Robotic Vacuum Evidence Recovery for Low Yield Samples Overlooked Post Investigation

By

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A thesis submitted in fulfilment of the requirements for the degree of

Master of Forensic Science (Professional Practice)

in

The School of Veterinary and Life Sciences

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Supervisors:

Mr. Brendan Chapman

Dr. John Coumbaros

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Declaration

I declare that this thesis does not contain any material submitted previously for the award of any other degree or diploma at any university or other tertiary institution. Furthermore, to the best of my knowledge, it does not contain any material previously published or written by another individual, except where due reference has been made in the text. Finally, I declare that all reported experimentations performed in this research were carried out by myself, except that any contribution by others, with whom I have worked is explicitly acknowledged.

Signed: Paige Luckhurst

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Part One

Literature Review

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List of Abbreviations

AFIS – Automated Fingerprint Identification System

AFP- Australian Federal Police

CSD – Crime Sample Database

IBIS – Integrated Ballistics Identification System

NND- National DNA Database

M-Vac – Microbial Vac Wet-Vacuum Instrument

1. Abstract

Prioritization during a criminal investigation is always the most challenging aspect for a crime scene investigator. For the purpose of not letting any biological evidence go undetected, research into different collection techniques is being investigated. Different types of collection techniques suitable for collecting all potential forensic evidence types were reviewed to determine the most efficient technique suitable at detecting minute amounts of biological material. Forensic Intelligence is also explored due to the importance of crime scene linking and the incorporation of current databases to assist criminal investigations. The main aim of this review is to demonstrate, that collecting all possible unnoticed biological material is very important, as even the most minute samples can help solve a criminal investigation. This is to be assessed using a robotic vacuum device, to ensure mass coverage of an area of interest.

2. Introduction

DNA analysis is frequently used to obtain information from biological material to aid in examinations associated with criminal offences. The ability to recover and analyse an assailant's DNA where no bodily fluids were deposited, presents an objective for forensic investigations.[1] Recovery of this cellular material may yield sufficient quantities required for current DNA analysis. With current technology, it is now possible to retrieve profiles from the minute amount of skin cells and debris left through brief physical contact with an object or location.[1] Within these criminal investigations, it is of importance to members of the family and the justice system for a thorough and systematic investigation to occur. Due to the relevance and value of DNA, the importance of generating information from small

quantities of DNA have increased.[2] "Trace DNA" refers to DNA from any source present in low levels, including "wearer" DNA recovered from the fabric of clothing. This also includes "touch" DNA which may not have originated from the individual, but was deposited by them.[3]

The success rate of obtaining relevant DNA and fibres is dependent upon the selection of the appropriate recovery method.[3] These recovery techniques include self-adhesive tapes, scraping and combing.[4] Of these techniques, tape-lifting is the most common for collection of touch DNA, especially from items of clothing.[5] The difficulty in searching for these fibres of interest pertaining to an investigation, may be difficult if a think layer of background fibres and debris are present.[6] Therefore, the successful use of a robotic vacuum, with the ability to collect minute traces of DNA, would be highly beneficial to many criminal investigations.

Crime scene linking is a basic inference in criminal investigations and based on various types of information can facilitate the discovery of critical relations. This is based on links which may be found when comparing all different types of traces collected. Forensic science mainly contributes to forensic intelligence by providing knowledge on how to extract intelligence through databases such as DNA databases. This inference of crime scene linking can help explore the recognition of a series of crimes, which can increase crime detection and prevention.[7]

There is a lack of research conducted in the area of post-investigative evidence collection and techniques. My project may help to aid investigators in ensuring that any unnoticed

DNA can be prevented and the ability to obtain other biological evidence, if further analysis is required.[6] This is particularly beneficial for cold cases, where all evidence samples have been utilised or incorrect storage and labelling protocols haven't been adhered to.[8]

3. Forensic Intelligence

3.1 Forensic Intelligence Framework

Forensic Intelligence is an emerging concept utilised in forensic investigations, combining numerous disciplines of criminology, forensic science and policing to logically process forensic data. This concept has been described by many authors as an accurate, timely and valuable product of focusing on crime prevention and linking crimes through computerized models.[9] It has been proven that linking crimes based on different types of information, known as traces, can result in uncovering significant information. If a perpetrator is associated with one crime, indictment on numerous other crimes can follow.[10] Forensic science is traditionally the study of traces, which are physical remains of a criminal activity. The information of traces which have been extracted, analysed and interpreted are retained on a database, such as AFIS and DNA databases. As of 2015, there was no current forensic intelligence model in Australia, and no generalised framework model worldwide. However, the adaptations of computer systems, algorithms and expanding current databases have been studied.[11]

Ribaux et al.[9] proposed the idea of innovatively encompassing databases that combine examining different trace types rather than solely focusing on investigating ways to develop similar databases such as the DNA databases currently utilised. By studying all relevant information and incorporating a computerised system it is possible to extract patterns and

linkages between perpetrators and criminal activity. The major problem with technology previously, was the complexity of transferring these matching and retrieval algorithms to other databases. Therefore, by developing innovative methods to combine the different traces is desirable. Ribaux[9], also focuses on the effects of databases on scene linkages, and how linking such crimes is a basic inference in criminal investigation and crime analysis. The information gathered by such databases should be stored, treated and exploited with other forensic case data. A formation of a two step process without the complexity of the algorithms was investigated utilising shoe and tool marks collected during 2000 to 2001. The database contained more than 3000 traces. This analysis was based on extracting information from the databases pertaining to each geographical location to represent "hot spots" and the occurrence of cases. Patterns were depicted from only the width of the tool marks found at the crime scenes. Although this is a basic framework only depicting cases relating to burglaries in Switzerland, there is the potential for an improved mathematical framework to be installed.

Another factor for developing a forensic intelligence framework is detecting crime repetition. Rossy et al.[12] emphasises the importance of collecting all possible forensic case data and evidence types to successfully link criminal investigations and integrating this information into a criminal database. This database is known as a memory, which is designed to organise and support various analytical processes. Over 9150 criminal cases were investigated, and the vast majority of these cases (99.2%) were linked only through one forensic evidence type, emphasising the importance of collecting all forensic evidence. Results also indicate that 37.8% of all link series were initially detected through relevant databases available and globally 29.7% of all events are linked with forensic information.

This heavily depicts that a combination of all forensic links are complimentary and demonstrates the impact that forensic case data has on the detection and follow-up of series of events. Another factor that is of significant importance is time. Rossy[12] hypothesized that the longer the delay in linking a case, the lesser chance there is of detecting a link. The time span was expressed in weeks between the date of each crime firstly linked in each series and the date of creation of the link were computed and compared for each link type. More than 63% of events linked with situational information were registered in the first week after the occurrence of the crime had occurred and more than 80% in three weeks. However, after three weeks has occurred 96% of events are linked with DNA and 69% with shoe mark patterns. These results show that a vast majority of crimes that are linked later on through forensic case information would not be detected through situational evidence.

A study conducted by Ribaux et al.[13] further considered crime scene processing into the framework of forensic intelligence. Crime intelligence is therefore fed by this data created by crime scene processing, it drives the system that influences priorities. An example mentioned by these authors is similarly discussed in the 2003 paper by Ribaux, however this article details the lack of knowledge about forensic intelligence and linking crimes can have on prevention. A series of burglaries occurred between 2006 and 2008 in a region in Switzerland and links between DNA evidence were discovered however there was no source for this on the national database. There was no intelligence-led structure or policy in place during this time. Each burglary was therefore treated as an individual case and processing routinely. DNA was obtained from one of the door handles and fingerprints from the jewelry box which had been moved in one of the homes. This fingerprint was on

the national database associated to someone who had committed previous burglaries. This example explores the idea of different possible uses of forensic case data for crime investigation and analysis as well as contextual information to detect traces. DNA linking would have assisted crime scene investigations for this particular series.

Databases are an integral aspect of a forensic intelligence framework. The New Zealand (NZ) DNA database comprises of two distinct databases. These databases are comprised of National DNA Databases (NDD) which holds the DNA profile information of convicted offenders and volunteer donors as well as the, Crime Sample Database (CSD) which holds DNA profile information from criminal investigations. Comparisons are made between each of these databases to identify crime-to-person or crime-to-crime linkages. These linkages are also investigated within each of the databases and reviewed to identify if there are any duplications within each of the DNA profiles obtained. The most common crime types submitted to these databases include burglary and theft, indicating that the prevalence of these crimes indicates that DNA analysis provides a valuable means for linking an individual or other offences that are of interest. Examining trends relating to DNA database linkages assists in understanding the overall effectiveness of this particular type of forensic analysis as a crime solving application. There was also submission of less obvious evidence types such as “trace” evidence samples that had a higher than average crime-to-crime linkage which clearly depicts the importance of collection and submission of these samples.

3.2 Models/Methodologies

An intelligence network chart highlights the relationship between entities by arranging data to emphasise associations using more than one inter-related source.[11] The more

recently studied network charts, incorporates mathematical algorithms to link evidence types to crimes. Spaulding et al.[11] utilised a three-step import specification model which incorporates information relevant to the incident, evidence recovered during that investigation, analytical results and any performed database searches. This model aimed to produce a more universal approach to crime scene analysis and forensic intelligence. With technology increasing the aim for having a digital interfaced network to automatically uncover linkages is the desired result. This desired result was utilised through a simulation of 51 cases from an already existing profile of criminal cases. This was utilised to formulate a more diverse set of criminal cases. The simulation of these cases was accomplished using R (The R Project for Statistical Computing, 2018). A random name generator was utilised to simulate personal information. Three forensic databases were used to integrate a forensic intelligence network, these include the DNA database, AFIS and the Integrated Ballistics Identification System (IBIS). These were all created using an excel spreadsheet to mimic real databases. The generation of the forensic intelligence network is through importing all the relevant information into Analysts Notebook with a specific icon in relation to each evidence type, person and crime. The evidence therefore can be imported as its collected and the import specification integrates them into the network. The third part of this network is the integration of forensic analysis results from the forensic databases. The model was created to add an analytical assessment into investigations by exploiting case information. It has the ability to uncover relationships between different criminal cases, such as through DNA samples and fingerprint evidence. This model has the potential to close more cases such as cold case in network through similarities, new evidence or stimulate a lead to refocus the investigation.[11]

As of 2015 there was no forensic intelligence model that had been introduced in Australia. As of result of this, the Australian Federal Police (AFP) incorporated an integrated 11 model of policing and forensic resources which supports a FORINT pilot model. This is known as a forensic intelligence cell compromised of a CSI analyst and a AFP intelligence analyst embedded within the Forensics Rapid Laboratory. This reduced the amount of time delay between linking and detecting crimes. This model proved to have a positive impact on crime reduction, as shown through the continual decrease in crimes from the period of 2009 to 2013. The forensic cell proved to identify crime linkages and trends that would have otherwise been missed, which has led the police to implement new procedures allowing them to act on this information when the crimes are active. An initial discovery made during this experimentation of the cell was the low rate that police officers were collecting reference samples, this led to a high number of unidentified samples being collected at crime scenes. The result of this model was the intelligence product identifying suspects, once their DNA samples were collected, were then further linked to 20 or more crime scenes. The visualisation of this link chart has also proven to strengthen the relationship between the court system and forensic science. An example of this in relation to real cases is a series of burglaries that occurred in Canberra. It was believed that the three burglaries were related through timeframe, geographical location and modus operandi. Two of the cases were linked through forensic traces. No fingerprints from the scenes could be linked to the possible offender, and the DNA that were linked from each of the scenes could neither be linked to any particular person. However, the DNA that was discovered at each of the scenes, were linked to four other cases in Canberra. Through this particular model, two people were raised to question, and through the reference DNA

samples, 15 other crime scenes were linked to these individuals. The importance of this model is to identify the collaboration of both evidence and intelligence.[15]

With the evolution of forensic science, intelligence-led policing models are being studied. These models incorporate the conception of forensic science more efficiently in the policing part of the investigation. For example, clarifying the main objectives of the investigators on the particular crime scene. These main objectives help to collect, process and interpret the traces found at the crime scene. This intelligence program also helps to increase security by linking traces to already existing crimes, or future crimes and the detection and reduction of crimes.[16] Although crime detection may not necessarily be the aim of these models, the crime reduction and crime control is more focused. Walsh et al.[17] reported on a study in Australia where an increase in high volume crime scene attendance as well as the optimisation of traces collected at crime scenes caused a global drop in crime activity. Traces however, are only one part of a complex layer and seem to have little potential until the integration of forensic intelligence. Ribaux[16] discusses the need for partial DNA to be considered into the DNA database, forensic intelligence has the capability to test hypotheses which may benefit from this information. Such as through crimes that are suspected to be linked through the same modus operandi, a selective comparison of poor quality traces has the potential to support or refute hypotheses.

3.3 Limitations

Conclusively, the literature has similar discrepancies with the intelligence network charts, the types of crime discussed and future considerations to improve these studies. Spaulding[11] has discussed using an intelligence network chart to highlight the relationship

between evidence to emphasize associations to other inter-related sources. This however includes a number of limitations, including the manipulation of the data. As discussed 29 cases were utilised from the database of a local police agency, however a further 51 cases were simulated to create extra diverse cases. The access that they had to evidence types and personal information was limited to what was available from the police agency. Therefore, the creation of this data may seem presumptuous as each case is different with independent evidence types. It is difficult to understand if they created these linkages between people and evidence or it was completely randomised. This model would be efficient in localised areas where a low number of offenders engaged in the vast majority of criminal activity. This model would be more complicated; police wouldn't be able to focus on a specific prolific group which could influence the general level of criminality. The databases also had to be simulated because access to these were also unavailable, therefore simulation of this was also not genuine. Legal issues are also concerning regarding ownership of the data and storage of the data. This includes the intended use of forensic intelligence, human rights and information sharing. The ideal solution to over come these problems would be to have implementations for each jurisdiction. This model therefore may not be suitable for each state. Rossy[13] mentions that remote access to laboratory systems for investigators would add efficiency to the investigator process.

In majority of the other literature discussed, most crime types that are mentioned as examples of forensic intelligence are of burglaries. There is not much diversity into other crime types including high volume crime. Rossy et al.[13] mentions some high volume crimes including murder and sexual offences, however burglaries are the main crime type discussed. Dependent on the crime analysts, some crimes may be irrelevant to criminal

studies such as sexual offences were the offender is known to the victim. This should be considered when reviewing any sort of criminal data, and should be mentioned if these cases are not part of the study, and how many cases are deemed irrelevant. Time spans of these data sets should also be regarded, as there is only a small time span when regarding these cases. Such as in Rossy et al.[13] were they have discussed cases from 2009 to 2011, however have mentioned 55 previous cases, however not mentioned which cases these are or the time that these previous cases occurred. When discussing the results of these cases, all relationships have been discussed, regardless of the uncertainties of each type of link. This is questionable as data has been assumed to have been conducted by the same offender for a number of cases. The potential for forensic outcomes is underestimated, there may be evidence that was never collected from crime scenes. Future considerations for these studies all include the increase or acceleration of work flow in the laboratory, preventing the back log of results.

It should be mentioned that the literature on forensic intelligence, mainly focuses on data that is in Switzerland. The crimes and crime rates that occur in Switzerland may be different globally. As well, there is little literature on forensic intelligence data from recent years of crime data. The crime detection and crime rates may be different to what it is currently. The network charts discussed, are also based on the inference that all data was collected from the crime scene, therefore it should be noted that all relevant data should be correctly packaged and preserved for any possible traces that could link current and cold cases.

4. Evidence Types

4.1 DNA Collection Techniques

There are many different collection techniques that have been studied within the forensic community regarding trace DNA. Trace DNA refers to the DNA recovered from epithelial cells that have been left behind once a person has been in contact with that item.[18] The main question regarding trace DNA that many laboratories have is comparing recovery rates by collection methods.[3] It is imperative that the correct collection technique is utilised for the correct surface type to obtain the best results.[5] The amount of literature is limited to collection of DNA on different surface types and little is reviewed on DNA collection on clothing.

There are three common techniques that are employed for DNA retrieval on clothing; such as cutting, swabbing and tape lifting.[5] With the emergence of forensic science becoming a vast evolving field, there has been more research conducted into newer techniques, such as double swabbing and the performance of different types of tape lifts such as mini tapes. The swabbing technique has been the most common approach to sampling biological evidence in forensic laboratories and crime scene investigations. This is mainly due to its inexpensive nature, simplicity and its easy transportation to the laboratory from the crime scene.[19] The effectiveness of a swab may be influenced on many factors. The most important factor in terms of DNA recovery and sampling is the tip composition and design. If there is utilisation of the incorrect swab composition, there is a possibility of vital forensic evidence not being collected.[19] There are many advantages and disadvantages to the double swabbing and the single swabbing technique. Essentially, the double swabbing technique is normally employed for efficient results for the collection from DNA from

evidentiary items. This technique encompasses a wet cotton swab followed by a dry cotton swab.[20] Plaza et al.[20] describes that this technique is not always effective and is dependent on the surface type. It has been shown to visibly damage paper surfaces and caution should be taken to preserve the appearance of the substrate in question. Dry swabbing is also a common technique that has been utilised, however research from Plaza et al.[20] and O'Brien et al.[21] have stated that this technique can result in a reduction in DNA profiles and profile quality. This may be due to the cellular material becoming trapped in the cotton fibres comprising of the swab head. The inability to solubilize biological material also limits the surface area available for collection, and multiple different swabs are needed to collect a surface of interest.

There are some comparative studies regarding porous and non porous surfaces in relation to the significance of collection techniques. Hansson et al.[22] examined sampling epithelial cells from porous and non porous surfaces utilising the double swabbing technique, single dry swabbing and tape lifting (SceneSafe Fast™). Cotton, flocked and foam swabs were also observed in this study to establish if there were any differences in performance. This study demonstrated that tape lifting was the most efficient at sampling from porous surfaces than cotton, flocked and foam tip swabs. This was demonstrated by a higher DNA concentration yield than the other swabs. Comparatively, foam tip swabs depicted equal yields of DNA than the mini tapes on non porous surfaces. When focusing on DNA profiles, the mini tapes provided full DNA profiles, in comparison to the foam tip swabs, which only provided partial profiles. Brownlow et al.[23] also commented on similar results, depicting that nylon flocked swabs produced significantly higher yields of DNA than the cotton swabs

using a manual extraction method. For future studies, experimenting on extraction methods for each type of swab should be explored.

Hess et al.[18] provided a comparison of collection techniques on different items of clothing in order to determine the best DNA recovery on different clothing surfaces. These included the same collection techniques as mentioned above. A comparison of STR results demonstrated that tape lifting had 67% of alleles detected whilst the swabbing technique only depicted 51%, for synthetic and natural fibre clothing. For the raincoats, the dry swabbing and tape lifting techniques performed better (60% and 65% of alleles detected) in comparison to the wet swabbing technique (51%). The reliability of these results is however questioned due to contamination issues raised.

Based on the following literature reviewed, there is no definitive collection technique that is the best for every surface type or nature of biological material. Therefore, care should be taken when assessing the technique to apply on porous and non porous surfaces.

4.2 Fibres

4.2.1 Collection Techniques, Tape Quality and Surface Types

There are several techniques that are employed at crime scenes for the retrieval of fibre evidence. Tape lifting is notably the most common technique discussed throughout the literature. Tape lifting is generally utilised due to its ease of use, ability to systematically process a specific area and the reduction of contamination. However, due to the background substrate, tape lifting may not always be preferable. The most common surface type to collect fibre evidence is clothing from suspects and victims.[4]

There are many conflicting results regarding the efficiency of tape lifting. Schotman et al.[24] investigated the recovery of fibres from various clothing garments using a variety of different tapes. These texture garments included cotton, polyester and acrylic materials. Bright colours were utilised for their high fluorescence, as well as determining the difference between the donor and recipient fabrics. The surfaces of the donor materials were roughened with sandpaper to increase the shedding and the recipient material was placed over the donor material. Tape was then applied to the recipient material. In general, this study demonstrated very high retrieval rates of 85.8-97.5%, this is comparatively different with Wael et al.[25] study which only achieved a retrieval rate of 23.5- 61%. The difference in the efficiency could possibly be concluded by the methodology conducted. Wael et al.[25] seeded fibres into fabric chairs which could have proven difficult to tape lift due to the depth of the fibres. Schotman et al.[24] may have placed the fibres onto the surface of these garments, which could easily have been tape lifted. The pressure that has been applied to each of these fibres onto their respective surfaces is unknown, and therefore hard to compare. In Jones4 the lowest retrieval rate was from the long-pile carpet which was 71.64%, which is still higher than Wael et al.[25]

There are a range of different tapes that are utilised for fibre evidence, such as tapes that vary in size and adhesiveness. Many authors have compared different tapes, however those that are only relevant to their jurisdiction, therefore the tape utilised by law enforcement is typically dependent upon the area. It is consequently hard to compare many of the studies conducted as there are multiple tapes that are utilised globally. Jones et al.[4] has reported on two different types of tapes J-Lar and Crystal Tabs. These are two tapes that are utilised by UK enforcement. Schotman[24] is the only other author to discuss the effect of J-Lar tape, however only its effectiveness on garments. It is hard to make

comparisons of these articles, as Jones[4] utilised 12 different surface types including both garments and flooring (rough and smooth surfaces). Scotman[24] demonstrated an average of 94.6% mean recovery rate on surface types such as cotton, polyester and acrylics. This is further contradicted in Jones[4] with a mean recovery rate of 56.9-99.7%. This is indicative of surface types, as surfaces with a smoother and less sheddable material have a higher retrieval rate rather than rougher surfaces. Surfaces such as carpets, cushion covers and jumpers/trousers depict lower retrieval rates between 57-80%.

Other tapes of interest include 3M and Neschan tape, which have also been comparatively reviewed. Schotman[24] utilised the same methodology as above utilising three different garment materials, and explored the potential of Neschan tape and the 3M tape. This proved to have an average recovery of 95.6% across all materials and the 3M tape had an average of 94.1%. The only occurrence of the 3M tape outperforming the Nechan tape was when the polyester was the recipient textile. This may be due to polyester characteristically having a smooth surface, however this needs to be further researched.[26] Wael et al.[25] also researched the effectiveness of 3M and Neschan tape utilising acrylic fibres seeded onto a woolen fabric chair. Comparatively, the mean recovery rate was only 23.5% for the Neschan tape, and 61% for the 3M tape. This was the highest depicted result for the entire study. The discussion for each of the different tape results is not mentioned in this study, hence it is difficult to understand why this is significantly higher than the rest of the other tapes. These figures are based on the fibres detected by the stereomicroscopy after taping and the total number of fibres retrieved. Even though 3M tape has the highest recovery percentage, High Tack tape according to this study is the most efficient tape due to its ease of use, the recovery and doesn't saturate too quickly. Saturation is when a maximal fibre

uptake is reached and no amount of adhesive is left, this is to ensure a proper placement of the tape onto the substrate. Fibre uptake is defined as the amount of fibres recovered when applied only once to a surface. The 3M tape, although the most effective recovery rate, was discovered to have the worst fibre uptake and saturation. Therefore, when choosing a tape, multiple considerations should be considered when applying the chosen tape to the material of interest.[25]

Lastly, two other tape types have been explored which are considered to be well known brands when attending a crime scene. These two tapes are Scapa 4405 tape and SelloTape. Samlal-Soedhoe et al.[27] reports on fibre evidence recovery utilising only Scapa 4405 tape. Two tests were conducted to test the efficiency of the tape, a stability test and an efficiency test. Each test consisted of utilising different textile materials. The stability test consisted of 80 sources, consisting of 40 cotton samples and 40 polyester samples. The efficiency test utilised cotton t-shits, jeans polyester jacket and a knitted jumper. There was no significant difference between the recovery rates of the different textile materials, which is contradictory of Schotman[24] which states that the sheddability of rougher surfaces such as jumpers may affect recovery rates. The overall mean recovery rate of the Scapa 4405 tape was 80%. This is a relatively high recovery rate considering the small size of the tape, however this is still quite low in comparison to other literature and standard protocols.[24,27] The lower recovery rate comparatively to other studies could be due to the experimental procedure applied. This procedure ensured the tape was placed repeatedly on adjacent positions so that the area of interest was bigger than the tape used.

Schotman et al.[24] also studied the effectiveness of Scapa 4405 tape. This was the least efficient tape, however still produced results of 93.65%. According to the statistical

test performed, ANOVA, there was no statistical difference between the tapes examined in that particular study. These results are comparable to those reported in Pounds[28], however also indicates large differences between high and low adhesive tapes. The terms of these were not defined in Pounds[28] study and therefore further comparisons with other studies are difficult. Schotman et al.[24] notes that there is no direct relation between adhesive strength and recovery.

Lowrie and Jackon[29] discuss the effect of SelloTape on fibre retrieval. Three different fibre types (wool, acrylic and cotton) were donated to three different garment types (wool jumper, acrylic jumper and polyester jumper) that were worn over an 8-hour period. After this they were retrieved by zonal taping with SelloTape. Mean retrieval rates ranging from 30.3% to 49.5% were reported from the acrylic jumper. The mean retrieval rates reported by Jones4 for the acrylic jumper ranged from 71.11% to 92.9%. It is most likely shown that the difference in retrieval rates reported are due to the methodology utilised by Lowrie and Jackson[29] by wearing of the garment. This could have possibly induced the loss of fibres whereas Jones[4] were loosely adhered to the surface and were therefore easier to remove via tape lifting.

Essentially, when studying fibre recovery rates on various surface types, it is important to understand how a target fibre is adhered to a rough or smooth surface. Typically, smoother and less sheddable surfaces produce higher recovery rates than the rougher and more sheddable surface. The background fibres may therefore interfere with the retrieval of the target fibre. There was however only one author that commented on the recovery of fibre retrieval from floor surfaces. Jones[4] commented on the effects that carpet has on recovery

rates, and also mentioned that tile was one of the best surface types for collecting fibres, with a recovery rate of 98%.

4.2.2 Temperature

Currently Jones et al.[4] is the only author to investigate the effect of tape storage on efficiency rates of fibres. There were only three temperatures that were investigated; -5°C, 19°C and 35°C. These temperatures were chosen due to the geographical area of the UK, to encompass a typical season. Tapes stored at -5°C and 35°C tended to outperform the tapes stored at 19°C. When comparing J-LAR it was noted that temperature did effect the ease of use. When stored at -5°C the tape was more susceptible to ripping in comparison to 19°C and 35°C. At 35°C it was easier to remove from the roll without ripping. Crystal Tabs at any temperature were not shown to rip, and 35°C was seen to be more flexible therefore was easier to bend around surfaces.

4.2.3 Method of taping

There are two types of methods that can be applied to a given surface; zonal and one to one taping.[30] Zonal taping involves using a single piece of tape multiple times to cover the area of interest.[4,31] One to one taping involves covering the area of interest with overlapping tape. The main advantage of one to one taping is the ability to discover the exact location that the fibres came from. Consequently, this can be time consuming in comparison to zonal taping. Jones4 discusses that the mean fibre recovery from the 72 conditions tested using JLar tape and Crystal Tabs in 12 different garment settings and three different temperatures was between 56.9%-100% for zonal taping. This fibre recovery increased for one to one taping at 80.4-100%. Of the 72 conditions tested 73.6%

of the conditions utilising the one to one taping method established a larger proportion of the target fibres. As implied in Decke et al.[32] the one to one method is a more systematic approach than the zonal method. During the zonal method there is a possibility that some of the area may be missed as there is no indication of where the tape has previously been in contact with. This indicates that there could be a physical barrier between the adhesive and the fibre. This is indicative as to why the one to one method outperformed the zonal method. Other studies such as Wael et al.[33] discusses the ease of examination using one to one taping method, as each tape has only been placed once, therefore the tapes aren't so heavily loaded. The lower number of background fibres makes it easier to search for target fibres. Applying the tape several times, as seen in the zonal method, would make it harder to search for target fibres, as this accumulates background fibres to the tape.

There is currently no literature to establish whether pressure exerted during the application of a tape has an impact on the efficiency. Some studies such as Verdon et al.[34] that pressure may have an impact upon collection efficiency, leading to potential variation among practitioners. This statement however, has not been explored in depth enough to comment on the direct correlation between pressure and efficiency. Pressure that is utilised throughout experimentations of different research articles is not effectively measured. Jones et al.[4] comments that it is entirely possible that the pressure used when applying the tape is a variable that impacts fibre recovery, however there is no published literature in this field.

4.2.4 Extraction

Sampling using tape lifting is quick and straight forward, however DNA extraction is much more difficult due to the stickiness, rigidity and size of the tape.[35] Currently, there are only a three studies that provide a methodical comparison of different direct extraction methods for tapes.[36] To assess the full potential of tape lifting, the most efficient extraction protocol should be utilised, to avoid an underestimation of tapes compared to swabbing.[5] Many researchers have tired to improve the DNA extraction including swabbing the tape with an organic solvent and then performing extraction on the swab, submersing the tape in buffer or applying tape that dissolves in extraction buffer.[35]

Forsberg et al.[35] compares different extraction protocols such as Prepfiler BTA, direct lysis with Chelex and direct lysis with TE. Two reference materials were sleeves from t-shirts and cuffs of button down shirts, however the textile material from these garments are unknown. SceneSafe Fast™ tape was the tape that was utilised to compare these extraction techniques, most likely as it's the most common tape researched. Direct lysis with Chelex demonstrated higher DNA yields from both reference materials (0.029ng/µL and 0.017ng/µL). Direct lysis with TE buffer performed better than Prepfiler BTA for t-shirts but produced lower DNA yields taken from the button down shirts. Therefore, this study preferred direct lysis with Chelex to be implemented in routine case work with SceneSafe Fast™ tape due to the respectable DNA yield and amplifiability and the low cost in comparison to Prepfiler BTA. It should be noted, that this study only conducted their research in relation to SceneSafe Fast™ tape and there are many different types of tapes that are now being incorporated in different countries into their case work, this should be further examined.

Stoop et al.[5] explored multiple extraction techniques applied to both SceneSafe FastTM mini tapes and to swabs. Three extraction methods were utilised in this study; Phenol-Chloroform extraction, iPrep forensic kit and Prepfiler Express BTA kit. To compare each of these extraction techniques, saliva of a male contributor was mixed 1:1 with NaCl and applied onto a mini tape and left overnight. The Phenol-Chloroform appeared to be twice as efficient than the other bead-based methods with DNA quantities of 146.6ng, in comparison to 74.8ng for the iPrep extraction. This is surprising results considering the Prepfiler Express manufacturer[37] stated that this extraction technique was especially designed for adhesives, but however could only extract half the DNA that could be obtained from organic solvent extraction. As this as been studied so little, there is not much evidence as to why this could have potentially occurred. The authors have speculated that the tape from the adhesives may have interfered with the beads, but there is no information as to the chemical composition of the tapes and of the extraction kits.

5. Collection Devices

5.1.1 M-Vac

Swabbing and tape lifting are the main conventional sampling techniques that are required at a crime scene. This is however dependent on the size of the area of interest. A potential sampling alternative is the Microbial Vac (M-Vac) wet-vacuum instrument (M-Vac Systems Inc.). The M-Vac was first introduced to sample a larger surface area rather than using the traditional methods. There have only been a few studies regarding this latest technique, mainly in the area of saliva collection from skin and sampling of bloodstains on different surfaces.[38] The wet vacuum consists of a handset collection device, a sample bottle and a sterile buffer. The buffer is sprayed onto the stain whilst the vacuum simultaneously

collects the buffer for any biological/cellular material on the surface. Due to the buffer being sprayed onto the surface of the substrate, pressure and aggravation to the stain is applied. The pressure from the vacuum may in turn increase the amount of biological material that may be drawn from the surface of interest.[38] It also has no limit to the amount that can be sampled, and allows for more surface area and substrates to be sampled at any given time.[39]

Hedman et al.[38] evaluated the use of the M-Vac for sampling dried saliva on porous and non porous surfaces, shed cells on clothes and touch DNA. Saliva was spread out on laminated wood, glass, cloth towel and cotton fabric and left to dry. A swab of the saliva was also performed on all surfaces to test the efficiency of each of the techniques. The M-Vac produced significantly higher DNA yield results than the swabbing technique on the laminated wood, 1.14ng/µL compared to 0.57ng/µL. It is dependent on the non porous surface type that the M-Vac will provide greater yields of DNA than the swabbing technique. In comparison of different types of materials, the M-Vac recovered more DNA from dried saliva stains on t-shirts than cloth towels (0.42ng/µL than 0.12ng/µL). When observing wearer DNA on clothes complete DNA profiles were observed from denim jeans, leggings and cotton t-shirts. Hedman[38] indicates that the M-Vac however may not be the best technique, in terms of touch DNA in terms of assault cases. The main constituent of the mixed profiles, determined by the wearer DNA clothes produced by a mock assault consisting of pressing hands against the shoulder of the victim, was the victim's DNA. In terms of this sampling technique, tape lifting may be the best suited technique.

Garrett et al.[39] made a comparison between the double swabbing, tape lifting and M-Vac technique. The methodology to compare these techniques, was collecting blood from tiles. The collection techniques all produced similar results regarding collecting blood from tiles, as well as similar limits of detection supporting the notion that these techniques produce similar results. However, in cases such as denim and carpet it suggests that the surface type affected the type of collection technique utilised. In regards to denim fabrics, the M-Vac technique was the best technique to result in higher DNA yields. When considering low volumes of blood on denim fabrics, the M-Vac and taping method demonstrated higher DNA yields than the double swabbing technique. The differences between taping and wet vacuuming are however very low, taping never produced any results that were significantly greater than vacuuming. Results from carpet surfaces are also dependent on the amount of blood deposited. When observing blood deposited of 75µL the wet vacuum and the double swabbing technique collected significantly more DNA than the taping method. From both surfaces recorded, the M-Vac out performed both the taping and swabbing techniques producing consistently higher DNA yields.

There is an aspect of the wet vacuum technique which should be considered when using this technique. As the wet vacuum technique utilises a system that sprays the buffer onto the surface of interest, it should be considered whether this action has significant enough force to propel any of the cellular material found on this surface to any other surrounding surface not of interest. Tile was the proposed surface area to test this, as it was expected to have the highest potential for propulsion. This however was not discussed and no reference was given to determine where this information was gathered from. When comparing different volumes of blood (100, 10, 1, 0.1µL) at 1-4 inches apart, there was no real correlation between distance and concentrations of blood. There was no result from

any of the low volumes of blood, 100ul of blood resulted in the highest amount of blood collected from the surrounding area. There are however no other studies regarding force of buffer and concentrations of blood deposited. This should be studied more, as any cellular material missed could be harmful to many criminal cases.

Williams et al.[40] compared two techniques for recovery of salivary DNA from the victim's skin after showering. Swabbing and wet vacuuming were compared from different regions of the body. This study focused on whether they could collect enough salivary DNA to obtain a complete DNA profile, and whether the M-Vac is a more effective technique than swabbing for large surface areas. Based on the results there was no significant differences between the M-Vac and swabbing, and it was difficult to collect the male DNA from the victim's body regions. It is however hard to compare these results to other literature, as this is based off of human skin after showering, the biggest variable being showering. Everyone has different ways of showering and different regions they focus on more. For both the sample techniques, 25% of the DNA collected were male DNA. When comparing techniques in relation to the amount of loci that can be determined, the swab samples obtained more loci. The M-Vac is a less abrasive technique, a more abrasive technique in terms of collecting biological material after showering would be more efficient. There are multiple limitations to this study including bias to where the saliva was placed onto the body and where the researchers sampled from. If this was a blind study the M-Vac may prove to be more efficient, as well the M-Vac could cover a large surface area across the whole body, whereas you would need a lot of swabs to cover the entire body region.

5.2 Robotic Vacuum

A Roomba is a series of independent robotic vacuum cleaners sold by iRobot.[41] The robotic vacuum incorporates a series of sensors that are able to navigate the floor of an entire home. These sensors can detect the presence of any obstacles and detecting any foreign material that may be present on the floor. Dependent on the model there are various different features including tangle free brushes, obstacle avoidance and performance mapping which 29 is displayed via a smartphone device. This robotic vacuum could potentially uncover small amounts of DNA that are invisible to the naked eye, such as through the iRobot's brushes and filters. With these small amounts of DNA this has the potential to increase the solvability of cold cases and current criminal activity.

6. Project Brief

Research Aims

A household robotic vacuum, run for approximately 120 minutes in a simulated mock assault post crime scene investigation, will recover a higher quantifiable amount of DNA via Quantifiler™ Trio compared to traditional methods of crime scene investigation.

7. Conclusion

With majority of crime scenes, the collection and analysis of forensic biological material is crucial. Different types of collection techniques still need to be further explored in order to determine the most efficient technique. There are many factors which can contribute to the retrieval rate of these evidence types including surface materials, quality of the technique and methodology. Future recommendations for determining the efficiency of recovery rates of fibre evidence include researching the effect that pressure has on the

application of tape lifting. All of these factors reviewed still need to be further researched, as there was not a lot of literature that had common methodologies in order to effectively compare results. The same applies to methodologies and models explored for forensic intelligence frameworks. As there is no current model employed in Australia, much more research into current databases and algorithms that can effectively assist in crime scene linking needs to explored.

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Part Two

Manuscript

Robotic Vacuum Evidence Recovery for Low Yield Samples Overlooked Post Investigation

Masters in Forensic Science Manuscript

Robotic Vacuum Evidence Recovery for Low Yield Samples Overlooked Post Investigation

By

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A manuscript submitted as part of the requirements for the unit

BIO612

in

The School of Veterinary and Life Sciences

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List of Abbreviations

ALS – Alternative Light Source

Hi-Vis – High Visibility Garment

PPE – Personal Protective Equipment

1. Abstract

Post-investigative techniques are not a common technique that has been researched. This experimentation aimed to assess if an iRobot e5150 robotic vacuum can successfully, in a clean room, be utilised, via a simulated mock assault, collect all possible trace evidence that can be microscopically analysed to differentiate between individuals. After the 2-and-a-half-minute mock assault, the robotic vacuum could successfully collect an immense amount of orange and yellow hi-vis t-shirt fibres and a number of dark and light coloured hair. There were different trends noticed between each of the two pairs and replications. Pair one demonstrated a 5.8 and 6.6 times increase from replicate one and replicate two. However, pair two demonstrated equal numbers of orange and yellow hi-vis fibres. There are a number of factors that may have influenced this amount of fibres and hairs, such as fibre composition, pressure and fit of clothing. Although there are a number of limitations and modifications that need to be considered before this can be utilised in a forensic context, this robotic vacuum has the potential to recover microscope “trace evidence”.

2. Keywords

trace evidence, robotic vacuum, fibres, hair, stereo microscope

3. Introduction

"Trace evidence" is commonly used to describe a minute amount of material, that is often microscopic in nature, that can be utilised to aid investigations by providing linkages between potential suspects, victims and the crime scene.[1] Such physical evidence exists in the form of hair or fibres shed from clothing. The comparison of "trace evidence" forms the basic inference of criminal investigations, which are formed by various types of information that can facilitate the discovery of critical relations. This construction of links is known as crime scene linking.[2]

When two people come into contact or contact items from a crime scene, there is the possibility that a transfer of fibres will occur. Fibres are readily transferred and are slow to degrade from majority of crime scene environments.[3] It is of significant importance, that although fibres may be common as a class, individual fibre types, even discovered in combination, are rare. Fibres are also reproducible transfer and persistence behaviours. In accordance with "Locard's Principle of Exchange" these fibre types can be examined at a source and activity level. This exchange can be either primary or secondary transfer. Primary transfer is when a fibre is transferred from a fabric directly onto a victim's clothing, and secondary transfer is when already transferred fibres on the clothing of the suspect transfer to the clothing of the victim.[4] There are many variables which affect fibre transfer such as; the sheddability of a garment, such as through the construction and composition of the fabric, the duration and force of the contact and the condition of the garments. Therefore, it is pivotal that forensic investigators are collectively about to search, recover and analyse fibres that are discovered at a crime scene.[4]

It is also crucial that the ideal method of fibre recovery is adhered to. This methodology should be cost effective, portable, simple and quick to perform with minimising the risk of contamination. Several methods are currently employed at crime scenes, including tape lifting, combing and vacuuming.[5]

As with fibre evidence, there is the potential for hair transfer to occur. One of the most commonly encountered types of trace evidence recovered during a criminal investigation from the crime scene, suspect and victim, is hair.[6] It is estimated that humans naturally shed between 50 to 150 hairs daily. As with all biological samples that may be collected, hair has 7 the potential to provide valuable intelligence via DNA analysis, pertaining to the identity of offenders and victims.[7]

As there is such importance surrounding the collection of “trace evidence” from crime scenes, this study aims to create discussion surrounding the idea of post-investigative techniques. This may ensure that investigators are maximizing the possibility of detecting any unnoticed “trace evidence” and the ability to obtain any other biological evidence, if further analysis is required. This may also minimize the number of cold cases, where all samples collected initially have been analyzed without success. This study explores using a robotic vacuum after the simulation of a mock assault to collect all possible “trace evidence”, that can be microscopically analyzed to differentiate between individuals.

The aim of this experimentation was, a mock assault, using 2 and a half minutes, was conducted in a clean room and thereafter a sterile iRobot e5150 was set forth to recover biological trace evidence that can be microscopically analysed to differentiate between individuals.

4. Method/Materials

4.1 Cleaning Procedure of Transportable Room

Two transportable rooms located at Murdoch University were utilised for the purpose of this experimentation. This cleaning procedure was conducted in complete personal protective equipment (PPE) including; gloves, hair net, mask, cover shoes and coveralls. A Sirchie SIRCHVAC Evidence Vacuum Sweeper, 220V AC was utilised to clean any debris that were present on the floor of both rooms. This included the skirting underneath the floor of the rooms.

Following the Sirchie Vacuum a 16% bleach solution was prepared. Utilizing a sponge mop, the entirety of the floor was scrubbed using the bleach solution, including approximately 30 cm of the wall to minimize contamination with the robotic vacuum. The first transportable room was allowed to dry overnight, the second transportable room due to wetness of the bleach solution was allowed to dry over two nights. Following bleaching, tape lifting of the entirety of the room floor was conducted to further minimize the contamination of any unknown debris. Tape lifting was conducted using Paint Partner 48mm x 48m Clear Tape, using a single strip of tape to adhere to any debris along the ground. To prevent any contamination from outside, tape was placed along the bottom edge of the door.

This cleaning procedure was conducted twice for each replicate of the rooms. The exact time taken between cleaning of each of the rooms was also replicated. Two days was taken in between bleaching and tape lifting. A control swab of both transportable rooms, from every clean was taken using a cotton swab to ensure that there was no contamination in

the room. A reference swab was also conducted from each participant for further profiling analysis if required. These swabs were stored in a refrigerator at 4°C.

4.2 Cleaning Procedure of Robotic Vacuum (IRobot e5150)

The robotic vacuum was cleaned using a 10% solution of Trigene. Each part of the robotic vacuum that would touch the ground was taken apart and cleaned using the Trigene solution followed by distilled water. This was undertaken using Kimtech® Science™ Kimwipes™ Delicate Task Wipers. The parts included in the cleaning procedure were; the dual multi-surface rubber brushes, the wheels and the side brushes. This was replicated four times, to ensure that it was clean in between each experimentation.

4.3 Execution of Mock Assault

Two pairs of individuals, male and female, were given three items of clothing each before entering the transportable rooms. These pieces of clothing were; Hi-Vis shirts (yellow shirts were given to the males, and orange shirts were given to the females), navy blue cotton shorts and grey wool blend socks. For the purpose of contamination, the pair was instructed to place the wool socks on when stepping into the room to avoid risking any outside material transferring to the socks. Once the pair entered the room, they were instructed to pull at each other's clothing sleeves for one minute. One at a time, each participant was then instructed to roll on the ground for 30 seconds. Lastly, the participants were instructed to pull at each other's clothing sleeves again for another 30 seconds. The participants clothing was then removed and stored appropriately. It should be noted, that the same individuals were paired for each replication, for example male A was paired with female A, and male B was paired with female B.

4.4 Robotic Vacuum (IRobot e5150)

The robotic vacuum was placed in the first transportable room, one day after the execution of the mock assaults. The IRobot e5150 is designed to vacuum the room until it has determined that the room is clean using its sensors. The time that the robotic vacuum took for each room was recorded, to ensure reproducibility.

4.5 Extraction of Robotic Vacuum (IRobot e5150) Components

The filter, dual multi-surface rubber brushes and the bin container were disassembled from the vacuum. A foam swab of both the multi-surface rubber brushes was taken, and stored in the refrigerator at 4°C for further DNA analysis. The filter was disassembled and placed into a zip lock bag and correctly labelled for further fibre analysis. The bin container was emptied onto an A3 sheet of paper, and the contents of the container was stored in three separate petri dishes. Each petri dish was sorted into hair, fibre and other. The petri dishes were labelled and taped using Scotch™ Tape to ensure no contents could be removed. These petri dishes were stored in the laboratory for further microscopic analysis. This procedure was replicated as per each sample. Each replicate, the robotic vacuum was cleaned, using 10% Trigene and rinsed with distilled water, and the filters were replaced. The components were not replaced, until they were fully dry.

4.6 Microscopic Analysis

Microscopic analysis was conducted of each of the three petri dishes was undertaken after the final robotic sampling occurred. A stereo microscope with a white light, along with grid paper, acetate sheets, tweezers, scissors and packing tape was used. Each individual petri dish's contents were spread onto the acetate sheet, which had been taped onto the back

of grid paper. Using the stereo microscope, each individual hair and fibre was counted at every 1cm square grid. A tally was conducted to keep count of the amount of hairs and fibres that were collected. An Alternative Light Source (ALS) using a blue light (450nm) was utilised to enhance the visualisation of fibres.

5. Results and Discussion

5.1. Evaluation of Fibre Evidence

The robotic vacuum (IRobot e5150) after a two-and-a-half-minute simulated mock assault, proved to successfully collect an immense amount of orange and yellow hi-vis fibres (Table 1 and 2). Although this is a simulated mock assault, there are a number of variables which need to be considered when evaluating the data. These variables are but not limited to; the construction and fibre composition of the fibre material, the duration and force of contact, and the condition of the garment with regard to damage.[4]

The data, in relation to pair one, demonstrates possible trends between the two replicate samples, as well as between the two hi-vis fibres. As seen in Table 1, replicate two demonstrated a 5.8 times and a 6.6 times increase in both orange and yellow fibre types. This may be due to the natural shed of the fibre material. Shedding, is however a complicated process which include tensile fracture and flex fatigue of fibres. Shedding is more commonly discussed in fibres that have been washed.[8] The clothing utilised for this experimentation was not washed prior to wear for either replicates. There are several authors that discuss the persistence and transfer of fibres during a simulated assault. Robertson[9], mentions that there is no quantitative analysis that has been conducted to recognise that fibres would be lost following contact with clothing. Pounds[10], only studied

the persistence of two different fibre types (wool and acrylic) on a number of recipient garments during various periods of wear. They demonstrated that following an initial rapid loss of fibres, that there was 5-10% loss after six to eight hours after experimentation. This may explain the dramatic increase in fibres over the replications, however this experiment was only a period of 2 and a half minutes for each simulated mock assault. Fibre loss and fibre persistence, however has not been thoroughly researched, in relation to general shedding of the fibre. As well as, researching only a small period of wear in accordance with simulated assaults. In a real crime scene scenario, this would be an important factor that could increase the amount of fibres that the vacuum could potentially collect. The pressure exerted during the mock assault, may also have influenced the amount of fibres present. The force was not a measurable factor that was assessed in this experimentation, and many authors omit force from their studies, due to the complexity of measuring this variable. This variable, is not heavily researched either, which may be due to the ethical nature of exerting force on an individual. Lastly, the fibre composition of the garment is also an important factor in determining persistence. The hi-vis shirts that were worn, were polyester material. The texture of the recipient garment was also an important factor in determining persistence, such as cotton garments had a very rapid loss of fibres. Lowrie and Jackson[11], observed that a smooth polyester garment gave the highest retrieval rate compared to a wool or acrylic garment. In comparison, cotton produced a high retrieval rate (97.4%).[3] This is however, only a representation of retrieval from clothing, and not general shedding onto the ground. Hi-Vis clothing was only used to visually aid in counting of the fibres that were lost, and not for persistence and shedding purposes. In future studies, other fibre types would be researched and made comparisons against, to see if other fibre types shed more than others. The navy blue shorts and the woolen grey socks,

were counted in petri dish's labelled as "other." However, these were not noted, as its too hard to depict if those fibres were already present in the room, as the tape lifts from the room during the initial clean were not kept as references.

Table 1. Pair 1 of orange and yellow hi-vis fibre counts from the bin container and filter of the iRobot e5150.

	Orange	**Yellow**	**Ratio**
Replicate 1	512	61	0.119
Replicate 2	2979	403	0.135
Ratio	5.8	6.6	

Table 2. Pair 2 of orange and yellow hi-vis fibre counts from the bin container and filter of the iRobot e5150.

	Orange	**Yellow**	**Ratio**
Replicate 1	429	609	1.420
Replicate 2	328	560	1.707
Ratio	0.76	0.92	

Table 2 indicates different trends in comparison to Table 1. Table 1 represents that more fibres were shed from the items of clothing during the first replicate sampling. Although, there were less fibres shed, there were similar ratios between the fibre types. Importantly, there are a similar amount of fibres shed between both the orange and the yellow fibres, in comparison to pair one. This may be indicated by similar force exerted between the two 14 pairs. The amount of force exerted could indicate the different trend between the pairs. However, this is just an assumption, as the force used was not measurable for this experimentation. The limitation in regards to these samples, is all individuals involved didn't change pairs. If the individuals had changed, a better indication between how many fibres shed could have been established. A greater sample size of pairs, would also demonstrate a better representation of fibre transfer and persistence. Another variable, which may indicate different wear patterns of the fibres, and between the two pairs of participants, is fit of the clothing worn. All participants were given the same size clothing, dependent on the fit of the clothing sleeves, could indicate how much fibres are shed. The amount of pressure applied to the individual, during the simulated mock assault, may affect how the clothing sleeves pull against the individual's arm. If the clothing sleeve was pulled tighter towards the arm, less fibres could have potentially been shed. This however, is just an assumption, and with further research could emphasis the importance of the robotic vacuuming for post- investigative sampling.

5.2 Hair Evidence

The robotic vacuum (IRobot e5150) after a two-and-a-half-minute simulated mock assault, proved to successfully collected range of dark and light coloured hair, represented in Table 3 and 4. Dark hair was characterised by black hair and dark brown hair, and the light hair

was characterised by blonde hair. This was categorised for the purpose of identification, and proved an easier method for tallying. The purpose of hair evidence, is that there is a possibility of collecting DNA from hair. This however, can only be undertaken when the root is present so that the DNA may be obtained from adhering epithelial cells in that area.[12] With time constraints, the hair collected from the robotic vacuum was not used for visual analysis of the root. As well, the simulated mock assault, was solely focused on pulling at the clothing sleeves of participants and rolling on the ground. This may be the reason for less hair collected, as in order to reduce the amount of variables, hair pulling or simulating activities to induce hair loss was not replicated. The amount that individuals shed, is independent, and therefore comparing between the pairing is difficult. There are many factors that could influence shedding of hair; including grooming and different compositions of hair.[13] For the purpose of this experimentation, it was important to establish that the robotic vacuum had the capability to collect hair evidence, that could assist in the identification of individuals. This is especially important if reference samples have already been taken, dependent on the location of the crime scene.

Table 3. Pair 1 depicting dark and light hair counts from the bin container and filter of the iRobot e5150.

	Dark	**Light**
Replicate 1	95	29
Replicate 2	31	12
Ratio	0.326	0.414

Table 4. Pair 2 depicting dark and light hair counts from the bin container and filter of the iRobot e5150

	Dark	**Light**
Replicate 1	15	16
Replicate 2	4	7
Ratio	0.267	0.438

5.3 Limitations

There are many limitations and factors that should be taken into consideration when undertaking this experimentation. The swabs taken from the robotic vacuum that were to be utilised for DNA analysis, due to time constraints, were not extracted. This therefore, should be incorporated into future experimentations, to establish if it is possible to extract and profile an individual. The components of the robotic vacuum proved hard to extract fibres. The filter was composed of a mat of randomly arranged fibres, these fibres when attempting to tweeze out the "other" fibres located in the filter, were also pulling out of the filter. This made it extremely hard to differentiate between the grey woolen fibres and the filter fibres. For this reason, the fibres located in the filter were not counted. The bin container, located at the back of the robotic vacuum, was also unable to open the entire way. This proved difficult when trying to collect all possible fibres and hair from the vacuum. Microscopically, when counting the fibres, due to the dense amount of fibres bundled together, approximations were made. This could potentially increase or decrease the number of fibres that were collected. The location of the transportable rooms located at Murdoch University, were near trees and bush that contained pollen. When cleaning the transportable rooms, and opening of the doors in-between each replicate samples there was the possibility of pollen entering the room. To prevent this contamination, tape was placed at the bottom of the door.

5.4 Future Research

There are modifications to the robotic vacuum that could be potentially made to make this more forensically relevant to post-investigative research. Currently, the HEPA filter that is used, can collect dust up to 10 microns. The average cross section of hair is 50 microns, and

majority of epithelial cells are measured between 9-17 microns.[14] There are large differences that exist between individuals, and therefore the HEPA filter should accommodate to all cell sizes, so that there is the possibility for extraction. Therefore, the hepa filter should be 5 microns so that all cells would be trapped, and can be extracted. The filter should also be redesigned, to form a flat matrix and have the capability of being able to pull the filter off the vacuum. The bin should also be modified, so that the lid of the bin container can be pulled completely apart, so that no fibres and hair is trapped. For forensic purposes, these components should be replaceable, so that for every case that the vacuum is employed to, the robotic vacuum wouldn't have to be cleaned every time, and would save time on future cases.

DNA analysis should be incorporated into the analysis part of the robotic vacuum. By swabbing every component on the bottom of the vacuum, there is the possibility of collecting epithelial cells. Swabbing the multi-surface rubber brushes, the side brushes and the filter incorporates a higher chance of discovering some shed epithelial cells, that could be later profiled. An increased sampling number, such as incorporating more pairs, may provide a greater insight into fibre and hair shed. Focusing on identifying if a root on the hair is present, would help investigators profile individuals that may be involved with particular criminal investigations.

6. Conclusion

With majority of crime scenes, the collection and analysis of forensic biological material is crucial. There is a strong importance on collecting all possible “trace evidence”, and ensuring that any microscope material doesn’t go unnoticed. Enhancing this collection, through robotic vacuum, post-investigative techniques could greatly help the crime scene investigators. This experimentation, proved that an IRobot robotic vacuum e5150 can successfully collect a range of orange and yellow hi-vis fibres, and different hair types. However, there are many variables that can affect the fibres and hair that were collected. These variables include composition of fibres, force used during the assault, and the activities involved in the assault which could increase the amount of fibres and hair shed. Research into the modifications to the components of the vacuum and the different fibre types which can naturally shed should be prioritized to increase the realistic forensic capabilities of this technique. This robotic recovery technique, should be reviewed for future applications to real forensic cases, because if all evidence types have been analyzed, this could ensure that no case goes cold.

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