively low evidential value is currently attributed to matching cotton fibres accordingly. The preference for synthetic fibres in previous work is probably based on the easy extraction of dyes from these fibres. Isolation of dyes from cotton, especially reactive dyes, is more laborious.

# **Experimental**

#### Samples and materials

Samples of textiles with nine different dyes as well as the corresponding powder dye references were used. Powder dye references and dyed textiles were kindly provided by Chemische Fabriek Triade BV (Naaldwijk, The Netherlands). The Colour Index (CI) and commercial names of the used dyes are presented in table 1; their formulae are presented in figure 1.

#### Solvents and solutions

During extraction, digestion, and analysis, several materials were used:

Dimethyl sulphoxide (DMSO, z.a.), methanol (reag), formic acid (98-100%), acetonitrile (lichrosolv), ammonium acetate (98%, z.a.), acetic acid (glacial 100%) and sodium hydroxide (Emsure) were obtained from Merck (Amsterdam, The Netherlands). Water was purified using Millipore equipment. Methanol (HPLC grade) was obtained from Rathburn (Rathburn Chemicals Ltd, Walkerburn, Scotland). Cellulase (Trichoderma Viride, 1,1 U/mg) was obtained from Brunschwig Chemie.

Acetic acid solution (0,5 M) was obtained by dissolving 1 mL of acetic acid in 32 mL distilled water. Sodium hydroxide (NaOH) solution (3 M) was prepared by dissolving 2 g of NaOH into 16,7 mL distilled water. Cellulase solution was prepared by adding 10 mL of an acetic acid solution in water (pH5) to 0.01 g of cellulase. This solution was allowed to settle at least 4 hours before use.

#### **Extraction and digestion**

Three procedures, namely the formic acid, DMSO, and cellulase digestion procedures, are used to isolate the dye molecules from the fibres. These three methods are detailed below. The choice of the suitable procedure depends on the class of the dye. In the current study, each procedure is used for three of the nine textile samples, as shown in table 1. All analyses reported below are preceded by a separate isolation. In this way, the validation is not limited to the analysis by HPLC-DADMS, but also covers the dye isolation procedures.

In the current study, the selection of the suitable extraction procedure is based on the (known) composition of the reference textiles. Unknown samples need to be analysed by optical and/or infrared microscopy to select the suitable procedure. Acrylic fibres are identified based on their morphology and low birefringence, or on their infrared spectrum. They are mostly dyed using basic dyes and are subjected to the formic acid procedure. Other fibres types (e.g. cotton, regenerated cellulose, polyester, polyamide, wool often contain direct, disperse, or acid dyes and are subjected to the DMSO procedure. If dyes in cotton or regenerated cellulose are not extracted using DMSO, the cellulase digestion procedure is applied as the fibre may contain reactive dyes.

# Formic acid procedure

The formic acid method is used for basic dyes, which are mostly used on acrylic fibres. 10 mm of fibre (unless stated otherwise) is submerged in 20 KL of formic acid in a closed vial and heated to 60 °C until the fibre is discoloured or to a maximum of 20 minutes. The formic acid (without the fibre) is then transferred to a new, open vial and left at 60 °C. After complete evaporation of the formic

# acid, 20 KL of DMSO is added. DMSO procedure

The DMSO procedure can be used to extract direct, disperse and acid dyes, which are used on several types of fibres, including cotton, regenerated cellulose, wool, polyamide, and polyester. 10 mm of fibre (unless stated otherwise) is submerged in 20 KL DMSO and heated to 100 °C until the fibre is discoloured or to a maximum of 2 hours.

*Cellulase digestion procedure* The cellulase digestion procedure

can be used to hydrolyse cellulose polymer, e.g. cotton, so that reactive dyes covalently bound to cotton dissolve and become available for analysis by chromatographic techniques. In our experience, extraction using a 2% NaOH solution, as proposed by Home and Dudley<sup>[26]</sup>, and used later by Xu et al.<sup>[17]</sup> and Dockery et al.<sup>[6]</sup> failed to provide reproducible results. Therefore, we used the procedure proposed by Wiggins<sup>[21]</sup>. The method was altered, as the cellulase proposed by Wiggins could not be obtained commercially.

10 mm of fibre (unless stated otherwise) is submerged in 10 KL NaOH solution and cooled (4 °C for 4 hours). Trapped air bubbles, if present, are removed before cooling by gentle tapping. The NaOH solution is removed after cooling and the fibre rinsed in acetic acid solution and twice in cellulase solution. The fibre is then submerged in 10 KL cellulase solution and mixed in a thermo mixer (Eppendorf Comfort, 50 °C, 550 RPM) for 20 hours. Afterwards, the samples are centrifuged (5000 RPM, 5 minutes) and 10 KL methanol is added.

Reference dye samples 10 mg of a dye reference is dissolved in 10 mL MeOH (1 Kg/ KL) as a stock solution. This solution

Table 1. Dyes used in the current study. Commercial names are provided by Chemische Fabriek Triade, supplier of the used samples. (CI: Colour index name)

Formic a	cid	DMSO		Cellulase			
Commercial Name	C.I. Name	Commercial Name	C.I. Name	Commercial Name	C.I. Name		
Triacryl red GTL	Basic Red 18	Triamin Blue 3RL	Direct Blue 67	Triactive Yellow S3R 150%	Reactive Yellow 145		
Triacryl red GRL	Basic Red 46	Trianyl Light Blue ANB	Acid Blue 78	Triacion Red SE-3B	Reactive Red 120		
Triacryl blue 5G	Basic Blue 3	Triasperse Blue BGL-S	Disperse Blue 73	Triactive Orange 3R	Reactive Orange 16		



Fig. 1 Structures of the dyes used in the current studies. Information extracted from the Colour Index (www.colour-index.com; Society of Dyers and Colourists).

is diluted with MeOH 10 times (100 ng/KL) as working solution. The injection sample is made by adding 1 KL of the working solution to 19 KL DMSO solvent (5 ng/KL).

# **HPLC Instrumentation**

Analyses were carried out on an HPLC system, consisting of an auto sampler (Thermo Scientific Finnigan Surveyor Auto sampler Plus), a pump (Thermo Scientific Finnigan Surveyor MS Pump Plus), a pre-column (AJO-4286 and Guard cartridge holder KJ10-4282), a column (Grom-sil 120 ODS-5 ST 150×2.0 mm i.d., 3  $\mu$ m, Grace Davison Discovery Sciences, Deerfield, USA). The column is kept at 22 °C by a column oven Spark Holland Mistral). The column oven is equipped with both a heating and a cooling system to accurately maintain the set temperature.

The injection volume amounted to 10 KL. The analysis time of the analysis was 67 minutes. During the first 53 minutes of a run, two mobile phases were used as a linear gradient, namely ammonium acetate 10 mM in water/ methanol (95:5) and ammonium acetate 25 mM in acetonitrile/ methanol (50:50). From 53-67 minutes, the acetonitrile containing mobile phase was used.

Eluents were analysed by diode array detection (DAD, Thermo Scientific Finnigan Surveyor PDA Plus Detector, spectral range 200-800 nm) and mass spectrometry (Thermo Scientific LTQ Orbitrap, scan range



Fig. 2 Chromatograms and absorbance spectra of a, b) Extracted Reactive Orange 16; c, d) Reactive Orange 16 powder dye reference; e, f) Disperse Blue 73 and g, h) Basic Red 46. Plots a, c, e, and g present absorbance chromatograms, extracted by monitoring the light absorption at a single wavelength (black curves) and mass chromatograms, extracted by monitoring the response at a single m/z value (grey curves). Also see table 2 for the selected wavelengths and masses. Plots b, d, f, and h present absorbance spectra at selected retention times (RT, indicated in minutes). All curves, except those in plots c and d are acquired from dyes isolated from fibres. All curves are normalised and, where appropriate for clarity, given an offset.

150 - 2000 m/z). The obtained mass accuracy of the Orbitrap system is better than 2 ppm with the use of a lock mass.

Entrance of the eluents into the mass spectrometer was enabled by an ESI source at 4 kV, a discharge current of 20  $\mu$ A, and a capillary temperature of 300 °C. A nitrogen flow was used as sheath gas.

Data were acquired using standard instrument software (Thermo Scientific). The spectral search engine of NIST MS search 2.0 was used to compare the acquired spectra. The NIST software was developed for mass spectra, but achieves excellent results when used with absorbance spectra and has an easy integration with the Thermo Scientific software. The mass spectral databases provided by NIST are not used for this application. Instead, user databases based on known reference samples need to be composed. A match factor calculated by the NIST software is,

according to the manual, based on a normalised dot product. The same manual describes that a match factor of 800 or higher is a 'good match', while a match factor higher than 900 is an 'excellent match'.

#### **Results and Discussion**

During the HPLC analyses, both detectors (DAD, MS) acquire spectra continuously. In this way, ample data are recorded. In the next section, a number of cross-sections of data obtained from Reactive Orange 16 will be shown in detail. Afterwards, summaries will be provided for the other dyes analysed.

#### **Reactive Orange 16**

Chromatograms of extracted Reactive Orange 16 are shown in figures 2a. The black curve in this figure represents the absorbance chromatogram, acquired after hydrolysis of dyed fibres using the cellulase method. It shows

Table 2. Retention times (RT), calculated mass and optimal wavelength of detection (absorbance spectra) of the studied dyes under the proposed condition. Properties are mentioned for extracted and for dissolved powder dye references. A number of dyes lead reproducibly to the presence of a mixture of compounds. These are shown as separated entries in the table.

Dye	Source	Rt (minutes)	λmax (nm)	Calculated mass (m/z)
Direct blue 67	Pure, fibre	30.8	600	395.53282
Acid blue 78	Pure, fibre	41.3	586	486.97808
Disperse blue 73	Pure, fibre	45.6	627	361.08190
		51.0	627	375.09755
Basic red 46	Pure, fibre	35.0	532	321.18222
Basic bue 3	Pure, fibre	38.0	649	324.20704
Basic red 18	Pure, fibre	44.6	478	390.16913
		45.0	478	410.13783
Reactive yellow 145	Pure	15.9	417	458.49050
		18.4	417	409.50681
		19.9	417	467.47256
	Fibre	14.5	417	823.64415
		14.8	417	519.64296
		16.0	417	580.56492
		15.7	417	830.65198
		17.2	417	742.61774
Reactive orange 16	Pure	19.4	494	572.00980
		24.8	494	474.04242
	Fibre	17.6	494	774.14806
		19.7	494	816.15863
Reactive red 120	Pure	22.8	540	444.30740
	Fibre	15.5	540	756.43563
		15.8	540	760.79802
		17.0	540	594.34948
		16.9	540	892.07812
		17.5	540	599.05469
		17.5	540	899.08595
		18.7	540	540.36520
		18.5	540	811.05172

the absorbance of the effluent at a wavelength of 494 nm during the HPLC run. The value of 494 nm was chosen, as the absorption at this wavelength is high while the interference with other compound is limited. The mass chromatogram (signal at m/z 816.15863) acquired of the same effluent (grey curve) in figure 2a is related to the molecular ion. Detection of the molecular ion is possible as electron spray ionisation (ESI) is a relatively 'soft' ionisation method.

Comparison of the grey and black curves shows that the mass chromatogram has a flat baseline and little or no signals other than the band at retention time 19.7 minutes. The absorbance chromatogram (black line) shows a variable baseline. This is attributed to the lower specificity of the absorbance spectra compared to mass spectra. Figure 1b shows the absorbance spectrum at 19.7 minutes. The spectrum shows several broader bands. The band at 494 nm is visible as the highest band in the visible region ( $> \sim 400$  nm). However, the spectrum is non-zero from 200 to around 600 nm. It can be anticipated that other materials leaving the column also cause absorbance at 494 nm, thereby inducing a variable baseline.

Figure 3 shows the mass spectrum at an RT of 19.7 minutes. The main peak in this spectrum, (m/ z 816.15863) is attributed to the structure drawn in figure 3. The inset in figure 3 shows that the relevant peak is narrow due to the high mass resolution of the used mass spectrometer. Consequently, the chance that other species disturb the chromatogram is small. This explains the almost featureless baseline of the mass chromatogram in figure 2a.

Figure 2c shows chromatograms obtained from powder references. The absorbance chromatogram (black curve) shows two main bands, which are attributed to the original dye molecules and the dye molecule









after hydrolysis of the reactive site. The molecular mass of original and hydrolysed dyes is different, and the mass chromatogram (grey curve) consequently shows a single peak.

The retention times (RTs) observed for the powder dye references (figure 2c) and extracted dyes (figure 2a) shown for Reactive Orange 16 differ (also see table 2). This is explained by the properties of reactive dyes and cellulase. On application, reactive dyes form a covalent bond with the cellulose units of cotton. This bond cannot easily be broken. Instead, the pre-processing step with cellulase hydrolyses the bond between different cellulose units rather than the bond between the dye and the attached cellulose unit. This implies that the recovered dye is still linked to one or more cellulose units and thus differs from the chemical structure of unreacted dye. This alters the RT and the observed molecular mass. The signal at m/z 816.15863 is attributed to the structure drawn in figure 3, which contains the dye molecule connected to two cellulose units.

#### Other dyes

Figure 2 also shows extracts from Disperse Blue 73 (figure 2ef) and Basic Red 46 (figure 2g-h). These figures are prepared in a similar to those in figures 2a-d, though the used wavelengths and m/z values are optimised for the specific dyes. The variables used to extract the different curves from the data sets are presented in figure 2 and in table 2. For disperse, basic, acid and direct dyes, no relevant differences were found between powder dye references and dyes extracted from fibres. Therefore, the results of analyses of powder dye references are not included in figures 2e-h.

The chromatograms of Disperse Blue 73 (figure 2e) shows two bands in the absorbance chromatogram (black line, 45.6 and 51.0 minutes) while the mass chromatogram (grey curve) only shows a single peak (51.0 minutes). This mass chromatogram was extracted at m/z 375.0976. The mass spectrum acquired at an RT of 45.6 minutes shows the presence of a compound with m/z 361.082. These results imply that Disperse Blue 73 consists of two different structures having different masses, but both absorb light at 627 nm. Indeed, figure 1 shows that Disperse Blue 73 contains a mixture of two different structures. One of these contains a methoxy group; the other contains hydroxy group. The structures shown have comparable absorbance spectra, but their masses were found to differ by 14 amu (i.e. the difference between H and CH3, see table 2).

The mass chromatogram of Basic Red 46 (grey curve in figure 2g) contains a double band (35 and 37 minutes). The light absorption of the latter of these bands (black line) is relatively small and seen as a shoulder. This effect is assigned to the presence of two isomers with different properties.

A number of characteristics can be deduced from Figure 2 and table 2:

- The RTs reported for different dyes vary considerably. This facilitates a good separation of different dyes. In our experience (no further data shown), the combination of RT, mass range, and charge state of a dye provides a first indication on the class of the dye;

- The absorbance spectra show large differences between dyes and thus can aid the identification and discrimination of different dyes.

- The obtained mass spectra have a very high accuracy and can thereby assist in the elucidation of the molecular formula of the dye structure under investigation.

#### Validation study

Based on the first results obtained with the HPLC-DAD-MS system, the method was considered a very powerful addition in forensic fibre investigation. To facilitate the introduction into routine case work, we set up a validation study. This validation is divided in two parts. The first part, reported here, focuses on the robustness of the method and the accuracy of the used procedures and instrumentation. The second part will focus on the evidential values that can be obtained and will be based on a much larger set of samples. The second part is currently in progress and planned as a future publication.

The validation of the procedures and instrumentation is based on several analyses on a set of nine dyes. This set, shown in table 1, was chosen to cover all three isolation techniques (formic acid, DMSO, and cellulase). For every measurement in the validation, three different fibres were put together and their dyes isolated simultaneously. The resulting solution thus contains a mixture of dyes. Initial results showed that these could be separated well by HPLC under the chosen conditions. Therefore, the different dyes are analysed independently. This approach was chosen to test the possibility to separate dyes and to reduce the required instrument time.

The current section presents the experiments carried out to validate the repeatability, limit of detection, and specificity of the proposed method. *Reproducibility* 

As stated above, the HPLC-DAD-MS system can yield indications on the identity of a compound by three properties, namely via the retention time RT, the absorbance spectrum and the mass spectrum. The reproducibility of these properties was studied by a series of replicate measurements over a period of 16 weeks. During this period, dyes were isolated from the fibres before every analysis to include the isolation procedure in the reproducibility study. In addition, solutions of pure dyes were analysed over the same period. Figures 4a-c respectively show the main results of the robustness study for the RT, the absorbance spectra and the mass spectrometric results of Reactive Orange 16. The data for other dyes is summarised in table 3.

In figures 4a-c, the x-axis shows the measurement number, corresponding to the 16 analyses that were carried out during 16 weeks. Figure 4a shows the results of the RT. The limits shown in this figure amount to a difference of 2.5% of the average value of the determined RT (19.7 minutes, see table 2). It appears that the RT is within these limits for most measurements. In some cases. RTs outside the set limits were obtained. These deviations have been attributed to the replacement of one of the solvents used in the analyses and to a partial blockage of the HPLC pre-column. Similar deviations have also been observed for other dyes. Later adjustments improved the repeatability, but it is realised that the RT is relatively sensitive for small changes in the analysis and are not fully repeatable.

The rather large deviations found for the RT did not affect the separation of the different dyes analysed in one run, as shown in table 1. Instead, the RTs of all dyes in a single run were all affected in a similar fashion and did not compromise the observed separation or band widths. Results for the other dyes are presented in table 3.

In order to assess the repeatability of the absorbance spectra, we calculated the similarity of the absorbance spectrum and a previously acquired spectrum. The similarity of these spectra, calculated by NIST software, is expressed as the match factor. Based on initial tests, we decided that a match factor of 800, described by NIST as a 'good match' is useful for identification purposes. Match factors found for Reactive Orange analyses over a period of 16 weeks are provided in figure 4b. The robustness of absorbance detection appears high: the match factors presented in figure 4b are generally above 900. Also the match factors of other dyes, provided in table 3, are generally at or above 900.

Figure 4c shows the m/z values obtained for Reactive Orange 16 over the 16 week period. As the formula of Reactive Orange 16 is known, and the formula of the dye bound to a few cellulose units can be derived, the expected masses can be calculated. The mass is indicated in figure 4c along with the upper and lower limits defined as a deviation of 5 ppm of the calculated mass. The mass accuracy of the mass spectrometer is shown to be very high. The deviation is well within the 5 ppm range. The m/z values shown have a very high robustness, albeit with a slight offset. Similar robustness was observed during the analyses of the other dyes (see table 3).

The mass resolution is calculated by the instrument software and was found to be higher than 120,000 at m/ z 400 in all reported experiments.

# Limit of detection

The limit of detection (LOD) has been obtained using dissolved powder dye references. These solutions can be prepared at known concentrations and provide an accurate value for the LOD. However, the derived values may not be relevant for practical use, as the dye content, thickness, and weight of a fibre are normally unknown. Therefore, we also used extracted dye to analyse the limit of detection. In this case, the limit of detection is expressed as the length of the fibre needed for identification of the dye. This expression of the LOD is closer to the considerations of the forensic scientist. However, an inhomogeneous colouration of the fibre, or a variable diameter of

the fibres will affect the accuracy of these analyses. Results on the limit of detection of Reactive Orange 16 are presented in figure 5. Numeric data on the different dyes included in the current study are provided in table 3.

Figure 5a shows the signal intensities obtained in mass spectra from dissolved Reactive Orange 16 powder at different concentrations. The noise level indicated in this figure is the highest noise level encountered during the series. The limit of detection was set at the concentration where the signal is three times this noise level. Figure 5b shows the signal intensities obtained for fibres at three different lengths.

The plots in figure 5 show that the system response is roughly proportional to the introduced amount of dye: reduction of the dye concentration by a factor of 100 ( $10^4$ to  $10^2$  ng·mL<sup>-1</sup>) reduces the obtained signal by two orders of magnitude. In a similar fashion, reduction of the fibre length from 10 to 1 mm decreases the obtained signal by one

Table 3. Summary of results of the validation study. The values for the HPLC retention times (RT), the match factor, and the mass accuracy are based on analyses of dyes extracted from fibres. Other values are provided for both the extracted dyes and for powder dye references. The values for the LOD represent the minimum concentration dissolved powder dye references (Kg/L) and on the minimum length of fibre needed for identification of the dye. A number of dyes lead reproducibly to the presence of a mixture of compounds. These are shown as separated entries in the table.

HPLC				DAD						MS				
Dye name	Rt fibre minutes	(sd)	match index Arb.	(sd)	LOD fibre mm	(sd)	LOD powder µg/L	(sd)	Acc ppm	(sd)	LOD fibre mm	(sd)	LOD powder µg/L	(sd)
Direct blue 67	30.7	(0.99)	996	(5)	0.04	(0.03)	20.5	(39.2)	1.7	(0.1)	0.017	(0.007)	7.3	(11.1)
Acid blue 78	41.2	(0.67)	998	(2)	0.01	(0.00)	5.4	(3.8)	1.9	(0.2)	0.003	(0.002)	1.9	(0.9)
Disperse blue 73	45.5	(0.47)	922	(46)	0.23	(0.12)	72.0	(41.4)	2.5	(0.4)	0.003	(0.002)	1.1	(0.9)
	51.0	(0.25)	939	(18)	0.14	(0.08)	50.7	(23.1)	2.5	(0.2)	0.044	(0.022)	20.6	(20.4)
Basic red 46	34.9	(0.75)	902	(47)	0.17	(0.12)	13.9	(5.5)	1.0	(0.2)	0.014	(0.011)	2.2	(2.5)
Basic blue 3	37.9	(0.70)	911	(72)	0.13	(0.15)	4.7	(2.6)	0.8	(0.1)	0.002	(0.002)	0.1	(0.0)
Basic red 18	44.5	(0.38)	894	(51)	0.32	(0.16)	60.8	(27.8)	0.4	(0.2)	0.268	(0.352)	0.5	(0.2)
	45.0	(0.42)	894	(51)	0.32	(0.16)	-		0.2	(0.2)	0.003	(0.002)	-	
Reactive yellow 145	14.5	(0.94)	897	(44)	0.41	(0.20)	47.6	(15.0)	1.3	(0.5)	0.242	(0.165)	29.4	(15.4)
	14.8	(0.98)	897	(44)	0.41	(0.20)	-		1.5	(0.2)	0.153	(0.093)	-	
	16.0	(0.95)	922	(46)	0.37	(0.25)	132.0	(43.3)	1.5	(0.2)	0.130	(0.119)	61.2	(32.4)
	15.7	(0.38)	932	(40)	0.37	(0.25)	-		1.0	(0.4)	0.352	(0.291)	-	
	17.2	(0.90)	933	(39)	0.35	(0.26)	41.6	(13.6)	1.2	(0.3)	0.096	(0.105)	53.5	(43.3)
Reactive orange 16	17.6	(0.95)	911	(39)	0.46	(0.29)	25.8	(7.7)	1.6	(0.3)	0.178	(0.166)	8.2	(2.8)
	19.7	(0.90)	973	(12)	0.06	(0.05)	37.3	(11.2)	1.3	(0.3)	0.011	(0.009)	4.2	(1.3)
Reactive red 120	15.5	(0.93)	952	(40)	0.24	(0.26)	107.0	(81.2)	1.2	(0.7)	0.418	(0.320)	153.3	(79.5)
	15.8	(0.79)	959	(26)	0.24	(0.26)	-		1.2	(0.7)	0.741	(0.709)	-	
	17.0	(0.85)	944	(47)	0.32	(0.33)	-		0.3	(0.2)	0.248	(0.238)	-	
	16.9	(0.75)	955	(28)	0.32	(0.33)	-		0.9	(0.4)	0.615	(0.408)	-	
	17.5	(0.15)	930	(26)	0.21	(0.10)	-		1.2	(0.9)	0.473	(0.340)	-	
	17.5	(0.19)	932	(29)	0.21	(0.11)	-		1.1	(0.9)	1.080	(0.708)	-	
	18.7	(0.70)	916	(37)	0.44	(0.29)	-		1.1	(0.5)	0.687	(0.454)	-	
	18.5	(0.14)	916	(37)	0.44	(0.29)	-		0.9	(0.4)	0.889	(0.430)	-	

order of magnitude. We are aware that the quantitation of the mass signal is not perfect. We did not strive to optimise quantitation, as the described method is proposed as a qualitative method.

The limit of detection can be calculated by interpolation of the curves in figure 5. However, if proportionality between introduced amount of dye and the obtained signal is assumed, the limit of detection can also be assessed by a single measurement. This approach was followed for the other dyes. The results are presented in table 3. The limit of detection based on absorbance spectra was calculated in a similar way. Also these results are presented in table 3.

# Specificity

The specificity of the described method is based on three basically independent parameters, namely the RT, the absorbance spectrum, and the mass spectrum. The combined specificity is therefore considered promising. The most straightforward way to assess the specificity is the analysis of a large number of fibre dyes. This is the subject of current research and will be reported in due time. Nevertheless, the data presented in the current study provides a number





of indications that the specificity of the proposed method is remarkably high. A number of results will be summarised below:

- The described validation procedure was based on mixtures of three dyes. In all cases, these could be discriminated based on RT, absorbance spectrum, and mass spectrum.

- The insert in figure 3 shows that the mass peak has a high resolution. The combination with a high mass accuracy makes a dye identification based on mass spectra highly specific.

- The presence of a mixture of compounds was shown, even for reference textiles that were, according to the supplier, dyed with a single dye. Most of the mixed compounds could be attributed to different reaction products of expected dye on the basis of their molecular mass (results not shown). The presence and relative amounts of these mixtures were found to be relatively stable and the LOD has been calculated for each of these compounds. An overview is provided in tables 2 and 3. Specificity is thus improved, as the identification is based on a number of compounds.

- Disperse Blue 73 is, according the colour index, a mixture of two related compounds. Both compounds were identified.

A further improvement in specificity may be achieved by the acquisition of higher order mass spectrometry (MS<sup>n</sup>). These were not taken into account in the current study.

# Conclusion

ConclusionThe HPLC-DAD-MS method described was shown to be suitable for the forensic analysis of textile dyes in different classes (acid, basic, reactive, direct, disperse). In addition, the limit of detection was found to be around 1 mm or less for the analysed fibres.

To our knowledge, this is the first study in which reactive dyes on

cotton are analysed using an HPLC approach. In addition, it is the first study since the work of Speers<sup>[22]</sup> and Dockery<sup>[6]</sup> that describes an HPLC system that is suitable for the analysis of different classes of dyes.

The repeatability of the retention time RT was lower than expected. Recent work (not reported here) indicates that robustness can be improved by a more frequent replacement of the pre-column. However, it is realised that the RTs are relatively sensitive for small changes in the analysis and are not fully repeatable. Repeatability of the analyses was found to be very high. The accuracy of the determined mass was generally found to be better than 2 ppm over a period of several weeks. Mass resolution was found to be higher than 120,000 at m/z 400 in all reported experiments. The reproducibility of the acquired absorbance spectra (as analysed by NIST MS search 2.0 software) was found to be excellent.

Analyses on reference dye samples indicate a limit of detection of less than 100 Kg/L for most dyes. This suffices to analyse single fibres with a length of a few mm or less. For most fibres, except those with a very pale colour, this implies that dye analysis is possible whenever physical handling of the fibre using tweezers is possible.

The provided results indicate that the specificity of the proposed method is very high, as closely related compounds can be discriminated based on RT, absorbance spectrum and/or mass spectrum. Current research aims at a more thorough evaluation of the specificity by the compilation of data bases of reference materials and street samples.

The analysis time, around one hour excluding sample preparation, is relatively long, but analysis can run unattended by use of an auto sampler. The described features make the technique reliable, versatile, and very specific. Therefore, we are currently implementing this methodology into routine case work in our laboratory.

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# xploring the Relationship between Finger/Palm Prints and Blood

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**Abstract** The identification of an individual's fingerprint in the blood of a victim of crime is extremely powerful evidence, but little literature to disucss the various factors that affect the appearance of a fingerprint with the interaction of blood. Figures in this paper demonstrate that by analyzing the mark of a fingerprint, the scientist would be able to determine if: 1. The finger was wet with blood when it made contact with the object; 2. A clean finger made contact with blood that was already on the object; 3. Blood has come into contact with an existing finger mark on the object. Not all ridges associated with blood are as apparent, and marks can often be developed during chemical treatments. It's critical they are independently reviewed in each case to ensure that justice always prevails.

Keywords: Forensic science, Bloodstain pattern, Fingerprint, Palmprint.

# Introduction

The identification of an individual's fingerprint in the blood of a victim of crime is extremely powerful evidence. However, there's very little published literature on the various factors that affect the appearance of a fingerprint with the interaction of blood.

One published technical report states that it's not possible to determine how a fingerprint has interacted with blood just from its appearance. Some fingerprint experts are prepared to comment on how a fingerprint has been formed, while others will only comment on the identification.

From previous experience, authentication of a fingerprint associated with blood should be a joint examination by a fingerprint expert and a forensic scientist. The scientist would consider the interaction and distribution of blood on the surface of the object and the fingerprint expert would look at the interaction of blood with the ridges and furrows of the fingerprint. This paper demonstrates that by analyzing the mark of a fingerprint, the scientist would be able to determine if:

1. The finger was wet with blood when it made contact with the object;

2. A clean finger made contact with blood that was already on the object;

3. Blood has come into contact with an existing finger mark on the object.

There may be other explanations such as combinations of the three above. However, in the author"s experience these are the most common explanations.

## **Proposition 1**

The finger was wet with blood when it made contact with the object.

Occasionally, it can be obvious if a mark has been made by a finger bearing wet blood, but at other times, you have to look for the subtle detail (Figure 1).

Here, the heavier distribution of the blood is only on one end of

the fingerprint, which indicates that this finger has been rolled across the surface with moderate force.

# **Proposition 2**

A clean finger made contact with blood that was already on the object.

These types of marks are dependent on the type of object, pressure of the finger and the rate at which the blood dries. Figures 2a and 2b demonstrate how fingerprints are formed when they come into contact with blood at various time intervals. Figure 2b shows that the optimum time for formation of a good mark was around fourteen minutes after the finger came into contact with the wet blood.

# **Proposition 3**

Blood has come into contact with an existing finger mark on the object.

These types of marks are less common but can often be considered by the defense counsel in an attempt to reduce the impact of the fingerprint





(a)



Fig. 1 Rolled finger with blood accumulating at one end of the print.

Fig. 7





Fig. 3 Optimum time - fourteen minutes.



Fig. 4 There is no interaction with the blood and the fingerprint in sweat.





Fig. 6 Blood migrating along the edges of the fingerprint.



Fig. 8 Mark produced with the palm of hand bearing wet blood.

evidence. This is because if the fingerprint was simply from sweat with very little sebaceous material, then there isn"t much interaction with blood. The majority of sweat is water soluble, so it dissolves away when it comes into contact with blood. (Figure 4).

However, as the grease content of the fingerprint increases, then there is interaction with the blood (Figures 5 and 6).

The scientist reviews the appearance of the fingerprint under a microscope with the distributions of any other blood on the object to determine a suitable area to sample. The object may be subjected to a sequence of optical, physical and chemical treatments to establish the presence of blood and the proposed means for its formation. Figures 7a and 7b show two hand marks associated with blood. Figure 7a was made by a hand contacting wet blood and 7b was made by a hand bearing wet blood.

# Guidance for the Different Appearances with these Mechanisms

It is not always possible to determine whether it is a hand bearing blood or a hand going into wet blood and there is sometimes a combination of events. The following mark was produced with the palm of the hand bearing wet blood (Figure 8).

The first observation is the

distribution of blood is either side of the palm mark as indicated by black elliptical lines. Note also the absence of blood within the central region of the palm mark. The hand has made contact and on lifting the hand from the surface, the blood has pooled, due to the vacuum created. The following image (Figure 9) is a close up of the palm detail, as indicated by the blue circle.

Note the amount ridge detail in blood is still present under the pooling effect, as indicated by the black circle. This amount of detail would not be expected if the blood was already present and the effect is probably due to the blood drying on the hand prior to contact with the surface.

The following mark was produced with the palm placed into wet blood (Figure 10).

The first observation is the presence of the large pool of blood in the central region, as indicated by the black circle. Note also that the majority of the friction ridge detail is only present on the outer aspects of the blood. There is also the odd satellite of blood forced out by the pressure of the contact, as indicated by the red circle. The following image is a close up of the palm detail as indicated by the blue circle (Figure 11).

Hardly any friction ridge detail under the pooled area, as indicated by the black circle and blood has flowed to the end with little pooling when the hand has lifted from the surface. Sometimes it not always possible to determine which mechanism is the most likely; however there is additional information with each mark. Both these impressions have been made whilst the blood is wet and there are no obvious signs of clotting/ drying, which may assist with the time line for the enquiry.

# Conclusions

These mechanisms are only part of the process. Not all ridges associated with blood are as apparent, and marks can often be developed during chemical treatments. It's critical they are independently reviewed in each case to ensure that justice always prevails. The development of such marks associated with blood and the effects on DNA by such chemicals will be explored in a future paper.

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Fig. 9 Close view of palm detail of figure 8.



Fig. 10 Mark produced with palm of hand placed into wet blood.



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# Blast-related Fracture Patterns: A Forensic Biomechanical Approach

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Abstract Improved protective measures and medical care has increased the survivability from battlefield injuries. In an attempt to reduce the debilitating consequences of blast injury, understanding and mitigating the effects of explosion on the extremities is key. In this study, forensic biomechanical analyses have been applied to determine mechanisms of injury after the traumatic event. The aims of this study were (i) to determine which effects of the explosion are responsible for combat casualty extremity bone injury in two distinct environments, namely open, free-field (open group), and in vehicle or in cover (enclosed group), and (ii) to determine whether patterns of combat casualty bone injury differed between environments. Medical records of casualties admitted to a military hospital in Afghanistan were reviewed over a six-month period. Explosive injuries have been sub-divided traditionally into primary, secondary and tertiary effects. All radiographs were independently reviewed by a military radiologist, a team of military orthopaedic surgeons and a team of academic biomechanists, in order to determine 'zones of injury' (ZoIs), and their related mechanisms. Sixty-two combat casualties with 115 ZoIs were identified. Thirty-four casualties in the open group sustained 56 ZoIs; 28 casualties in the enclosed group sustained 59 ZoIs. There was no statistical difference in mean ZoIs per casualty between groups (p = 0.54). There was a higher proportion of lower limb injuries in the enclosed group compared with the open group ( p < 0.05). Of the casualties in the open group, 1 ZoI was owing to the primary effects of blast, 10 owing to a combination of primary and secondary blast effects, 23 owing to secondary blast effects and 24 owing to tertiary blast effects. In contrast, tertiary blast effects predominated in the enclosed group, accounting for 96 per cent of ZoIs. These data clearly demonstrate two distinct injury groups based upon the casualties' environment. The enclosed environment appears to attenuate the primary and secondary effects of the explosion. However, tertiary blast effects were the predominant mechanism of injury, with severe axial loading to the lower extremity being a characteristic of the fractures seen. The development of future mitigation strategies must focus on reducing all explosion-related injury mechanisms. Integral to this process is an urgent requirement to better understand the behaviour of bone in this unique environment.

Keywords: Forensic science, Explosions, Fractures, Biomechanics, Forensics, Blast injury, Landmines.

# 1 Introduction

Since World War I, explosive weapons and fragmentation devices have accounted for over 70 per cent of all deaths and injuries to combatants in conflict <sup>[1-4]</sup>. Survivability from battlefield injuries has increased from 69.7 per cent in World War II to 88.6 per cent most recently in Iraq <sup>[5]</sup>. This has been attributed to a number of factors including improved torso protection, enhanced prehospital care, and rapid aeromedical evacuation to medical facilities capable of providing optimized damage control, resuscitation and surgery. Consequently, there has been an increased incidence of severely injured casualties surviving with multiple extremity injuries. In Iraq and Afghanistan, extremity injuries comprise 54–68% of combat wounds, of which approximately one third are fractures <sup>[6,7]</sup>. This has been echoed in literature on civilian blast victims; Frykberg & Tepas <sup>[8]</sup> reported that 85 per cent of terrorist bombing victims requiring surgery have soft tissue extremity injuries, with or without fractures.

Our understanding of extremity musculoskeletal injuries is limited by the paucity of blast injury research. Despite musculoskeletal trauma being the most common injury in military conflict and civilian terrorist activity, the study of the blast injury patho-physiology has focused almost exclusively on primary blast injuries of the pulmonary or central nervous systems <sup>[9–12]</sup>, resulting in the development of improved protective measures and medical interventions. As a consequence, there exists a dearth of scientific investigation into blast pathophysiology of the musculoskeletal system, appropriate injury profiling and subsequent predictive modelling, all fundamentally distinct from that described in blunt trauma research<sup>[13,14]</sup>. It is therefore incumbent upon clinicians, scientists and engineers to have a better understanding of underlying injury mechanisms of extremity trauma in order to drive the development of novel treatment and mitigation processes.

Forensic injury biomechanics can be considered to be the scientific field focused on if and how mechanical forces cause disruption to anatomic regions of a body <sup>[15]</sup>. Using a forensic injury biomechanical approach to blast injuries, it is possible to deconstruct the complex explosive injury process into its component injurious parts, and determine how they interact and disrupt physiological systems.

Despite the large number of studies reporting the injury profile from explosive events, there have been no attempts to describe the effects of explosion based on the pattern of skeletal injury found. Therefore the aims of this paper are to firstly describe the mechanical and physical processes that result in bone fracture in an explosive environment, secondly to determine which effects of explosion are responsible for bone injury and finally to determine the effects of the casualties' environment on the pattern of bone injury. This will then serve as a template for future research and the development of mitigation through environmental change, or protective clothing.

2 The Physics of Blast and its Effect on Bone

Detonation of an explosive initiates a shock wave process whereby the wave propagates through the explosive, causing an instantaneous (less than 1 ms) chemical reaction. Behind the detonation wave, the explosive has been converted to hot, high pressure gas: the detonation products. Local pressures are typically in the region of  $25 \times 10^5$  atm while temperatures are from 2,000 to 6,000 °C <sup>[16]</sup>. The hot gas expands forcing out the volume it occupies. As a consequence, a layer of compressed air (blast wave) forms in front of this gas volume containing most of the energy released by the explosion.

There is an instantaneous sharp rise in pressure within the air surrounding the explosion, rapidly attaining its peak overpressure. As the blast wave moves through the air, the pressure wave disperses in inverse proportion to the third power of the spherical explosive's radius<sup>[17]</sup>. Overexpansion of the detonation products results in the development of a sub-atmospheric pressure phase. In this phase, a partial vacuum is created and air is sucked in. This is also accompanied by high suction winds that carry debris for long distances away from the explosion source. The classical waveform (Friedlander wave) describes pressure changes from a fixed location relative to the explosive event (figure 1)<sup>[18]</sup>. It is idealized because the effects of structures and the ground have been omitted, as they produce multiple reflective waves that distort the waveform.

The physical properties of the blast wave in respect to physiological dysfunction are essentially the peak pressure, the impulse (the time integral of pressure), and the duration of the positive phase overpressure <sup>[19]</sup>. Wakeley <sup>[20]</sup> commented that a 'high peak overpressure is of little use if not sustained sufficiently long to distort the structure beyond its power of elastic recovery, and a large impulse is of little value if the pressure is less than the structure is able to withstand'. It has also been proposed that the dynamic overpressure of the detonation products (blast wind) and thermal energy released in the explosion contribute to blast injury<sup>[21,22]</sup>. By convention, blast injuries are classified according to the mechanism by which they are produced and their effect on the skeletal system is summarized below.

2.1. Primary orthopaedic blast



# injury

Primary orthopaedic blast injury is related to the effect of the blast wave on skeletal structures. Blast waves, interacting with the body, will transfer energy at interfaces between tissues of differing acoustic impedance. This leads to cellular disruption, soft tissue destruction and bone micro-fractures. Hull<sup>[23]</sup> demonstrated that a goat limb. shielded from the effects of the detonation products and fragments, could be fractured by the blast wave alone, when placed in close proximity (less than 50 cm) to the seat of the explosion. Based on finite element analysis, Hull predicted that the stress wave will have been propagated from the explosive to the limb prior to any displacement of the limb. If the blast wave entered the tibia laterally (bomb detonation to the side of the victim), the bending forces exerted by the blast wave, combined with the geometry of the tibia and the differential movement afforded by the knee and ankle joints result in the peak stresses being situated within the upper third. The resulting shear and axial stresses

exceed the tensile failure stress of bone causing fracture. From clinical experience, the proximal third of the tibia and femur are the most common sites for traumatic amputation in these circumstances (figure 2)<sup>[24]</sup>.

Once the bone is fractured by the blast wave, the detonation products expose the bone to significant bending stresses. It is suggested that these stresses, occurring at the site of blastwave induced bone fracture, are the probable mechanism of traumatic amputation <sup>[25,26]</sup>.

Clinically, this manifests as a traumatic amputation, with the proximal stump containing a short oblique or transverse fracture morphology (figure 2b).

# 2.2. Secondary orthopaedic blast injury

Secondary blast injury is marked by penetrating trauma from bomb casing fragments, from materials implanted within the explosive (e.g. nails, screws), or from local materials energized by proximity to the explosion. These fragments can cause fracture either directly or indirectly. Direct impact of a high

energy fragment into bone typically results in a highly comminuted fracture <sup>[27]</sup> (figure 3a). Experimental evidence has shown that these injuries result in multiple bone fragments with no periosteal attachment and thus no blood supply. In addition, these direct high transfer wounds produce significant contamination of the fracture site and into the medullary canal, thereby increasing the risk of developing long-term infective complications (osteomyelitis). In cadaveric studies. Huelke<sup>[27]</sup> demonstrated that direct fractures only occurred when steel projectiles weighing 1.05 g were travelling at velocities greater than 185 ms<sup>-1</sup>, and that the degree of comminution and size of injury increased with velocity.

As a projectile passes through tissue it imparts radial velocity to the surrounding medium, thereby causing a large temporary cavity <sup>[28]</sup>. The projectile, after penetrating one bone cortex, encounters the marrowfilled cancellous bone and propels the marrow radially at high velocity, fracturing the thin trabeculae. When the projectile penetrates the second



Fig. 2 (a) The blast wave interacts with the femur causing micro-fracture within the bone. Due to the bone geometry and the differential movement allowed by the knee and hip joints, the bending forces exerted on the femur by the blast wave result in an area of stress concentration. The peak hoop and axial stresses within this area exceed the tensile failure stress of bone, resulting in fracture; adapted from <sup>[23]</sup>. (b) A traumatic amputation of the femur. Note the absence of significant soft tissue disruption or fragments and the short oblique fracture pattern of the stump.

bone cortex, the exit hole is enlarged by the cavitation in the cancellous bone. Due to the relatively inelastic nature of bone compared with soft tissues, the cavity formed in the cancellous bone does not collapse and a permanent cavity is formed. With higher velocity impacts (more than  $500 \text{ ms}^{-1}$ ) the cavitation phenomenon produces widespread destruction of cancellous bone with increased fragmentation of the cortical bone on the exit hole. A similar effect has been noted with increasing projectile diameter <sup>[27,29]</sup>. Hence the size of the cavitation cavity and the relative size of the cortical defects can provide forensic indication as to the size, velocity and direction of the projectile.

If the fragment is travelling at a slower velocity, full penetration of the bone does not occur and only a single cortex is breached. In these cases, the classical 'drillhole' fracture is produced (figure 3b). Clinically, these injuries have a good prognosis and do not require surgical reconstruction. Rose et al. <sup>[30]</sup> reported 12 cases of drill-hole fractures of the femur treated conservatively with no complications.

Indirect fractures can be caused by a high energy fragment passing in close proximity to bone <sup>[28]</sup>. Such injuries are caused by the high pressures exerted on the bone surface by the leading edge of the rapidly expanding temporary cavity<sup>[31]</sup>. The fractures show no bone loss and the fragments retain periosteal attachments and are therefore likely to remain viable. The fracture configuration in these injuries is usually simple (i.e. transverse or oblique) with little comminution. This is analogous to primary blast injuries.

# 2.3. Mixed primary and secondary orthopaedic blast injury

If the casualty is located at the seat of the explosion, the effects of the shock wave and the detonation products occur almost instantaneously. This classically occurs upon detonation of an antipersonnel mine. The antipersonnel mine is designed to release a large amount of explosive energy at a short range, aiming to maim rather than kill. Upon detonation, the blast wave is transmitted directly into the limb causing a brissance (shattering) effect on bone (figure 4). This occurs within 200 ms of mine detonation. One or



Fig. 3 Radiographs depicting the features of secondary orthopaedic blast injury: (a) highly comminuted fracture from direct impact with a high energy fragment; (b) incomplete 'drill-hole' fracture from impact with a low energy fragment.



Fig. 4 Upon detonation of an anti-personnel mine (a), a blast wave is transmitted to the limb causing a brissance effect on the bones (b). Some 1–2 ms after detonation, the detonation products reach the limb and place huge stresses on the already damaged bone resulting in multiple fractures and potentially traumatic amputation of the affected limb (c).



Fig. 5 (a) Radiograph of a combined primary and secondary blast injury to the lower limb following an anti-personnel mine detonation. The close proximity to the seat of the explosion results in the significant amounts of foreign debris seen on the radiograph. (b) The clinical appearance underlines how the detonation products are driven through the fascial planes resulting in the classical umbrella effect of the remaining soft tissues (white arrow).

two milliseconds post-detonation, the detonation products and casing/ environmental fragments contact the limb (figure 4) causing destruction of traumatized soft tissue and applying maximal stresses on bone previously damaged by the blast wave <sup>[32,33]</sup>. The net result is either a total or subtotal amputation of the limb, with the zone of soft tissue injury (including significant amounts of foreign debris and fragments) extending more proximally to the damaged bone (figure 5).

# 2.4. Tertiary orthopaedic blast injury

Tertiary orthopaedic blast injuries occur as a result of bodily displacement of the casualty or impact against solid structures <sup>[34]</sup>. As such the injuries witnessed bear similar characteristics to those seen in civilian blunt trauma. When bone is subjected to external loads, local instabilities arise from osseous imperfections. This results in the nucleation, multiplication and growth of microcracks, their localization in certain areas, and finally the formation of a macroscopic fissure (fracture) owing to the coalescence of localized microcracks in the most densely damaged area <sup>[35]</sup>. The pattern of the resulting fracture is a function of the direction and intensity of the load applied, the geometry of the bone injured, and the subject- and location-specific material properties.

Kress et al. <sup>[36]</sup> reported the results of 588 long bone fractures induced by impacting whole limbs and dissected bones using a pneumatically driven impactor travelling at velocities of  $3.5-7.5 \text{ ms}^{-1}$ . They reported that with loads applied perpendicular to the axis of the bone, the most common fracture reported was a tension wedge (figure 6a) and that this did not change with the direction of the impact. Tensile wedge fractures originate at a location directly opposite the point of impact and the wedge segment radiates back through the bone initially forming a 90° vertex angle. This suggests failure owing to direct stress, i.e. axial loading of the bone in tension at the far cortex<sup>[37]</sup>. They also noted that the level of comminution at the fracture



Fig. 6 The influence of load application on fracture pattern. (a) A direct force applied perpendicular to the long axis of the bone results most commonly in a tension wedge fracture with the apex formed at the opposite cortex to force application. (b) In order to produce a spiral fracture, a torsional load must be applied to the bone.

site was related to increasing speed of impact. Spiral fractures only appeared when the bones were subjected to additional torsional loads and these fractures occurred 100 per cent of the time when a pure torsional load was applied (figure 6b). This implies failure owing to shear stress <sup>[37]</sup> and is directly equivalent to similar fractures seen in metacarpals and phalanges <sup>[38]</sup>.

Severe axial loading of the lower limbs from underground explosions, or casualties landing on their feet after being thrown can also be expected, with comminuted calcaneal (heel) fractures being a prominent feature (figure 7); a pattern of injury similar to parasuicide injuries sustained by falling from significant heights <sup>[39,40]</sup>. In cadaveric biomechanical testing, Yoganandan et al. <sup>[41]</sup> demonstrated that axial loads greater than 6.2 kN (approx. 8 times body weight) were sufficient to cause intra-articular calcaneal fractures in 50 per cent of cases.

# 2.5. The effect of environment on blast injury

The location of the explosion can have a significant effect on both the severity and spectrum of injuries seen following an explosion. Leibovici<sup>[42]</sup> compared the effects of explosions occurring in open spaces with those in confined spaces. He found that explosions in confined spaces were associated with a higher incidence of primary blast lung injury, increased injury severity and increased severity of burns compared with explosions in open air. Kosashvili<sup>[43]</sup> reported that explosions occurring in confined environments (e.g. restaurants or transportation) caused the highest number of severe injuries and casualties required the largest number of surgical interventions: open space explosions caused the largest number of casualties but with the smallest percentage of severe injuries or death.

Despite the large number of studies reporting the injury profile

from explosive events, there have been no attempts to describe the effects of explosion in non-fatal casualties based on the pattern of skeletal injury found. Considering that the fracture configurations caused by the individual blast components are very different, our hypothesis is that the pattern of fractures seen in victims of explosions would be dependent upon the incident environment.

Therefore, the specific aims of this study are to firstly determine which effects of the explosion are responsible for combat casualty extremity bone injury in two distinct environments: (i) in the open (open group) and (ii) enclosed space (either in vehicle or in cover, enclosed group), and secondly to determine whether patterns of combat casualty bone injury differed between environments.

# 3 Method

We reviewed all Emergency Department records, medical documentation and radiographs of surviving casualties injured by an explosive blast mechanism, presenting to the medical treatment facility situated at Camp Bastion, Helmand Province, southern Afghanistan between April and September 2008. From this review, we identified all casualties (both civilian and security forces) who had sustained



Fig. 7 Tertiary blast injury following an improvised explosive device. The comminuted fractured calcaneus (heel, white arrow) is a result of severe axial loading.

an extremity fracture. Paediatric patients (less than 18 years of age) were excluded from the analysis. Once identified, the radiographs were reviewed independently by a military radiologist, a team of military orthopaedic surgeons and academic biomechanists. Based on the environment of the incident, patients were categorized into two groups: open, free-field, known as the open group; and in vehicle, or in cover, known as the enclosed group.

Due to the complex nature of the fractures recorded, it was evident that individual reporting of single bones would be inappropriate and may significantly skew the results. As such we developed the term 'zone of injury' (ZoI) to describe an anatomical region injured by a particular blast mechanism (figure 8).



Fig. 8 A complex lower limb injury involving 29 bones. In this case the foot and ankle complex was designated a single zone of injury (ZoI) and determined to have been caused by a mixed primary and secondary blast mechanism.

For each ZoI, the anatomical location of injury and blast mechanism (primary, secondary, combined primary and secondary, and tertiary) was determined based upon the fracture characteristics (table 1). Additionally, the presence of an open fracture (i.e. fracture associated with a break in the skin) was also recorded.

The data were analysed using SPSS v. 17.0 (SPSS, USA) statistical software. For categorical data,  $x^2$ -test was applied. For non-parametric continuous data, the Mann–Whitney test was used and a p-value less than 0.05 was considered statistically significant.

## 4 Results

We identified 62 casualties who were eligible for inclusion in this study during the study period. In total they sustained 115 ZoIs  $(1.82 \pm 0.98)$ ; mean number of ZoIs per casualty  $\pm$  s.d.). Thirty-four casualties were in the open group and sustained 56 ZoIs (mean 1.65 ZoIs per casualty  $\pm$ 1.16); 28 casualties in the enclosed group sustained 59 ZoIs (mean 2.1 ZoIs per casualty  $\pm$  0.81). There was no statistical difference in the mean ZoIs in the open versus enclosed group (Mann–Whitney test, p =0.54). However, there were more open fractures within the open group (48/59) compared with the enclosed group (20/49) (x<sup>2</sup>-test, p < 0.001).

The effect of the environment on the mechanism of injury is presented in figure 9; 27 (43.6%) casualties sustained more than 1 ZoI (range 1–6). Of those, 11 had more than one mechanism of injury attributed to their fractures. Casualties in the open group sustained 1 ZoI from primary blast effect, 10 ZoIs from a combination of primary and secondary effects, 23 ZoIs owing to secondary effects. Fragmentation was a component in injury causation in 33 (58.9%) injuries. In contrast, tertiary blast effects predominated in the enclosed group, accounting for 57 (96%) ZoIs. In addition, there was no primary or combined primary and secondary blast effect ZoIs in this group, with only two secondary blast ZoIs recorded.

Twenty-seven (43.6%) casualties sustained more than 1 ZoI (range 1–6). Of those 11 had more than one mechanism of injury attributed to their fractures.

The anatomical pattern of injury is represented in figure 10. There was a higher proportion of lower leg injuries in the enclosed group (54/59) compared with the open group (40/58;  $x^2$ -test, p < 0.05).

A sub-group analysis of the mechanism of injury in the lower limb (figure 11a) demonstrates that in the enclosed group tertiary blast effects predominated in 47/48 (96%) ZoIs. In contrast, the open group showed a far more even distribution of injuries resulting from combined primary and secondary, secondary, and tertiary effects. In the upper limb, secondary blast effects predominated overall, affecting 14/23 (61%) ZoIs, with this effect being more pronounced in the open group (figure 11b).

## **5** Discussion

Our data clearly demonstrate a distinct correlation between the pattern of injury and environment. The enclosed environment afforded by structures appears to mitigate the primary and secondary effects of the explosion. When a detonation occurs close to, but outside a structure the resulting blast wave diffracts around, reflects off, and, to a much lesser extent, transmits into the interior <sup>[44]</sup>. Because only a small portion of the blast wave is transferred internally, the risk of blast wave related injuries is substantially reduced. Test data reported by Champion et al.<sup>[13]</sup>

illustrated the effect of a 17 kg bare charge of C-4 explosive detonated 3 m away from an armoured vehicle. The peak incident overpressure outside the vehicle was 28 times that inside the vehicle and the impulse was 3 times that inside the vehicle. Although these structures can reduce the effects of primary and secondary blast injury, the momentum imparted by the blast to the structure (vehicle) can cause acceleration and displacement of the occupants, and may in part explain the high proportion of tertiary blast injuries noted in this group.

In contrast, secondary fragments from the explosion were more likely to result in fractures of casualties caught in the open. The development of combat body armour, designed to protect the torso, has been shown to significantly reduce the severity of injury and improve survivability from ballistic trauma<sup>[45]</sup>. As a consequence, there has been an increase in survivors with severe penetrating trauma to the extremities without central involvement and this effect may be reflected in the large number of casualties in the open group surviving with extremity fractures caused by high energy fragments.

In this study, data were collected on survivors of explosion. It is conceivable that the injury patterns in fatalities maybe considerably different to those seen in survivors with a higher proportion of primary blast injuries. Data on fatalities during the study period were not available in this study. Mellor <sup>[46]</sup> reviewed the post-mortem data of 216 servicemen killed by explosion during the Northern Ireland civil conflict. Due to the availability of accurate incident data, he was able to correlate blast loading to death from explosions. Fifty-one per cent of the fatalities were subjected to peak overpressures greater than 550 kPa and of the 43 fatalities who sustained a traumatic limb amputation, 32 were subjected

to this level of blast loading. Indeed, the presence of a primary blast limb injury in an enclosed environment may be indicative of a breach in the structure and therefore act as a surrogate marker of the intensity of blast loading to which the occupant was subjected. We believe that future evaluation of post-mortem data of blast fatalities, using the methods demonstrated in this study, would help provide further forensic evidence in the evaluation of actual explosive incidents, and the effectiveness of protective measures.

In this study, 43.6 per cent of casualties had more than 1 ZoI, further demonstrating the devastating effects of explosion on the human body. A significant number of those with multiple ZoIs had more than one blast mechanism to account for their injuries. This suggests that the development of future mitigation strategies must be focused on reducing all the different mechanisms of injury caused by an explosion.

Anatomical analysis of the data revealed that the lower limb was more frequently affected in the enclosed group compared with the open group and nearly all of the lower limbs injured in the enclosed group sustained tertiary blast injuries. This may be attributed to the momentum effects of the explosion causing casualties to be thrown long distances before landing on their feet, or secondary to vertical acceleration and local floor-pan deformation from under-vehicle mine detonation <sup>[47]</sup>. As this was the predominant mechanism and location of injury in this study, further research is currently being undertaken to fully investigate the biomechanics of lower limb injury in explosions<sup>[14]</sup>.

The classification system used in this study was not developed to provide a prognostic indicator of overall clinical outcome. In a review of ballistic classification systems, Rosell & Clasper<sup>[48]</sup> commented that a main indicator of outcome will require some form of quantitative assessment of soft tissue injury and concluded that ballistic injuries should be treated on an individual basis, considering the soft tissue, anatomical location of the injury and the involvement of any joints. The use of plain radiographs prohibits the evaluation of soft tissue injury fully, but we believe that this forensic approach can aid the development of future mitigation strategies by identifying the root cause of the injury mechanism. Integral to this process is an urgent requirement to better understand the response of bone in this unique environment. This can only be achieved via a collaborative approach between clinicians, natural scientists and engineers, combining physical and numerical modelling tools with clinical data from explosive incidents.

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# 157118X.3.3.P Reviewed xperiments on Sweat Fingerprints Reflection Effects on Different Thickness Glass Surfaces by **Shortwave Ultraviolet**

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Abstract Objective To observe reflection effects of sweat fingerprints on surfaces of glasses of different thicknesses by shortwave Ultraviolet. Method Sweat fingerprints on slide and cover slide were appeared by use of UV reflectance imaging methods. The obtained results were compared. Result Differences in the thickness of the transparent glass objects significantly affect the UV reflectance imaging method for sweat fingerprints shooting. Conclusion For UV through the thin transparent glass, the transmission depth affects the fingerprints imaging. Certain methods have been proposed to improve the image quality.

Keywords: Forensic science, Shortwave Ultraviolet, Reflection photography, Sweat fingerprint, Transmission depth, Glass.

## Introduction

As a nondestructive testing technique in forensic sciences, UV photography has been widely used for the showing and recording of latent fingerprint<sup>[1, 2]</sup>. Sweat fingerprints adhered to the object surface, for its characteristics of reflection natural fluorescence of body fluids<sup>[3]</sup>, is capable of reflecting UV. With this feature, it can achieve optical appearance of sweat fingerprints on smooth objects by UV photography<sup>[4]</sup>. As transmission characteristics of shortwave UV in the transparent medium is very different from visible light <sup>[4-5]</sup>, in taking sweat fingerprints by this method, the thickness of the transparent object has a great impact on shooting <sup>[6]</sup>. Through controlled experiments as glass the object, it has compared the reflecting effects

in shooting by shortwave UV on transparent glass objects of different thicknesses, to explore the technique improvement of shortwave UV reflection of sweat fingerprints on thin transparent glass surface.

## 1 Materials and Methods

#### **1.1 Samples**

Without loss of generality, we adopt a glass slide and a cover glass that can be commonly seen and made of glass as bearing objects. The thickness of the glass slide is 1.1mm-1.3mm and the cover-glass thickness is 0.11-0.13mm. We press sweat fingerprints on the glass slide and the cover glass respectively.

# **1.2 Equipments for Experiments**

254nm ultraviolet source(US Spectroline E/12-series ); full-wave band CCD(US FLI PL4240-UV), an oiliness pen, a plotting scale.

# **1.3 Experimental Contents and** Methods

Put Glass Slide A and Cover Glass B on the metal platform engraved with graticule lines. By using shortwave Ultraviolet reflectance imaging methods, adjust polishing angle at about the angle of 45 to get the best shooting effect. By using full-wave band CCD to shoot sweat fingerprint image to adjust the luminance, contrast and gamma of the images;

Fetch a new Glass Slide C free of fingerprints, and put Cover Glass B onto Glass Slide C. You will get the shooting results by using shortwave Ultraviolet reflectance imaging methods and picture processing methods;

Use a pen of oiliness to smear the



Fig.1 The sweat fingerprint on Glass Slide A got by using 254nm shortwave Ultraviolet reflectance imaging method. (Adjusted the luminance, contrast and gamma of the images to get the best showing effect)



Fig.2 The shooting result got from Cover Glass B by using 254nm shortwave Ultraviolet reflectance imaging method. (Adjusted the luminance, contrast and gamma of the images to get the best showing effect)



Fig.3 Put Cover Glass B on Glass Slide C and get the sweat fingerprint by using 254nm shortwave Ultraviolet reflectance imaging method. (Adjusted the luminance, contrast and gamma of the images to get the best showing effect)

reverse side of Cover Glass B, and make sure that it is well-distributed. You will get the shooting results by using shortwave Ultraviolet reflectance imaging methods and picture processing methods.

# 2 The Results of the Experiments

2.1 The shooting results got from Glass Slide A (Figure 1) and Cover Glass B (Figure 2).

2.2 The shooting result got by putting Cover Glass B on a new Glass Slide C. (Figure 3)

2.3 The shooting results got from the reverse side of Cover Glass B which has been well-distributedly smeared. (Figure 4)

# **3** Discussion

Figure 1, Figure 2 have demonstrated the shooting results got by using 254nm shortwave Ultraviolet reflectance imaging method. Because the glass slide is thick (1.1mm-1.3mm), the sweat fingerprint got in Figure 1 is the same as the bright rays against the almost absolute black background. On Glass Slide A where there is no sweat fingerprint, 254nm ultraviolet ray is almost completely absorbed, making it almost completely black background; the place where there is sweat fingerprint has light fringes because of the reflection of the fingerprint streakline to ultraviolet. In Figure 2 there is pressed sweat fingerprint, but we cannot get the image of sweat fingerprint on Cover Glass B by using 254nm shortwave Ultraviolet reflectance imaging method and we can see clearly the graticule lines of the metal platform below Cover Glass B. 254nm shortwave Ultraviolet penetrates Cover Glass B and the reflection takes place on the platform

and penetrates Cover Glass B again and then reaches CCD and forms the image of the pattern of the platform. The cover glass is thin (0.11-0.13mm), 254nm shortwave Ultraviolet is not completely absorbed by the cover glass. We cannot get the image of sweat fingerprint by using 254nm shortwave Ultraviolet reflectance imaging method, but it penetrates the cover glass twice successively.

When light travels through substance, it will be absorbed by the substance<sup>[6]</sup>. The atom is made up of nucleus and electron. Actually, nucleus is quite active, it can absorb photon to increase its energy. As long as the light is absorbed, the substance is not transparent any more. But it does not mean that any kind of light will be absorbed. The specific selection is decided by quantum mechanics law. Light is electromagnetic wave, and when it comes into any medium or travels in any medium, the microscopic particle in the medium actually absorbs its energy and electric polarization and forced vibration takes place. The dipole oscillator appears and the vibratory dipole oscillator gives out subwave.

The light travels through the glass. The light we see is not the original light any more. It is the subwave given out by microscopic particle inside the glass. Amorphous substance is often transparent, such as the glass. As non-conductor, the incidence of the electromagnetic wave will not produce free charge and conduction current in it. Therefore, the electron of glass cannot absorb visible light because of the restriction of quantum mechanics<sup>[7]</sup>, and the light directly penetrate the glass and it looks transparent. However, the glass is not always transparent, for example, to some infrared ray and ultraviolet ray, it is not transparent, for the two

can be absorbed by glass<sup>[8]</sup>.

We can suppose that a hank of parallel light travels in homogeneous medium. After it travels through the lamina (thickness dl), because of the absorption of the medium, the decrement of the light intensity will be dl. The light intensity decreases from *I* to (*I*-*dI*). According to Lambert's law, *dI/I* should be in direct proportion to the thickness of the absorbed layer dl:

# $dI/I = -K \cdot dl$

*K* is absorption coefficient, minus means the reduction of the light intensity and the result of the differential equation is:

# $I = I_o e^{-K \cdot l}$

 $I_o$  is the light intensity when l = 0.

The bigger the absorption coefficient, the more intense the absorption of the light wave becomes. When l = 1/K, the light intensity will reduce to 1/e of the original intensity. The absorption coefficient K is the function of the wavelength. Within the scope of the visible light, general colorless transparent optical glass absorbs less and K hardly changes with the wavelength. The absorption coefficient *K* is about  $10^{-2}$  cm<sup>-1</sup>. That is to say, we can regard the general optical material to be transparent in visible region<sup>[6]</sup>.

However, in ultraviolet region, the absorption of the optical glass to the ultraviolet region has remarkable changes. Especially in SW ultraviolet region, though the optical glass has strong absorption, the SW ultraviolet will not be completely absorbed until it travels certain distance in optical glass. This distance is called depth of penetration. During the course of complete absorption of the glass to 254nm UV-light travels in glass, when the thickness of glass is greater than the depth of penetration, ultraviolet ray will be completely absorbed by glass; but when the thickness of glass is not greater than the depth of penetration, ultraviolet ray can still penetrate the glass, which has negative effects on sweat fingerprint image on the glass object.

Fingerprints taken from the glass slides by UV reflection demonstrates that, it is mainly used the complete absorption effect of 254nm UV for glass slides A, making great contrast of the sweat fingerprint part and the blank background and thus showing a sweat fingerprint image (Figure 1). And because the cover glass is thin, that 254nm UV light is not completely absorbed to penetrate



Fig.4 Well-distributedly smeared reverse side of Cover Glass B by using 254nm shortwave Ultraviolet reflectance imaging method. (Adjusted the luminance, contrast and gamma of the images to get the best showing effect)

the coverslip, which can not satisfy the conditions required for the UV reflection shooting method (Figure 2).

To realize the UV reflection shooting of sweat fingerprints on coverslips, it can be through a certain way to let the 254nm UV light be completely absorbed by the cover glass to achieve the desired condition. One method of the experiment was taken Superposition, that is, to coverslip the cover glass on the slide, increasing the penetrating thickness, so that the ultraviolet from the coverslip can be completely absorbed by . This method has been proven (Figure 3) to help achieving sweat fingerprints on the cover glass, but will not destroy the original of the cover glass. Superposition is from Beer-Lambert Law<sup>[6]</sup>, also known as the Bouguer-Lambert-Beer Law in optics. As the basic law of light absorption, when a bunch of monochromatic light hitting the absorption surface of the medium, after passing through a certain thickness of the media, because of the partly absorbing of the light for the media, the intensity of the transmitted light would be weakened. The greater concentration of the absorbing medium, the greater thickness of the medium, and the light intensity decreases more remarkable. Its physical meaning is that, when a parallel beam of monochromatic light going vertically through a light non-uniform scattering absorbing substance, the absorbance A is proportional to the concentration c of the light-absorbing substance, and to the thickness *l* of the absorption layer. For homogeneous glasses, then the absorbance A and the concentration c of light-absorbing substance are fixed, the absorption layer thickness l directly determines the transmission of light. Therefore, increasing the thickness of the thin glass, it can

obtain equal appearance effect to the thick glass, achieving the purpose of fingerprints appearance under short waves.

But there are some problems on Superposition. Under normal circumstances, due to the smooth surface of cover glass and slide, the gap between the cover and the slide will not have a significant effect on the UV reflection shooting. However, if these surfaces are not flat, or have other debris leaving a clear angle, it is easy to generate interference fringes and stamped line between them, as interference on sweat fingerprint lines <sup>[6]</sup>.

Thus, this paper also proposes the Back-coating method. Due to the strong absorption of shortwave ultraviolet for the colored ink oil<sup>[8]</sup>, it can spread evenly on the back of the cover glass ( side B without sweat fingerprints) by the daily used oil-based pen, to let the shortwave ultraviolet be completely absorbed by the colored ink on the cover glass, which can assist appearance of sweat fingerprints on cover glasses (Figure 4). However, this method also has limitations. Because of directly painting on the cover glass by the oil-based pen, which to some extent undermined the original samples, it is limited on situations of low requirements samples for the Backcoating method.

# 4 Conclusion

Although optical glass and other materials has a strong effect to absorb short-wave UV, but when the short-wave UV transports in these internal materials before being completely absorbed, there is a depth of penetration. For the thin object, the penetration depth impacts the shortwave UV reflection that it may not appear sweat fingerprints. In this situation, it can use the method with an optical interference effect, e.g., to increase the thickness (Superposition) to completely absorb; or to enhance the background's contrast (Backcoating method) to achieve the conditions to get fingerprints visualization. In actual cases, it should base on non-destructive requirements to choose the right visualization program.

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