Footwear Impression as Forensic Evidence – Prevalence, Characteristics and Evidence Value

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Titel
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Sammanfattning

The Forensic Science comprises a variety of sciences that are applied in order to assist and answer questions of interest to the legal system. Since the end of the 18th century footwear impression comparison has been applied to assist in crime investigations. By examining the characteristics of a footwear impression the forensic scientist may provide the investigator with valuable information about the footwear and sometimes even about the wearer. Ultimately, the footwear impression is so unique that it can be individualized and identified to a specific shoe.

In order to facilitate and improve the forensic evidence evaluation it is of great interest to statistically establish the prevalence of evidence. By collecting data of outsole patterns and then recording it in a database the strength of a specific footwear impression can be determined. In this survey 687 impressions were randomly collected and recorded in a visualised database classification system, SIMSALAPIM , whereupon a statistical evaluation was performed.

The result of this survey indicates that a specific outsole pattern typically only occurs once in the database, wherefore it can be stated that any footwear impression provides some strength/value as forensic evidence even though there are no individual characteristics present. Moreover, through additional statistical evaluations, a relation between age and shoe type also was revealed.

Nyckelord
Footwear impression, forensic, evidence value, survey, data bases

Abstract

The Forensic Science comprises a variety of sciences that are applied in order to assist and answer questions of interest to the legal system. Since the end of the 18th century footwear impression comparison has been applied to assist in crime investigations. By examining the characteristics of a footwear impression the forensic scientist may provide the investigator with valuable information about the footwear and sometimes even about the wearer. Ultimately, the footwear impression is so unique that it can be individualized and identified to a specific shoe.

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Sammanfattning

Den forensiska vetenskapen innefattar en mängd olika vetenskaper som tillämpas för att bistå och besvara frågor av intresse för rättsväsendet. Skoavtrycksjämförelser har använts sedan slutet av 1700-talet för att bistå i brottsutredningar. Genom att undersöka egenskaper hos ett skoavtryck kan en forensiker ge utredaren värdefull information om skon och ibland även om bäraren. I bästa fall är skoavtrycket så unikt att det kan individualiseras och identifieras till en specifik sko.

För att underlätta och förbättra den forensiska bevisvärderingen är det av stort intresse att statistiskt erhålla förekomsten av ett bevis. Genom att samla in data gällande sulmönster och sedan etablera en databas kan styrkan hos ett specifikt skoavtryck fastställas. I denna studie samlades 687 avtryck in slumpmässigt och lades in i ett visualiserat databasklassificeringssystem, SIMSALAPIM, varpå en statistisk utvärdering utfördes.

Resultatet i denna studie visar på att ett specifikt sulmönster generellt förekommer endast en gång i databasen, varför det kan sägas att ett skoavtryck tillför en viss styrka/värde som forensiskt bevis även om det inte besitter några individualiserande detaljer. Vidare, genom ytterliggare statistiska utvärderingar, kunde även ett samband mellan ålder och typ av sko ses.

[1] Shoe IMpressions Search And Linking with the Aid of a Partial IMpression

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Abbreviations

DNA - DeoxyriboNucleic Acid
BRÅ - Brottsförebyggande Rådet
DLK - Dustmark Lifting Kit
D-SLR - Digital Single Lens Reflexion
E - Evidence
ESDA - ElectroStatic Document Apparatus
H - Hypothesis
H_D - The suspect is the source of the questioned evidence
H_P - The suspect is not the source of the questioned evidence
LR - Likelihood Ratio
SIMSALAPIM - Shoe IMpressions Search And Linking with the Aid of a Partial IMpression
SKL - Statens Kriminaltekniska Laboratorium

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1. Introduction

Through the centuries several trace evidence have been recognized to be of significance in crime investigations. For instance, blood, body fluids, fibres, tool impressions, tire track impressions and footwear impressions are some general traces that can be recovered, examined and processed as evidence. (Jackson *et al.*, 2004)

By examining a footwear impression the forensic scientist may provide the investigator with valuable information about the footwear and sometimes even about the wearer. The characteristics of an impression can, in fact, be so unique that it enables for identification with a suspect shoe. Thus, the footwear impression may be considered to be forensic evidence of great significance. (Jackson *et al.*, 2004)

1.1 Background

Forensic science is defined as the application of a variety of sciences in order to assist and answer questions of interest to the legal system. The word forensic is a well-recognized international concept that comes from the Latin word "forensis" which means forum, or daily speaking; public. (Nationalencyklopedin, 2007). In the Roman society (~700 BC-400 AD) a criminal charge meant presenting the case before a group of public individuals. Both the person accused of the crime and the accuser would perform speeches based on their side of the story at the forum in Rome, i.e. Latin "forum romanum". The outcome of the case would be based on the individual argumentation and delivery and, therefore, the person with the best forensic ability would win. (Encyclopaedia Britannica, 2007)

1.1.1 Historical

Over the centuries the humanity will to do justice continuously has forced the forensic science forward. Although, it is primarily during the last decades that it has become a key part of the law enforcement. Today, all criminal investigations are, in some way, assisted by the forensic science. (Jackson *et al.*, 2004)

1.1.1.1 In General

The use of forensic science predates by more than 1000 years its first systematically application in the modern world. In Europe the forensic science generally emerged in the 17th century when, primarily, medics started to use their own knowledge to examine and determine cause of death. Subsequently, in the 18th and 19th century, in addition to the forensic medicine other forensic applications such as physical matching, fingerprint, footwear impression, ballistic and handwriting analysis were recognized. (Encyclopaedia Britannica, 2007)

In the 19th century medicine, psychiatry and toxicology were acknowledged as forensic specialities and the first detective agency was founded. This was also the century when the most well known detective, Sir Arthur Conan Doyle's, Sherlock Holmes came to light. (Encyclopaedia Britannica, 2007)

Nevertheless, the 20th century was, without a doubt, the century of most extensive revolutionary work within the forensic science. Among other things the identification with DNA had its breakthrough and the Federal Bureau of Investigation, FBI, was founded. Furthermore an Automated Fingerprint Identification System, AFIS, was introduced as the use of computers and internet grew at the end of the century. (Encyclopaedia Britannica, 2007)

Today, the forensic science takes a natural part in the legal system all around the world and continuously persists to develop and expand, i.e. be on advance (Jackson *et al.*, 2004). Consequently, the 21st century unquestionably will provide for "old" techniques to improve and new methods to develop. Most likely this century also, to a great extent, will be focused on what value to ascribe evidence secured at a crime scene, i.e. the evidence value.

1.1.1.2 Footwear Impression

According to literature the first application of footwear impression as evidence in a crime investigation can be dated back to the Richardson murder case in 1786 in Scotland. The investigator then recognized through a comparison between a footwear impression made at the crime scene and the outsole of a questioned shoe, that a positive identification could be made. Due to this establishment, the footwear imprint comparison subsequently became a vital complement to the more traditional forensic examinations. Today, the footwear impression is considered to be such powerful evidence in itself that it may hold as solitary evidence in a conviction. (Hilderbrand, 1999)

1.1.2 Theoretical

Since the great significance of footwear impressions in crime scene investigations was first recognized, about 200 years ago, there has been a continuous development of adequate techniques and methods to recover impressions made on different substrates and surfaces (Hilderbrand, 1999). However, as the existing recovery procedures today may provide for a sufficient quality the forensic scientist now also seems to begin to attempt improving the comparison and evaluation processes.

In order to facilitate the comparison examinations and evidence evaluations of footwear impressions, searchable databases including both reference and crime scene impressions have been established the world over. In Sweden there is today only one existing footwear impression database, positioned at and maintained by the police in Uppsala. It contains approximately 6000 impressions, both crime scene and test impressions, and is continuously expanding. (Kärsrud, 2007)

Due to the advance of footwear impression as forensic evidence it may be justified to examine the strength of support footwear impression evidence provides to a proposition put forward by the court. By establishing a footwear impression reference database the prevalence of different outsole patterns in a normal population may be recorded which enables for statistical evaluations that facilitate the evidence evaluation. In order to provide accuracy the database is required to be constantly updated, i.e. new patterns is added and old patterns are removed.

1.2 Aim and Object

This master thesis is performed on behalf of the Swedish National Forensic Laboratory, SKL, in Linköping, Sweden. The primary aim and object is to determine the prevalence of different outsole patterns in a normal population. In order to do so a reference database is to be established and subsequently statistically evaluated. Apart from prevalence, also characteristics and evidence value are parameters to explore.
To be able to understand why footwear impression evidence may reveal sufficient details to uniquely identify a specific shoe, a section of essential theory is added in this master thesis. The theory is first and foremost written for those who are novel to the footwear impression evidence however, the chapter regarding evidence evaluation may be of general interest.

1.3 Limitations

Primarily due to the time limitation of this master thesis, the survey has to be somewhat restricted. Thus, for the purpose of this project, it is restricted to the most significant group of the population. According to Swedish crime statistics[2], the group of selection is to be men over the age of 15, however, due to a requirement of anonymity[3] it is to be reduced to men over the age of 18.

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[2] Statistics from 2006, presented by the Swedish Crime Prevention Council (BRÅ), 2007.

[3] By ethical reasons should the participation in the current study by person under the age of 18 be granted by parents/guardian, which may jeopardize the anonymity.

2 Preliminary Studies

2.1 Pilot Study

Prior to this master thesis a two-week pilot study with the aim to obtain a general knowledge of the footwear impression and its significance as forensic evidence, was performed. Apart from a study visit at the Crime Investigation Unit in Uppsala, where the only Swedish footwear impression database is positioned, this study was to a great extent concentrated on searching the Internet for technical facts and scientific articles.

2.2 Literature Study

Due to some limited amount of factual book literature covering the area of footwear impression, this study was mainly concentrated on reading "Footwear Impression Evidence – Detection, Recovery and Examination" written by William J. Bodziak, a Supervisory Special Agent (retired). This book is often referred to as the "footwear impression bible" by the forensic scientists as it covers the whole strata of footwear impression.

Scientific articles, covering both footwear impressions in general and similar statistical surveys as the one to be performed in this master thesis were searched for on the Internet and in the library supplied by The National Laboratory of Forensic Science, Linköping, Sweden. Although some articles concerning technical facts about the materials and methods applied in the collecting and processing of footwear impressions were obtained, only one survey of significance was found; namely "Survey of 1276 Shoeprint Impressions and Development of an Automatic Shoeprint Pattern Matching Facility" by Hannigan *et al.* (2006). This article provides an Irish survey of the footwear impression prevalence and acknowledges a number of vital parameters of the footwear impression as forensic evidence. Especially the parameters in relation to each other are examined, resulting in some observable connections between them. As far as possible, a comparison between this survey and the one to be performed will be made.

3 Theory

3.1 Footwear Impression Evidence

According to William J. Bodziak the general definition of impression evidence is “Objects or materials that have retained the characteristics of other objects or materials through direct physical contact”. Within the forensic field several forms of impression evidence such as fingerprints, palm print, bare foot prints, bite marks, tool marks, contusion injuries, typewritten impressions, footwear impressions and tire impressions are encountered. Each impression constitutes a form of physical evidence that is carefully examined by the forensic scientist in order to provide the crime investigator with an important link between the offender and crime scene. (Bodziak, 2000)

Even though the footwear impression cannot identify the wearer and, thereby, direct link a person to the evidence, it is valuable physical evidence that can be found at almost all crime scenes (Bodziak, 2000; Hilderbrand *et al*., 1995). It is, therefore, important that the crime scene technicians and investigators understand its great significance and carefully search the crime scene for it (Bodziak, 2000). Nevertheless, the footwear impression is often disregarded as evidence, either due to failure in locating and recovering or undervaluation by the legal system due to limited knowledge (Bodziak, 2000; Hilderbrand *et al*., 1995).

3.1.1 Frequency and Durability

Each and every step of a person causes an interaction to occur between the outsole of the shoe and the ground. A direct physical contact will either result in a deformation of the ground or a transfer of trace materials and residues from the shoe to the ground surface or in reverse. (Bodziak, 2000)

The durability of a crime scene footwear impression is often sufficient enough to allow for its discovery, retrieval, recording, and examination. Even though a footwear impression may not be possible to recover properly, it can nonetheless be permanently recorded. (Bodziak, 2000)

3.1.2 Identification

A footwear impression can in many instances either be positively or negatively identified as having been made by a specific shoe. The identification is based on a physical match between individual characteristics of the impression and the questioned shoe. (Bodziak, 2000)
Although most forensic laboratories, including SKL, determine their own standard operations the basic process of footwear impression identification is generally the same, see fig. 3.1.

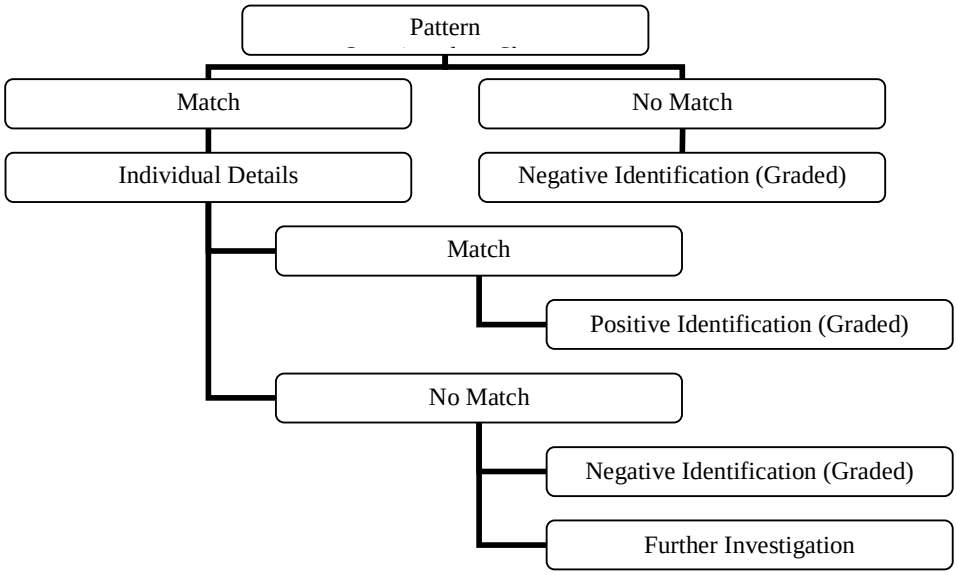

Fig. 3.1 A summary of the standard footwear impression identification process performed. The comparison concerns a questioned impression and a suspect shoe.

Even though the individual characteristics may be insufficient for a positive or negative identification there are other present features that can be of significance. For instance, factors such as outsole pattern and wear may to a great extent reduce the number of other shoes that could be the source of the impression. (Bodziak, 2000)

3.1.3 Information

In addition to being a reliable piece of evidence of a person's presence, a footwear impression can reveal vital information about the wearer such as body size, shoe size, and walk style. Ultimately, its internal characteristics such as size, pattern, and damages in combined may constitute sufficiently unique details to identify a specific shoe. (Bodziak, 2000)

When trying to reconstruct the crime also the presence, characteristic and condition of observed footwear impressions at the crime scene becomes crucial. This as it may reveal information about the number of offenders, the offenders' behaviour at the crime scene and way of entrance and escape. Also the absence of footwear impressions at a crime scene can provide vital information as it can tell what cannot have happened. (Bodziak, 2000)

If there are several successive footwear impressions present at the crime scene some methods have been suggested to record information of the shoe wearer's gait. However, as the gait characteristic varies within the same individual it is not given any significant value but instead it serves as a hint. (Bodziak, 2000)

3.1.4 Deformation of the Surface

Soft surfaces may yield to pressure exerted by the shoe on the ground and deform, either temporarily or permanently. Regardless of which, the deformation will retain the characteristics of the footwear. (Bodziak, 2000)

Soil, sand, snow, and similar material constitute somewhat inelastic surfaces and allows for relatively permanent three-dimensional impressions. On the contrary resilient surfaces such as

grass, carpet and skin only allows for temporary three-dimensional impressions but permanent two-dimensional impressions may occur in conjunction to them. These two-dimensional impressions are often marks or damage such as stains, contusions or transferred residues. (Bodziak, 2000)

3.1.5 Transfer of Trace or Residue Materials

Generally two-dimensional impressions occur due to a transfer of trace or residue materials between the footwear and the ground surface/substrate. There are two possible directions of material transfer, either from the shoe to the ground which provides a positive impression (most frequently found at the crime scene) or from the ground to the shoe which provides a negative impression. (Bodziak, 2000)

A two-dimensional impression may occur both for dry and wet shoes on several receiving surfaces. Dry impressions are made when both shoe and surface is dry while wet impressions occurs when either the shoe and/or the surface is wet. Common dry surfaces are floors, paper items, pieces of glass and other polished surface. The trace materials that constitute a footwear impression may either originate from the outsole itself or be adsorbed or ground into it leaving trace of the soles impression on the surface. Even an outsole that appears to be clean may deposit trace materials on the surface. (Bodziak, 2000)

A dry two-dimensional footwear impression may lack in contrast with the surface making it somewhat difficult to detect in normal light. An oblique light source is therefore to prefer. Further more, also wet impressions which often are dry when found, may be difficult to detect. However, even though there may be no visible residues present a disturbance in the surface can be detected by applying oblique light or fingerprint powder. Footwear impressions made in other materials such as blood and oil are usually more visible and, consequently, easier to detect. (Bodziak, 2000)

3.1.6 Detecting Footwear Impressions at the Crime Scene

Many times footwear impressions are overlooked by the investigators and crime scene technicians. Unaggressive and incomplete searches at the scene are especially common when the exact nature of the crime is not known or when the knowledge of the ways footwear impressions can occur and how they can be found is insufficient. (Bodziak, 2000; Hilderbrand, 1999)

The detection and recovery of footwear impression may be extremely difficult due to several factors. For instance, unauthorized people may have trampled over the crime scene and destroyed the impressions present or the shoe and surface characteristics may constitute a combination that is unable to conduct footwear impression. Further more, all impressions made outside will eventually be destroyed by the weather wherefore the time before detection becomes crucial. Unlikely, but possible, the offender may also intentionally destroy the impressions made at the crime scene. (Bodziak, 2000)

The likelihood of detecting footwear impressions varies depending on the circumstance and surface it has been made on. Generally it is very likely (almost every instance) to detect a visible or latent impression. Most likely to find footwear impressions is when the shoe sole is coated with materials like blood, oil or grease. Then the impressions may be seen regardless of the receiving surface. Second most likely to find are impressions made by a dry sole with dust or residues, which may be detected on almost all surfaces except for dirty floors. Impression made by damp or wet shoes are very likely or likely (occurs very often) to be

detected on all surfaces except for carpets while impressions made by clean dry shoes are likely to be found on almost all surfaces except for carpets and relatively clean, unwaxed floors. (Bodziak, 2000)

3.1.7 General Treatment

It is crucial that the recovery of footwear impressions is properly executed in order to retain all the impression characteristics. (Bodziak, 2000)

Due to the innumerable combinations of impression forms and receiving surfaces there is no single method that can provide for a sufficient recovery of all of them. Therefore, there are several techniques, materials and equipments to be used to maximize the success of recovery and the subsequent use of this evidence. (Bodziak, 2000)

Once a footwear impression is detected at the crime scene it should be treated and recovered according to this guideline:

- Take General Crime Scene Photographs. This in order to record and document the original features and location of the impression. For further details see section 3.2.1.1.
- Take "Examination Quality" Photographs with a Scale. Close-up photographs records the details required for scientific comparison with a suspect's shoe. For further details see section 3.2.1.2.
- Make Notes and Crime Scene Sketches. Document the exact whereabouts, and conditions and circumstances that encompass the footwear impression. This will coordinate the photographs, casts and lifts executed at the scene.
- Remove the Impressioned Item from the Scene. If possible, all original impressions should be removed from the scene to enable better processing of the evidence at the forensic laboratory. In case a physical removal from the scene is difficult or impossible to carry out, different techniques such as casting, lifting and enhancement are utilized to recover the impression.

(Bodziak, 2000)

3.2 The Recovery of Footwear Impressions

At a crime scene there may be a multitude of footwear impressions, both visible to the eye and latent. The visible impressions are often easily observed while the latent ones require some additional processing to emerge. Thus, the entering of a crime scene becomes extra crucial in order to maintain all the evidence. (Bodziak, 2000)

Different types of footwear impressions require different processing depending on parameters such as the surface they have been made on, and whether they are two- or three-dimensional. To maintain the quality of an impression it is very important to apply the right method when securing it. An inadequate method would at worst destroy the evidence and, thereby, make a subsequent comparison and identification impossible. If a footwear impression is made on a portable material it is preferably recovered at the forensic laboratory, as it provides for the best processing of evidence. (Bodziak, 2000) However, generally the recovery is performed directly at the crime scene and involves photography, lifting and casting. (Bodziak, 2000; Hilderbrand *et al*., 1995)

Due to the variety of footwear impressions there are several recovery methods available, of which some are best suited for crime scenes, others for laboratory work, and a few for both. The most powerful tool in the process of recovering evidence is photography, a non-destructive method that is primary applied at all crime scenes. Most of the times a

photographic enhancement provides sufficient details of the impression and, consequently, additional methods are not necessary. (Bodziak, 2000)

3.2.1 Photography

Photography is a very important recovery method that due to its non-destructive nature always can be applied at any the crime scene without influencing or destroying the evidence present. Not only does the photography provide an overall picture and documentation of the crime scene, but also it may assist the subsequent investigation and evidence evaluation. For instance, it enables reconstruction of the crime scene, if needed, and may be used to verify or refute witness testimonies and in determining the guilt or innocence of a suspect. (Bodziak, 2000)

To obtain high quality photos the photography has to be executed in a prescribed way and several parameters have to be taken into consideration, including camera, resolution, film, and lighting.
The general photography performed at the crime scene can be divided in two categories; general crime scene photography and examination quality photography. (Bodziak, 2000)

3.2.1.1 General Crime Scene Photography

The primary aim of performing general photography at the crime scene is to document and describe the recovery, location and orientation of evidence to get an overall picture. To facilitate the documentation and the subsequent interpretation of the photographs all evidence are assigned and marked with a numbered prior to the photography. (Bodziak, 2000)

In order to provide an as comprehensive picture as possible of the crime scene, photographs are taken from different angles at two or three different distances; long range, mid-range, and close range. Hence, a zoom-in effect on a specific area or object can be achieved. The long range photographs will provide an overall picture of the crime scene while the mid-range photographs give a closer view of a particular area. Further more, the close range photographs will focus on a certain object as it relates to its immediate surrounding. (Bodziak, 2000)

3.2.1.2 Examination Quality Photography

This type of photographs, also called evidence photographs, are taken to record all the details of the evidence required for a subsequent forensic examination and comparison. Unlike the general crime scene photography which only records the location of evidence this type of photography captures the very minute details of the evidence itself with maximum accuracy. To guarantee a sufficiently high quality of the pictures there are several important things to consider when performing photography. Therefore, often in order to facilitate the work of the photographer specific protocols to follow have been established. (Bodziak, 2000)

3.2.1.2.1 Footwear Impression Photography

In performing examination quality photography of footwear impressions light becomes an especially crucial parameter. Photographs may be taken solely with natural light but generally, regardless of the impression visibility and quality, an oblique additional light source is required. In most cases photography without an additional light source would not allow for maximum details to be recorded. A thumb rule is, therefore, that oblique light should always be used when photographing three-dimensional impressions and for most two-dimensional impressions, particularly those in dust or residue. (Bodziak, 2000)

The reason for the additional light to be oblique is that it creates shadowing between the high and low areas of a three-dimensional impression, which provides for a greater amount of contrast and details in the photographs. The deeper a three-dimensional impression is the higher up the oblique light has to be positioned in order to achieve a maximum contrast. Regarding the two-dimensional impressions the maximum contrast is to be achieved when the oblique light is positioned near the ground where it can reflect the dust. Commonly an external flash light, a flood light, or another bright light provide for the additional oblique light at the crime scene. (Bodziak, 2000)

Except for adequate lightning there are other important factors in the photography process that enables for high quality pictures to be taken. For instance, a tripod is used in order to place the camera in the right position and to make sure that the camera does not move during the exposure. This, regardless of the impression is photographed at the crime scene or at the laboratory. It is crucial that the camera is positioned parallel to the impression in order to avoid any perspective problems and to get an as accurate picture as possible. (Bodziak, 2000)

In general, to achieve high quality footwear impression photographs, several factors needs to be considered and the photography is required to be executed in a specific way. To facilitate the crime scene photography process Ernest D. Hamm, an expert in latent print, footwear and tire track examinations at the Florida Department of Law Enforcement, has developed a specific guideline called **F.U.S.S.** to apply (Bodziak, 2000; C.A.S.T., 2007):

- **F**ill the frame – Fill the frame with the impression. Also any documentation such as a label placed adjacent to the impression should be included.
- **U**se a Scale – Use a scale which is approximately the same size of the impression.
- **S**ide-light the Impression - Side-light the Impression with oblique lighting. This produces shadows in the impression and, thereby, reveals important characteristics.
- **S**everal photographs should be taken of the impression – Move the light source to several locations around the impression without changing the position of the camera.

By applying the guideline several photographs of each impression with varying shadow effects will be obtained. (C.A.S.T., 2007)

3.2.2 Three-Dimensional Footwear Impressions

The definition of a three-dimensional impression is that it has a significant depth (which can range from shallow to several inches deep) in addition to length and width. Unsurprisingly, a three-dimensional impression is always to emerge when a soft material such as sand, soil or snow constitutes the ground. Depending on the nature of the soft material, i.e. if it is elastic or inelastic, the impression may be either temporary or permanent. (Bodziak, 2000)

3.2.2.1 Enhancement of Three-Dimensional Impressions

It is crucial to obtain all details in a three-dimensional impression and, therefore, adequate enhancing methods are important. The three-dimensional impressions are often observed outdoors where weather and wind easily may influence or destroy them, which make it crucial to secure as soon as possible. (Bodziak, 2000)

In the past, when photography was less sophisticated, casting was the predominant method to recover three-dimensional impressions. However, as the photographic equipment improved, the casting was somewhat abandoned in the 1960s until it just recently recurred. The restoring of casting was mainly due to the fact that the forensic examiners recognized its potential to reproduce additional details of the footwear impression that cannot be capture by photography. (Bodziak, 2000)

Better casting materials and a simplified procedure have made the casting today more convenient and, along with photography, it now constitutes the routine method used to recover three-dimensional impressions. (Bodziak, 2000) Common excellent materials for casting footwear impressions are Dental stone, Die-Keen, Jade Stone and Traxtone (Hilderbrand *et al*., 1995).

3.2.2.1.1 Casting a three-dimensional impression

Casting is performed in order to obtain an exact model of the three-dimensional impression. To be able to retain all significant characteristics of an impression it is of great importance that the casting material has the capability to reproduce very small details. The casting materials used today are relatively stable and have a great potential to reproduce any irregularities of the surface. (Bodziak, 2000)

Depending on what the foundation constitutes different details may be observed in the impression. Thus, different casting materials are recommended to be used for different foundations and purposes. Some commonly used casting materials are silicon, paraffin wax, sulphur and dental stone. (Bodziak, 2000)

Impressions made in snow are somewhat more difficult to secure than impressions made in other soft materials. This, as they need to be enhanced and fixed before the photography and casting can be executed. For an example, the enhancement of contrast and fixation can be achieved through a sprayed layer of wax, see fig. 3.2. (Bodziak, 2000)

Fig. 3.2 An enhanced footwear impression made in snow. (*Photo:* Marcus Andrae, SKL)

3.2.2.1.2 Temporary three-dimensional impressions

An impression left on an elastic material like a carpet, skin or cushion first adopts a three-dimensional shape but after a while, as the resilience causes the material to return to its initial state it becomes two-dimensional. The most transient three-dimensional impressions are those left on skin. However, their two-dimensional shape is often the more resistant since visible contusions may emerge from the impact of the footwear. (Bodziak, 2000)

It is somewhat difficult to retain sufficient details of a temporary three-dimensional impression as the deformation observed on an elastic surface can only be recovered by

photography. However, in general all two-dimensional impressions that subsequently emerge can be lifted, although it is complicated. (Bodziak, 2000)

3.2.3 Two-Dimensional Footwear Impressions

There are two types of two-dimensional impressions, positive and negative, whereof the positive is the most common one. Generally, a positive two-dimensional impression is made on a hard plane and clean surface and consists of static charges and dust particles that create an image of the outsole. A negative impression is, evidently, the opposite of a positive impression and is made on a dirty surface by a clean outsole that removes particles from the surface and creates an inverted picture. Two-dimensional impressions may be either visible to the eye, latent or partly latent and by applying different methods all three types can be recovered. (Bodziak, 2000)

3.2.3.1 Enhancement of Two-Dimensional Impressions

To increase the contrast and visibility between the two-dimensional impression and the surface, several enhancement methods are applicable. Even though photography solely may provide for a sufficient enhancement it is often subsequently accompanied by some additional enhancement method, either physical or chemical, in order to retain a maximum amount of details. (Bodziak, 2000)

The physical enhancement method constitutes the lifting of an impression to enable further forensic analyses. In case lifting is not possible the impression is instead processed by a chemical enhancement method and then photographed. Parameters that influence the choice of method are:

- The composition of the surface (carpet, paper, asphalt etc.).
- The texture and porosity of the surface.
- The condition of the surface (wet, dry, clean etc.).
- The colour of the surface.
- The composition of any contaminant on the surface (dirt, grease etc.).
- Whether the impression is of wet or dry origin.

(Bodziak, 2000)

3.2.3.1.1 Detecting Latent Impressions

In some cases photography solely can emerge a latent impression but more often additional processing is required. One useful method to detect any latent footwear impression is to illuminate from a low angle. The light will then reflect the impression (i.e. the dust and residues it constitutes) which becomes more visible enabling for a subsequent lift or further enhancement. An adequate lightning at the crime scene is probably the most crucial parameter in detecting both latent and visible impressions. (Bodziak, 2000)

Another efficient method to apply in order to enhance latent impressions is to use fingerprint powder. This, as latent impressions may consist of static charges or damp to which the fingerprint powder can adhere. The powdering method is, however, not appropriate on porous, textured or dirty surfaces as they naturally attract the powder and, thereby, obscures the footwear impression. Once an impression is detected and enhanced it can be lifted and recovered for further investigation at the forensic laboratory. (Bodziak, 2000)

3.2.3.1.2 Physical enhancement

Visible impressions on portable materials are preferably lifted at the forensic laboratory where more adequate enhancing methods are available. A footwear impression should only be lifted at the crime scene if it cannot be safely removed, or if it is positioned on a material that is impossible to transport to the laboratory. (Bodziak, 2000)

The surface material is the most important thing to consider when deciding whether an impression is to be lifted or not, i.e. which enhancement method to use. There are two general lifting methods commonly applied today; the electrostatic lift and the gelatine lift. (Bodziak, 2000) However, studies show that two-dimensional impressions may also be recovered satisfactory by lifting with Dental Stone (Knaap et al., 2002).

3.2.3.1.2.1 Electrostatic Lift

The most common electrostatic lift device is the portable Dustmark Lifting Kit, DLK, shown in fig. 3.3. This piece of equipment consists of a main unit with a high-voltage source, a ground plate and a cable that connects the ground plate to the main unit, a metal hand-held probe, and a special lifting film. In order to lift an impression the film, that consists of black vinyl or polyester film and has one side coated with a conductive metal laminate, is placed upon it. The high-voltage source is then turned on creating static charges which cause a transfer of dust from the impression to the lifting film. (Bodziak, 2000) A lifted footwear impression can be viewed in fig. 3.4.

Fig. 3.3 Dust Lifting Kit (*Photo:* Marcus Andrae, SKL)

Another electrostatic lifting method is the ESDA[4]-procedure which is somewhat similar to the DLK. However, it is to some extent restricted in its application to materials like non-smooth papers (on which it performs very well) and needs to be executed at the forensic laboratory. In order to lift a footwear impression the material thought to comprise it is placed upon the ESDA-device, a vacuum box with a ground plate, and covered with a plastic film. Subsequently, by turning on the vacuum the film becomes pressed against the material whereupon a high-voltage is to be supplied to the film. The film then becomes positively

[4] ElectroStatic Document Apparatus

charged and present dust impressions, which are negatively charged, transfers to the film. (Bodziak, 2000)

An electrostatically lifted impression is very fragile and hence a proper storage is crucial in order to avoid any contamination or damage. Thus, subsequent to the lift the film should immediately be protected in a folder or in a shallow box. (Bodziak, 2000)

Electrostatic lifting performs best on dry dust and on surfaces that are clean but may be applicable on almost every surface, both porous and non-porous. Lifting of a footwear impression from a dirty surface can be possible if loose residues, which may transfer to the film and obscure the footwear impression, are removed. This can be achieved either by blowing carefully in the area adjacent to the impression or by performing a prior lift. Also in the case of a clean outsole treading a dirty surface the electrostatic lifting is applicable. This, as the lifted impression then will appear negative. Wet and damp impressions or impressions with a wet origin cannot be electrostatically lifted and require some other methods. (Bodziak, 2000)

Fig. 3.4 An electrostatically lifted footwear impression. (*Photo:* Marcus Andrae, SKL)

There are some great advantages of applying the electrostatic lift method. For instance, an unsuccessful lift would not affect the impression or damage it and, consequently, a secondary lift can be performed. Further more, the DLK can be applied to an extensive area which may facilitates the recovery of latent impressions. (Bodziak, 2000)

3.2.3.1.2.2 Gelatine Lifting

The gelatine lifter consists of a colourless (transparent), black or white thick self-assembly gelatine layer that prior to use is protected by a transparent polyester film. When applying the gelatine lifting method the gelatine is first to be cut into an appropriate size that matches the impression to be lifted. The protecting film is then to be removed whereupon the gel is applied to the impression, either with a roller or by touching the centre of the impression with the centre of the gel and spread in the gel across the impression. It is very important to avoid any air pockets since they can distort and damage the impression. By applying an adjustable hydraulic press when lifting the resolution of the impression can be improved (Shor *et al*.,

2003). Once the impression has been lifted it needs to be protected from contamination or damage. This can be achieved either by replacing the polyester film onto the gel (can only be made once) or by placing the gel in the bottom of a box. Due to decay, i.e. absorption by the gel, the lifted impression should not be stored more than a few days. (Bodziak, 2000)

The gelatine lift method is very versatile and can be applied to recover both visible and latent footwear impressions on a variety of surfaces, both porous and non-porous (due to the flexibility of the gel) Often a latent or partially latent impression becomes visible on the gel when lifted, otherwise an appropriate illumination may allow for it to emerge. See fig. 3.5. (Bodziak, 2000)

Fig. 3.5a A gel lifted footwear impression insufficiently illuminated.

Fig. 3.5b A gel lifted footwear impression sufficiently illuminated.
(*Photo:* Marcus Andrae, SKL)

The nature of the impressions generally determines which type of gel to use. For instance, regarding impressions enhanced with fingerprint powder the colour of the powder becomes an influencing factor. Still, the most commonly used gel in recovering footwear impressions is the black one used in fig. 3.5. The gelatine lift method is to be preferred when the impression cannot be removed from the crime scene or in case of an unsuccessful electrostatic lift. (Bodziak, 2000)

3.2.3.1.3 Chemical enhancement

Two-dimensional impressions made in grease, oil and blood does not usually adhere to a lifting material and can, therefore, not be lifted. Instead, they are enhanced by chemical methods involving either physical attraction between the impression and the chemical or chemical reactions. (Bodziak, 2000)

Preferably any chemical method is performed at the forensic laboratory, although that is not always possible. Therefore, there are several chemicals available appropriate for enhancing impressions in different types of substances both at the laboratory and the crime scene. Prior to applying any chemical enhancement method the chemical needs to be tested on a small section of the impression in order to make sure that an adequate method is selected. (Bodziak, 2000)

3.2.3.1.3.1 Impressions in blood

An impression made in blood can be of diverse quality due to the blood's unique internal characteristic of initially being a non-viscous liquid that becomes more and more viscous as it dries and coagulates. Also, the amount of blood influence the impression quality as excessive amounts of blood may obscure the details of the outsole. The best impressions are, thus, generally the vague ones (often those made by a bloody shoe and not those left in the blood). To summarize, both viscosity and quantity of the blood at the time the impression is made are crucial quality parameters. (Bodziak, 2000)

Vague footwear impressions made in blood are preferably chemically enhanced as it often provides for a very powerful enhancement (Jonasson, 1994). There are several chemicals appropriate for enhancing blood impressions, for example Ninhydrin, Luminol and Amido black. (Bodziak, 2000) Prior to any enhancement of an impression made in blood it is important to recover material for DNA-analysis (Jonasson, 1994).

3.3 The Identification Process

The variety of shoes on the market today is enormous due to a multitude of different manufacturing companies that produces thousands of different shoe designs, in numerous sizes and shapes, with diverse outsoles. Consequently, a specific shoe design will only be owned and worn by a very small fraction of the population. Each time a new characteristic is introduced to a shoe, consciously or unconsciously, the fraction of people owning or wearing that particular shoe design reduces. (Bodziak, 2000)

The science of footwear examination rests upon the basis that a questioned shoe impression containing a sufficient quality and quantity of detail, may be individualized with absolute certainty. As the comparison and individualization of a footwear impression can be performed long after it has been collected, it is crucial that every impression, regardless of its condition, is processed very carefully (as if it was the only impression recovered). (Bodziak, 2000)

In order to perform a qualified comparison and identification examination the footwear examiner must take into account three critical aspects: the physical characteristics of the outsoles, the manufacturing techniques of the known shoe, and the wearing of the shoe by the foot. Each and every aspect of a particular shoe contributes to the final determination of the examiner. (Bodziak, 2000)

There are three distinct types of characteristics that are to be considered by the forensic examiner in the identification process: class characteristics, wear characteristics, and individual characteristics. (Bodziak, 2000)

3.3.1 General Guidelines

To facilitate the footwear impression examination some general guidelines may be established. According to the Forensic Institute of Netherlands the examination may be divided in four different phases which are shortly described below. (Keereweer *et al.*, 2005)

Phase I: The investigation of footwear and impressions. Class and accidental characteristics are identified and described. (Keereweer *et al.*, 2005)

Phase II: The comparison of impressions to footwear and test impressions. Similarities and differences are recognized. If it is legitimate, i.e. similarities are present, proceed to phase III otherwise stop and draw a negative conclusion. (Keereweer *et al*., 2005)

Phase III: The evaluation of similarities and differences. First the encountered similarities are analyzed and their characteristic value ascertained, and then explanations for contingent differences are sought for. (Keereweer *et al*., 2005)

Phase IV: The report. In accordance to prevailing national standards a footwear impression examination report is produced. The conclusion may be expressed in terms of positive, negative or inconclusive. (Keereweer *et al*., 2005)

3.3.2 Class Characteristics

The class characteristics correspond to the more obvious and distinguishable features such as shape, design, size and outsole pattern that a shoe possesses. See fig. 3.6 where the footwear impression on the left is laterally transposed as it facilitates comparison. Bodziak defines the class characteristics as “intentional or unavoidable characteristics that will be repeated during the manufacturing process and shared by more than one shoe”. In the comparison process the class characteristics are divided in two separate areas: general and limited. (Bodziak, 2000)

Fig. 3.6a An example of the design of a casual shoe outsole.

Fig. 3.6b An example of the design of a sport shoe outsole.

The general characteristics are the basic design features in the outsole pattern that cannot be distinguished between different outsoles. In the comparison and identification process this type of characteristic is the weakest as it cannot individualize a particular shoe. However, it is conclusive for the purpose of elimination and may serve as screening criteria for further comparative examinations. (Bodziak, 2000)

The limited characteristics are the manufacturing or design features that are distinguishable between outsoles belonging to the same category of footwear. For instance, mould design or minute differences in the outsole pattern that may emerge due to different shoe sizes. (Bodziak, 2000)

When a shoe consists of separately manufactured parts, i.e. independent parts, it is considered to possess combined class characteristics. Logically, the more separate parts that constitute the outsole, the more the fraction of shoes sharing the same combined characteristics is reduced. (Bodziak, 2000)

3.3.2.1 Interpretation

If a shoe presents all visible class characteristics of a questioned impression, with some distortion tolerance, the examination should be extended to searching for individual/identifying characteristics. (Bodziak, 2000)

3.3.3 Individual Characteristics

The individual, also called identifying, characteristics are generally accidental and may be defined as the result of something being randomly added to or removed from the original shoe that provides for making the shoe unique. See fig. 3.7. The term random in this context implies that the position, orientation, shape and size of the present characteristic to some extent depends on chance. (Bodziak, 2000)

Fig. 3.7a A footwear impression/outsole with individual characteristics.

Fig. 3.7b A footwear impression/outsole with individual characteristics.

In general the individual characteristics occur during wear, although they may also originate from defects in the manufacturing process such as air bubbles, and are positioned on the outsole or on the side of the shoe. In the identification process the individual characteristics may be divided into two separate areas; damage/permanent characteristics and temporary characteristics.

The damage characteristics are commonly due to random cuts, scratches, etc. that originate either from wear or from the manufacturing process (before moulding), while the temporary characteristics constitute foreign debris or substances such as gravel, tape, or gum that may become attached to the outsole. The transient nature of the second type of characteristics makes them somewhat more powerful towards a positive identification as they can contribute in establishing a critical time factor. Further more, regardless of what adheres or becomes deposited the outsole it can transfer a unique pattern to the receiving surface, providing for a feature comparison. (Bodziak, 2000)

3.3.3.1 Interpretation

To be able to determine the value/significance of each unique identifying characteristic in an outsole the forensic examiner has to consider some important parameters: the clarity of the characteristic, its reproducibility, its confirmation of randomness, and its degree of uniqueness. The estimation of uniqueness of an individual characteristic is based on its combined orientation, position, shape and size. Through the comparison of individual characteristics an impression may be identified to one specific shoe. (Bodziak, 2000)

3.3.4 Wear Characteristics

In addition to the class and individual characteristics, wear has been introduced as an important element in footwear examinations. The general definition of shoe wear is: a continual change or erosion of the outsole class characteristics and some individual characteristics due to the frictional and abrasive forces occurring between the outsole and the ground (Bodziak, 2000; Encyclopaedia Britannica, 2007). With time the wear characteristics result in individualistic features which reflect the current condition of the outsole in contrast to its original condition. The wear pattern or position of wear may be defined as a pattern or arrangement of wear characteristics that stands out against areas of relatively less or greater wear. The footwear impression on the left in fig. 3.8 is laterally transposed as it facilitates comparison the different degrees of wear can be observed. The wear pattern is primarily influenced by the shape, size and function of the wearer's feet. (Bodziak, 2000)

Fig. 3.8a A footwear impression/outsole with minute wear characteristics.

Fig 3.8b A footwear impression with obvious wear characteristics.

A brand new shoe cannot be predestined to wear in a particular manner. Rather, the way and extent to which it wears are due to a great variety of parameters that depends on the wearer, the surrounding in which it is worn and the manufacture. Primarily the individual's foot type, i.e. the shape and size of the foot, and function influence the wear of the outsole. However, there may also be other factors such as: the wearer's body type and weight, occupation, and habits, the shoe style, the manufacturing materials, and the surfaces which that the shoe passes over as it is worn that needs to be considered. All the above mentioned influencing factors are independent of one and other, although most of them, if not all, simultaneously influence the wear of a shoe outsole. (Bodziak, 2000)

3.3.4.1 The Influence of Foot Type and Function

The foot is an incredibly complex mechanism that is constantly under stress. Depending on the foot's form and function it will exert pressure within the shoe that subsequently adapts. For instance, the upper shoe will form according to the foot and the outsole will wear in a specific pattern. The areas of the outsole directly beneath the weight-bearing areas of the foot will wear more quickly than other areas due to a greater amount of movement and frictional forces. (Bodziak, 2000)

To understand why the wear of shoes is unique for every individual, the forensic examiner needs to possess basic knowledge of the foot, of different foot types and of the foot's mechanics during walking. A foot is unique to each individual as the precise lengths, sizes and shapes of the foot bones are determined genetically. Subsequently, stresses and demands on the foot throughout a person's life significantly influence the growth and development of the bones and may cause further uniqueness. In addition to the foot's anatomy, the way it functions during the walking cycle may be of great assistance to the footwear examiner. There are four basic motions of the foot which are essential for a normal function. Each motion corresponds to a movement in a specific direction; downward, upward, inward or outward. The inward and outward motion is often called supination and pronation, respectively, and is shown in fig. 3.9. (Bodziak, 2000)

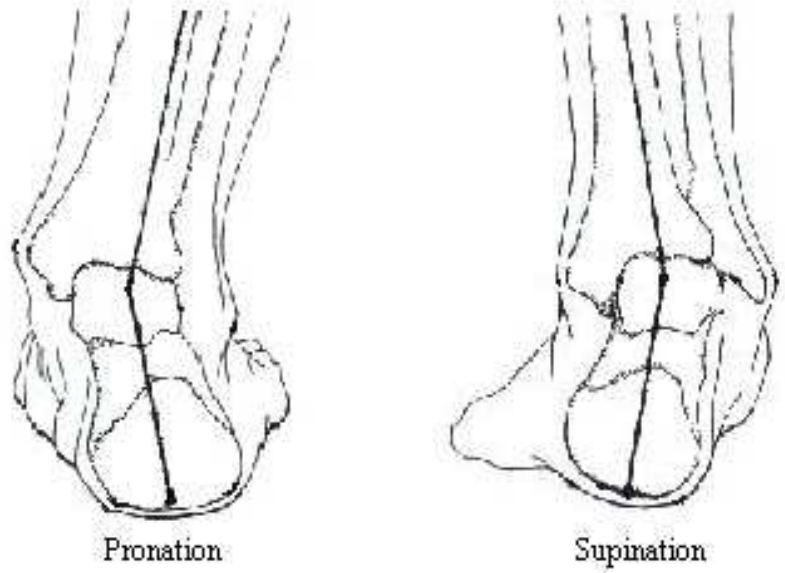

Fig. 3.9 The pronation and supination of the foot.

Generally, the heel part of the shoe strikes the ground first and absorbs a great deal of the shock and weight and, thus, it is most likely to wear down first. The position and angle of heel wear depend on a variety of factors such as the amount of supination or, less frequently, pronation and the amount of toe in or, more commonly, toe out. Other factors that may contribute to the specific location and angle of heal wear are lower leg flexibility and ankle flexibility. (Bodziak, 2000)

Hypothetically, similar foot types and functions and personal features should give the same wear pattern on the exact same type and size of shoe. However, any difference in the daily activities would cause a different wear. Even if one person would wear two identical pairs of shoes equally the wear pattern would never be the same. The wear is said to be the sum of all the influencing factors, which can never be duplicated. Although the wear characteristics in theory could never be duplicated it may not, in itself, constitute evidence uniqueness. The wear shown in a shoe of the same design and size but worn by different people could in fact be so similar that they have indistinguishable wear characteristics. (Bodziak, 2000)

When examining any questioned impressions the fact that the wear characteristics constantly change, as the shoe is worn, has to be considered. Due to this the evidence value may be lowered if the questioned shoe has been worn for a long time after that the crime was committed. (Bodziak, 2000)

3.3.4.2 The Influence of Wearer Features

Apart from a person's foot type and function during normal walking or standing, daily activities and habits as well as personal features influence the wear of the shoe. For example, a person's weight strongly influences the rate at which the shoe wears, as it is related to the amount of friction between the outsole and the ground. The greater the weight is the greater the frictional forces become when the shoe strikes the ground. (Bodziak, 2000)

Other personal features that influence the wear of a shoe are hip width, lower leg flexibility, unevenness in the length of the legs, and leg swing. The sex and body type may therefore be regarded as important factors when it comes to the wear characteristics. The walking manner of a person also affects the way the shoe wears. Different gaits and walking peculiarities along with significant foot problems or disabilities may result in wear in different areas of the shoe. The left and right foot of a person varies both in physical features, such as size and shape, and function giving rise to different wear patterns on respectively shoe. In other words the precise position and degree of wear will not exactly match between a person's left and right shoe. (Bodziak, 2000)

The daily activities and habits in a person's life may differ a lot from one person to another. Occupations and leisure-time activities that demand a lot of movement or contact of the shoe against the ground cause a more extensive wear on the shoe than any sedentary activity. Any outdoor activity is more prone to cause wear on the shoe than an indoor activity, due to the more roughed ground surface. A construction worker or a postman therefore most likely will wear their shoes more extensively than an office worker. (Bodziak, 2000)

The shoe may also wear in different areas depending on the nature of the activity, i.e. how it is carried out. For an example stepping in and out of a car several times a day will cause a different wear than stepping on and of a bike, as different areas of the shoe will be exposed to the primary friction when it strikes the ground. (Bodziak, 2000)

Little surprising the surface itself also makes an impact on wear, features such as condition, hardness and abrasive qualities all contribute to shoe wear in different degrees. A more smooth and soft surface, for instance a carpet, would not wear on a shoe at the same extent as a more roughed and hard surface, for example asphalt. This, as a more roughed ground would cause a greater friction between the outsole and the ground and thereby precipitate the shoe wear. (Bodziak, 2000)

3.3.4.3 Shoe Design and Manufacturing Influencing on Wear

There are two kinds of shoe lasts, straight or curved, which both influence the position of wear on the sole. Depending on whether the last is straight or curved the foot will be positioned differently over the outsole within the shoe and thereby cause different wear patterns. (Bodziak, 2000)

Today there are various materials, and combinations thereof, that are used in the shoe sole manufacturing. Depending on the components some soles wear down much faster than others. For example microcellular soling materials, commonly used in today's athletic shoes as they provides cushioning and shock absorption, such as ethyl vinyl acetate wear more rapidly than other synthetic rubbers and high-density polyurethane which resist wear and last much longer. (Bodziak, 2000)

In addition to the outsole material there are other manufacturing characteristics that may influence the wear position and pattern. If a shoe is manufactured with a grid on the opposite side of the moulded outsole there would be additional wear directly beneath the grid areas. This is due to the fact that the grid would transmit more of the weight through the outsole than the void areas. (Bodziak, 2000)

In a shoe with a siped herringbone design the peaks and valleys protrude as the shoe flexes during walking and thereby get exposed to wear. The prior sharp peaks and valleys wear

down to a more rounded herringbone pattern as a result and some point may even be torn away. It can be said that any part of the outsole that protrudes or bulges is more prone to wear down than other areas of the outsole. (Bodziak, 2000)

3.3.4.4 The Schallamach Pattern

Stippling, etching, sandblasting and polishing during the manufacturing process normally provides for the surface characteristics of a sole. With time, as the sole wears down, the manufactured surface features gradually wear away in some areas which instead may enable for a Schallamach pattern to occur. See fig. 3.10. The Schallamach pattern is a surface feature that is not due to the manufacturing process but a result of abrasive wear. (Bodziak, 2000)

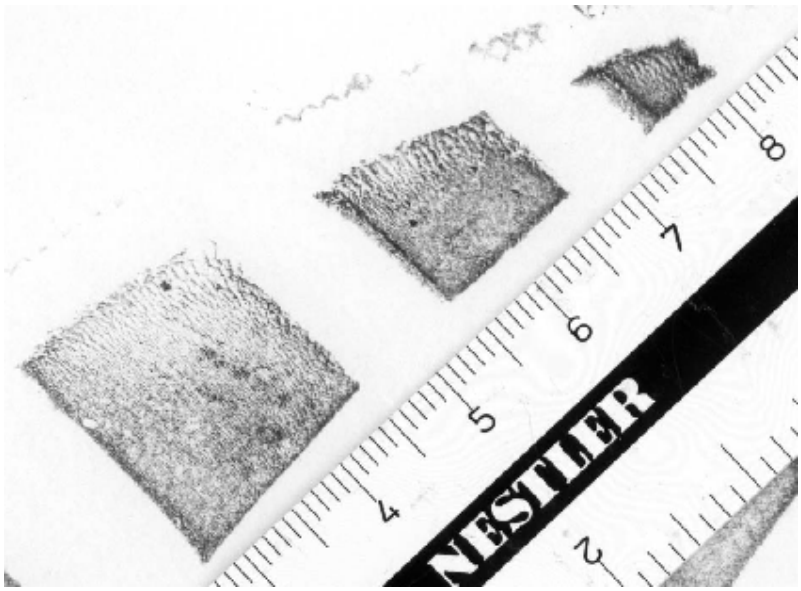

Fig. 3.10 A close view of the Schallamach pattern.

3.3.4.5 Interpretation

To be able to provide for an accurate interpretation of the wear characteristics it is crucial that the forensic examiner has a great understanding and knowledge of the anatomy of the foot. In the wear characteristics examination there are two significant aspects of wear for the forensic to consider; the position of wear on the shoe and the degree of that wear. Commonly, the outsole is first assigned a general wear condition that refers to its overall condition or general amount of wear, i.e. unworn, slightly worn, moderately worn, severely worn, and so forth. Subsequently the degree of wear is to be determined which refers to the extent that a particular position of the shoe is worn. (Bodziak, 2000)

There is a major problem to encounter in the field of wear characteristics, namely defining at what point the wear is to be considered as individual. Still, one thing is to be certain; the more extensive wear, the more individual feature in comparison to another outsole of the same design. (Bodziak, 2000)

3.3.5 Characteristics Required for a Positive Identification

Through the years there has been a worldwide discussion whether or not to establish a specific number of characteristics required to identify an impression to a shoe. However, as each characteristic may be seen as evidence having its own uniqueness/value most forensic

examiners consider an established minimum number of characteristics for identification to be unjustified. Instead, based on experience the forensics have unified on three types of criteria that is to be viewed in determining a positive identification; the level of training and experience possessed by the examiner, the quality of the known and unknown impressions, and the uniqueness of the characteristics. (Bodziak, 2000)

By definition identification is made when the questioned impression and the known shoe share one or more confirmed random characteristics that in the opinion of a qualified forensic examiner, possesses such uniqueness that it cannot be reproduced, not even on an outsole sharing the same class characteristics. (Bodziak, 2000)

3.4 Evidence Evaluation

Since the forensic science is featured by uncertainty, due to inferred identity of source, the standard statistical tests and methods of data analysis are not applicable. Therefore, it has been assigned its own unique area of statistical science called evidence evaluation which consists of both theoretical and practical knowledge that provides for the interpretation of evidence. The evidence evaluation may be defined as the application of a set of statistical thinking in order to interpret enumerated data. (Lucy, 2006)

The modern statistical evidence evaluation only considers “the probability of evidence” in relation to a set of competing hypotheses, and not the probability of a proposition such as “the suspect is guilty” or “the suspect is innocent”. Thus, the forensic scientists are enabled to make their statements and analysis solely within their field of expertise, mostly at the level of source. As mentioned, the evidence evaluation both comprises theoretical and practical knowledge which implies that the forensic statements correspond to the combination of an inferred evidence value and an intuitive value based on experience. (Lucy, 2006)

The evidence evaluation is not only an important tool in court, but also during the crime investigation as it enables the investigators to frame their intuition in terms of relative frequencies and, thus, makes it more apprehensible. Still, it needs to be pointed out that the forensic science is at its most certain when it can exclude suspects. (Lucy, 2006)

3.4.1 Evidence types

Naturally, in order to establish a link between a suspect and an offender there has to be some recovered evidence. Then, by reducing the potential suspect population from an initial population to a restricted class or unity, the identity of evidence source can be inferred. If any characteristic is to be shared by the suspect and the offender it forms a piece of evidence whose nature determines what inferences to make. (Aitken *et al.*, 2004)

There are some classes of characteristic that fail to undermine positive evidence linking. For example the absence of variable characteristics would not detract from the evidence value. Another class of observable characteristics can eliminate suspects due to their immutable nature. For an example a tattoo or a DNA-profile possessed by the offender but not by the suspect would effectively exclude the suspect. Intrinsic properties of the offender and suspect, such as tattoos or DNA can be very strong positive evidence as well. However, even a specific DNA-profile may be possessed by a small set of individuals and is, therefore, not absolutely reliable as evidence. (Lucy, 2006)

In case of a shared characteristic(s) between an offender and a suspect, the value of evidence has to be established by the forensics. Then, depending on the validity of the evidence, the

question of guilt or innocence of a suspect on the basis of the shared characteristic(s) with the offender is evaluated by the court. (Lucy, 2006)

3.4.2 The Strength of Evidence

To facilitate deliberations and decision of the court, the forensic expert preferably testifies to a quantitative measure of the strength of evidence, i.e. the effect the given evidence has on the probability (Aitken *et al.*, 2004). However, this is generally not possible wherefore an unquantified value needs to be denoted. The forensic scientist generally provides statements of support, even if it is simply a subjective probability based on experience, as the statistical evaluation of evidence solely applies to that. How to make statements of the strength of evidence may differ between the forensic laboratories around the world. (Lucy, 2006) At the Swedish National Forensic Laboratory, SKL, the forensic examiners provide statements of support according to a predefined scale ranging from +4 to -4 in support of a given proposition, se appendix 9.5 . The scale is also verbally denoted where a statement of the value +4 would imply that the result with certainty supports that the evidence is derived from the source while a statement of the value -4 would imply with certainty no support for the evidence to be derived from the source. Further more, a statement of 0 would imply that the result is inconclusive. (SKL, 2007)

When the forensic examiners are able to provide a quantitative measure of the strength of evidence they generally express it in terms of the likelihood ratio of some competing hypotheses. (Aitken *et al.*, 2004) In order to establish the strength of evidence some different approaches based on either the probability of guilt, the effect of evidence or the frequency of occurrence has been suggested. (Lucy, 2006)

3.4.2.1 Probability Reasoning

By examining the probability of source given the observation, one may establish by how much a shared characteristic between a suspect source and the evidence supports the proposition that the evidence originates from the source against a proposition of the contrary. For example, an observed footwear impression (not considering any individual details) possessed by 1000 individual shoes in the population, one being the source, would without any further information provide a probability of 1/1000 that the suspect shoe is the source. More common and portable characteristics in the population such as clothing would provide a lower probability, while less common characteristics such as DNA would provide a much higher probability. (Lucy, 2006)

Although the probability approach may seem convenient, it encounters some problems in interpreting the probability of source. Especially, the definition of what is to be considered as high or low probability is somewhat obscure. Further more, the probability method is also sensitive to the size of the total population as; if the proportion of individuals with the same characteristics remains constant relative to the potential suspect population size the number of individuals possessing the characteristic will increase with the population. This results in a lover probability of source since the source now is one of a greater set of suspects. It is, however, intuitively not conceivable that the persuasive value of a piece of evidence is less simply because it originates from a larger population of potential suspects. If it was to be true, the infrequency of specific evidence in the population of potential suspects would not be significant when increasing the population. Yet, another problem is that the estimated probability only assesses the probability of source given the evidence and not the strength of the evidence itself. (Lucy, 2006)

3.4.2.2 The Effect of Evidence

In order to isolate and determine the effect of evidence, the probability of source prior to the introduction of evidence is compared to that after. For instance, assuming that every individual in a population of 100000 members is equally likely to be the source of evidence, the probability of each individual being the source prior to the introduction of evidence would be 1/100000. Then, by introducing evidence such as a footwear impression observed to be possessed by the source (footwear) and by a total of 1000 members in the population the potential suspect population will reduce provide for a new posterior probability of source 1/1000. This gives a 100-fold increase in the probability of the suspect being the source which corresponds to the effect of the evidence. Evidently, the more the introduced evidence narrows down the potential suspect population the more valuable it is and the greater strength it will be ascribed. Due to the approach, the established weight of evidence is only influenced by the number of individuals sharing the characteristic in the population. (Lucy, 2006)

A problem with the measure of the effect of evidence is that it requires an unjustifiable explicit assumption, that every individual in the potential suspect population is equally likely to be the source. Even though the strength of evidence is, unlike the probability of source, invariant to the absolute size of the population the number of individuals still needs to be accounted for. (Lucy, 2006)

3.4.2.3 The Frequency of Occurrence

One way to avoid the problems of population specifics is to interpret the frequency of occurrence in terms of the question of source. This, as the frequency of occurrence of the characteristic which forms the evidence may be estimated without knowing the size of the absolute population. For example, the frequency of finding a specific outsole pattern in any given population is 100/100000; 100 being the number of members in the population possessing the characteristic and 100000 being the absolute size of the population. Assuming that there is only one offender observed which owns one pair of shoes with the questioned outsole pattern, the frequency of finding the same pattern in a shoe belonging to a non-offender becomes (100-1)/(100000-1). This is analogous to the probability of observing the evidence were the suspect innocent. By putting the probabilities of observing the evidence if the suspect is the offender and if the suspect is innocent in relation to each other, a measurement of the effect of the evidence can be obtained. The increase of support of the proposition that the suspect is in fact the offender is all due to the strength of the introduced evidence. This approach is somewhat the same as the calculation considering the prior and posterior probabilities, only different data is utilized. (Lucy, 2006)

In the case of intrinsic characteristics the probability of observing the evidence when the suspect is the offender is inevitable 1, and no calculation is required. However, considering variable characteristics this probability has to be estimated introducing a constant feature of uncertainty to the evaluation of evidence. (Lucy, 2006)

3.4.3 Significance Testing and Evidence Evaluation

In order to make qualified probabilistic inferences about the connection between any two objects, both some measure of similarity in characteristics and how many other objects in the population share those characteristics is required. Due to the constant uncertainty in the evaluation of evidence standard statistical tests cannot be used to deduce the probability, significance or confidence level for a “match” between two objects. Unless the exact

occurrence of a similar “match” is established, a statement of “match” is somewhat meaningless. (Lucy, 2006)

3.4.3.1 The Challenge of Statistical Inferences

In order to apply any mathematically based inferential systems in evidence evaluation four major challenges have to be countered; the challenge of the complexity of the real life forensic problems, the challenge of realistic modelling, the challenge of directing the search for new data, and the challenge of dealing with imponderables. (Evett, 1987)

Typically, a criminal investigation comprises a multitude of trace material originating from different sources with the possibility of transfer in both directions which results in multivariate analytical data that to a great extent contributes to the complexity of the real life forensic problems.
When it comes to establishing a realistic modelling the challenge is to adopt a not too complex mathematical model without making too many assumptions. This as the more assumptions the more the area of applicability reduces and the further from reality the derived result will become. (Evett, 1987)

It is, in general, very difficult to collect the exact desired data (reference data). For example, establishing the distribution of a material would require a survey that extends to the whole population which would be not only time consuming but also very expensive. Therefore, the collected data, typically, only constitutes the data available, i.e. the data collected in the criminal investigation. (Evett, 1987)

Even though the forensic scientist possesses great knowledge he will only have a vague picture, if any, of the circumstances of the crime. Thus, eventual imponderables have to be considered in the evaluation of evidence. (Evett, 1987)

In general the forensic scientist carries out his examinations in the light of circumstantial information supplied by the police. If any new circumstances or alternative explanations for the evidence come forward, the forensic has to perform new examinations and make additional evaluations. (Evett, 1987)

3.4.4 Bayes’ Theorem

Bayes’ theorem provides a flexible model that enables the forensic scientist to identify and, in principle, answer questions of great importance to the investigator or court. By applying the likelihood ratio the forensic scientists can consider questions like “what is the probability of the evidence given that the suspect source was, or, was not at the crime scene”. (Evett, 1987)

3.4.4.1 Bayesian Interpretation of Evidence

The odds form of the Bayes’ theorem demonstrates how new evidence can be combined with prior background knowledge, i.e. odds, to give posterior odds. The revision is based on the likelihood ratio, LR, of the evidence provided by the forensic scientist and is applied to a set of competing hypothesis. For instance, H_P: The suspect footwear is the source of the questioned evidence, and H_D: The suspect footwear is not the source of the questioned evidence. (Aitken *et al.*, 2004)

The hypothetical-deductive reasoning that the Bayesian Model provides enables the evaluation of a likelihood ratio of the evidence and, thus, the forensic scientist can make a statement of the value of support for one hypothesis against the other. (Aitken *et al.*, 2004)

A forensic scientist is never to evaluate neither the prior odds nor the posterior odds in criminal cases, but solely the likelihood ratio. The prior and posterior odds are instead ascribed the court to consider. Simply, by applying different prior information several different and more realistic scenarios may be examined. (Lucy, 2006)

3.4.4.2 Probability

In evidence evaluation the prior odds communicates the probability of an event before introducing the evidence (unconditional probability), while the posterior odds communicates the probability of an event given the evidence (conditional probability). Bayes' theorem relates prior probabilities to posterior probabilities. (Lucy, 2006)

If the probability of evidence is denoted $\Pr(E)$ and the probability of a hypothesis is denoted $\Pr(H)$ then the probability of the hypothesis given the evidence is $\Pr(H \mid E)$.

By applying the third law of probability for dependent events, the probability of observing the evidence and at the same time have a correct hypothesis becomes:

$$\Pr(E,H) = \Pr(E) \times \Pr(H \mid E) \qquad \text{(Eq. 1)}$$

As $\Pr(E,H)$ has to be equal to $\Pr(H,E)$ then:

$$\Pr(E) \times \Pr(H \mid E) = \Pr(H) \times \Pr(E \mid H) \qquad \text{(Eq. 2)}$$

and, by dividing with $\Pr(E)$:

$$\Pr(H \mid E) = \frac{\Pr(H) \times \Pr(E \mid H)}{\Pr(E)} \qquad \text{(Eq. 3)}$$

(Lucy, 2006)

3.4.4.2.1 The Odds of Guilt

The odds for the prosecutor's hypothesis, H_P: The suspect footwear is the source, is defined as:

$$odds(H_P) = \frac{P(H_P)}{P(H_D)} \qquad \text{(Eq. 4)}$$

Where H_D: The suspect footwear is not the source is the hypothesis of the defence. (Lucy, 2006)

Given the evidence E the corresponding odds can be written as:

$$odds(H_P \mid E) = \frac{P(H_P \mid E)}{P(H_D \mid E)} \qquad \text{(Eq. 5)}$$

By inserting Eq. 3:

$$\underbrace{\frac{\Pr(H_P \mid E)}{\Pr(H_D \mid E)}}_{Posterior\ \ odds} = \frac{\Pr(E \mid H_P) \times \Pr(H_P)}{\Pr(E \mid H_D) \times \Pr(H_D)} = \underbrace{\frac{\Pr(E \mid H_P)}{\Pr(E \mid H_D)}}_{Likelihood\ \ ratio} \times \underbrace{\frac{\Pr(H_P)}{\Pr(H_D)}}_{\Pr ior\ \ odds} \qquad \text{(Eq. 6)}$$

where the likelihood ratio is:

$$LR = \frac{\Pr(E \mid H_P)}{\Pr(E \mid H_D)} \qquad \text{(Eq. 7)}$$

(Lucy, 2006)

As can be seen in Eq. 7, the likelihood ratio is directly dependent on the evidence and the hypothesis to support, but strictly independent of the prior odds.

3.4.4.3 Professional Acceptance

Some scientists and investigators are sceptic to the Bayesian formulation of the forensic science problem due to reluctance to think in terms of prior and posterior odds. They consider, for example, the prior information to be based on assumption by the investigator and, therefore, it is unreliable. However, as the sample priors are substituted by survey priors the assumptions made are somewhat legitimate and the utilization of a prior probability, therefore, reasonable. (Lucy, 2006; Sjerps, 1998)

In order to achieve acceptability verbal conventions, consistent to the current legal system, may be declared and adopted at the different national forensic laboratories. (Lucy, 2006) However, according to an experiment made by Marjan Sjerps at the National Forensic Science Laboratory in Netherlands it is very difficult to develop a likelihood scale of the correct type that is adequate to the jurists. An optimal verbal scale should be clear, acceptable and provide for a uniform interpretation for both jurists and forensic experts. (Sjerps, 1998) A verbal convention suggested by Evett *et al.* (2000) is:

- $1 < LR \leq 10$ The evidence provides limited support for H_P against H_D
- $10 < LR \leq 10^2$ The evidence provides moderate support for H_P against H_D
- $10^2 < LR \leq 10^3$ The evidence provides moderately strong support for H_P against H_D
- $10^3 < LR \leq 10^4$ The evidence provides strong support for H_P against H_D
- $10^4 < LR$ The evidence provides very strong support for H_P against H_D

(Evett *et al.*, 2000)

3.5 Footwear Impression Databases

In order to facilitate crime investigations, databases of different types of evidence such as DNA, finger prints, fibres, armours, tire impressions and footwear impressions have been established. The databases may be either local or general and provide for reference and/or crime scene material. Regardless, they all share the common feature of being designed to assist the forensic comparison examination. Examples of existing databases are the fingerprint database AFIS and the DNA database CODIS. (Jackson *et al.*, 2004)

As the outsole patterns of shoes constantly changes a footwear impression database needs to be continuously updated, this by adding new patterns and removing relatively old ones. Thus, they differ a lot from other evidence databases such as DNA and fingerprint which may bee seen as constant. (Jackson *et al.* 2004)

To be able to establish a footwear impression database some kind of classification system needs to be provided. Two of the systems available today are SICAR from Foster and Freeman and the one used in this survey, SIMSALAPIM. (Jackson *et al.*, 2004; Mikkonen, 2007a)

3.5.1 SIMSALAPIM

SIMSALAPIM, Shoe IMpressions Search And Linking with the Aid of a Partial IMpression, is a new visualised database classification system for footwear developed by Sirkka Mikkonen at the National Bureau of Investigation, Crime Laboratory, in Vantaa, Finland. The precursor of SIMSALAPIM, the Shoeprint Data System from 1992, lacks of visualization as the classification coding is only seen as codes and verbal descriptions. Thus, it is somewhat complex to apprehend and only substantial knowledge of the logic used in classification coding and in comparing impressions would provide for a complete utilization, making errors very common. In order to increase the application of handiness of the system the new upgraded version, SIMSALAPIM, has been provided with a number of graphic plans visualizing the classification coding. As it is said "One picture tells more than a thousand words". (Mikkonen, 2007a)

Some new characteristics have also been introduced to the SIMSALAPIM classification system. By reducing the set obtained from a search these features have proved to be very good retrieval criteria. In spite of all the emending changes the principal of the classification coding has remained unchanged from the initial Shoeprint Data System. (Mikkonen, 2007a)

SIMSALAPIM has three primary scopes of use; to identify possible suspects, to link crime scenes, and to get brand names and models for crime scene impressions.
(Mikkonen, 2007a)

3.5.1.1 Features of SIMSALAPIM

SIMSALAPIM is a graphic data based classification system for footwear which requires the operating system win2000 or winXP. Great features of the system is that it is quick and, in addition to single criteria searches, it can perform AND, OR, NOT-continued searches which enables for diverse search possibilities. Its design also allows for the possibility to provide a candidate set of shoe impressions and link crime scenes at the same search. (Mikkonen, 2007a)

SIMSALAPIM provides a very flexible classification coding applicable to all types of outsole pattern designs. The classification coding is visualized with "drag and drop" – icons, and consequently every selection may be seen as an image. Due to available classification coding icons with a grey area corresponding to an indistinct area the system enables for indistinct partial impression classification. Another great feature of the system is that it possesses well-defined and restricted rules for the shapes and the edge area which prevents for erroneous classification coding. Thus, SIMSALAPIM is adequate as a multi-user system.
(Mikkonen, 2007a)

3.5.1.2 Classification Coding

The inside and outside edges of the outsole are divided into different areas; the end, the edge and central areas of foresole, instep and heel, which all are classified separately. Discrimination is also made on shape and pattern and, further, the density of lines, waves and zigzags can be defined. There are a limited number of defined shapes that constitutes the classification coding; 21 geometric shapes and stitching, number, letter, writing, logo, animal, and motif. All shapes have an altitude, a number and regularity as well as a location in relation to other shapes. Two altitudes are possible; raised or depressed. When it comes to number, three or more shapes with the same classification are defined as a pattern. If the shapes in a pattern can be seen as regularly placed they constitute a mesh. The location of

shapes relative to each other is visualized by dragging them to different areas of the outsole. (Mikkonen, 2007a)

More complex search criterion icons, for example icons with features such as “a shape or a pattern inside a shape” and “a shape surrounded by a pattern”, are designed by dragging appropriate icons in a specific order to a construction box. The icon is then dragged to its right location on the sole. (Mikkonen, 2007a)

3.5.1.3 User Levels

There are four user levels available; administrator, main user, user, and viewer. The administrator is responsible for updating the system, for example insert new classification criteria. The main user is the one accountable for recording impressions and performing classification coding of outsoles. The user has the access to record information of footwear and arrested persons while the viewer is only allowed to browse and to perform searches. (Mikkonen, 2007b)

3.5.1.4 The Database Record

The data of test/model and crime scene impressions are recorded somewhat different. Common record pages are; Impression, Classification, Images, Keywords, Lists of linking and candidates and Misc. However, while the crime scene impressions have an offence information page the test impressions have a reference information page and the model impressions have none at all. (Mikkonen, 2007b)

3.5.1.4.1 Mode

SIMSALAPIM can be set in either record or search mode. Both modes provide the possibility to perform an automatic classification search on the Impression and Classification page. Available automatic searches to select are; foresole-instep-heel, foresole-heel search, or an outsole search. In the search mode it is also possible to perform manual searches on both the Impression and the Classification page by selecting different search criteria.
The List of Linking and Candidates page will show linked crimes and give candidates obtained in a search. In an automatic search linked impressions and given candidates are also shown on the Impression page. (Mikkonen, 2007b)

3.5.1.4.2 The Impression Page

The Impression page keeps a record of vital information concerning the footwear. General parameters such as size, style, material, brand name, and made in are entered along with information concerning the heel, written information on the outsole and if any of the outsole areas, i.e. the foresole, instep, or heel, share the same pattern. (Mikkonen, 2007b)

The Crime Scene Impression pages are not likely to provide equally comprehensive information as the Test and Model Impressions pages as the available information strongly depends on the quality of the impression. (Mikkonen, 2007b)

3.5.1.4.3 The Classification Page

As the title indicates this page contains the classification coding of the outsole. Due to available help screens to every classification and zoomable symbol icons with residing verbal descriptions the classification coding is well guided and easy to apprehend. Further more, any classified impression may easily be copied, modified or deleted additionally facilitating the classification coding. (Mikkonen, 2007b)

3.5.1.4.4 The Image Page

The Image page holds images, either captured live on the screen, imported from a file or scanned, of the footwear and residing impression. Further more, this page has an important operation for measuring distances available; by calibrating the scale in the image, if existing, measurements can be performed by dragging the mouse from one point to another. (Mikkonen, 2007b)

3.5.1.4.5 The Keyword Page

This page contains several electable keywords describing different features of the outsole. It also displays some describing pictures. (Mikkonen, 2007b)

3.5.1.4.6 The Reference Information Page

The Reference Information page is available for test impressions and keeps record of owner of the footwear and impression. The personal information section consist of Name and ID, while report number, offence, seizure made in, recorder, and recording date makes up the impression information section. (Mikkonen, 2007b)

There are some operations available on this page; deletion of a single test impression (a person was not sentenced of that offence), conversion of a test impression into a model and printing of a pre-filled test impression data form with information of the footwear and person. (Mikkonen, 2007b)

3.5.1.4.7 The Offence Information Page

The Offence Information page is available for crime scene impressions and keeps a record of the offence. The documentation consists of report number, offence, crime scene or complainant, investigator, and offence date. The information of impressions obtained in a manual search, i.e. they have shared characteristics but originate from different crime scenes, are entered into one record. This procedure links crime scene impressions to each other and is called manual linking. Information of crime scene impressions entered into different records may, however, be linked through the automatic search. (Mikkonen, 2007b)

4 Materials and Procedure

This project may be separated into four different segments: preparatory work, collection of data, establishment of database, and, ultimately, evaluation of database, each requiring the use and application of different materials and courses of action.

4.1 Materials

Lists of materials used in this project:

Preparatory work:

- Steal tubes, sheets, lead weights, ruler, thread, safety pins etc. for building the "photo-studio" device
- Computer
    - Adobe Illustrator to create posters and forms
    - Printer
- "Photo-studio" device
- Camera equipment:
    - 2x Cameras + stand
    - 2x Flashes + stand
- Inkless Foot/Shoe Print Kit

Collection of data:

- 4x Poster + frame
- Forms
- "Photo-studio" device
- Camera equipment:
    - 2x Cameras + stand
    - 2x Flashes + stand
- 7x Inkless Foot/Shoe Print Kit + Refill Paper (17,7 cm x 35,4 cm)

Establishment of database:

- 2x Computer
    - Scanner
    - Photoshop Elements
    - SIMSALAPIM

Evaluation of database:

- 2x Computer
    - Microsoft Access
    - Microsoft Excel

4.2 Course of Action

4.2.1 Preparatory Phase

This part of the project consisted of planning and preparing the data collection. Questions like what parameters are significant to collect and who is to participate in the survey, were issued. Subsequently an adequate plan of selection and course of action was established and the recognized required material was gathered. Some potential problems that may arise during the

collecting phase were recognized by performing a prior test and evaluation of the collecting procedure at SKL, whereupon the procedure was somewhat improved.

In order to facilitate the collection of data, posters to inform and attract eventually voluntarily participants as well as forms to simplify the process of collecting parameters of interest were made.

4.2.1.1 Parameters of significance

By studying literature and scientific articles the most common and significant parameters regarding the footwear impression as forensic evidence were acknowledged. However, due to some limitation this survey was unable to cover them all and, therefore, in line with the aim and object they were restricted to class characteristics (type of shoe and shoe size), brand, and approximate age of the shoe and wearer. The parameters of interest were collected by photography of the shoe and outsole and by asking the participants to fill in a form.

4.2.1.2 Plan of Selection

Due to the limited time of this project the survey was required to be somewhat restricted. The approach was, therefore, to select the most significant group for the purpose of this project in the population. According to the statistics in 2006, presented by the Swedish Crime Prevention Council, BRÅ, men above the age of 15 most frequently occur in crime investigations and would, therefore, constitute the group of selection (BRÅ, 2007). However, as the study is to be anonymous and minors would require a signed paper from a parent, only men over the age of 18 were to participate.

In this statistical study the variation of shoes with residing footwear impressions, i.e. test impressions, was the primary subject of matter. To achieve an as fair survey as possible, the collected data should represent the whole stratum of the population which required some vital parameters to be accounted for. Different occupations, habits and interests require different types of footwear and, therefore, the class of society becomes a parameter of great significance. The age is also to be considered as a parameter of importance as it, to a large extent may influence the choice of footwear. For instance, you expect younger people to be more active and are, consequently, more likely to wear sports footwear. The means of transportation is another parameter to be accounted for in the survey as it may influence a person's choice of footwear. For instance, walking, biking, and driving a car most probably implicate different choices of footwear.

In order to comprise all significant parameters possible in the survey, the location and to some extent the time-point of data collection became crucial. For the sake of convenience the collection of data was performed at different shopping centres where all society classes and all age groups are thought to be present, and all means of transportation are possible. The time-points of collection were rather random as they depended on factors such as clearance to collect from the shopping centres, and accessibility of car and camera equipment. Every day of the week was represented and the time of day ranged from midmorning to late evening. Still, it needs to be pointed out that the collection phase only ranged from the beginning of May to the end of July in 2007, and therefore, the collected outsole patterns and residing impressions only extends to spring and summer footwear.

The selection of participants in this survey, i.e. men over the age of 18, was to be random and consequently, in the absence of volunteers any active selection was performed arbitrarily. In

case of a group of voluntarily individuals only one or two were to participate in order to maintain the variation.

4.2.1.3 The Device

The constructed “photo-studio” device was built in two levels in order to make the two steps of photography easier and more convenient. The highest level, seen from the ground, was made for taking the outsole pictures and, therefore, it comprised a ruler placed at the same level next to the outsole in order to record its “real” proportions. This level also included a padded wall on which the lower leg of the participant was placed and a pole with a knob on the top for balance support. The other, lower, level of the “photo-studio” device consisted of a platform on which the participants’ foot was placed in order to take the shoe photograph. The whole device was also covered with white sheets to minimize the disturbance from the background, i.e. create a “photo-studio” environment. In order to stabilize the device and prevent it to move around during the photography a box of lead weights were attached to the bottom of the platform.

4.2.1.4 The Form

To facilitate the process of collecting the parameters of significance an anonymous form for the participants to fill in, was created. The parameters included in the form were the age of the participant and the brand, model, size and age of the shoe. Further more, to achieve traceability the photograph numbers were recorded in the form which in turn was assigned a reference number (the same was assigned its residing footwear impression paper). See appendix 9.1.

4.2.1.5 The Poster

In order to inform and attract volunteers posters were made and set up adjacent to the photography set-up at the location for collecting data. The poster primarily included the purpose of the survey and the criteria of participants wanted. See appendix 9.2.

4.2.1.6 Evaluation of the Collecting Procedure

To evaluate and recognize the potential problems and inefficiencies of the collecting procedure an authentic test at SKL was performed, whereupon the cause of action was somewhat improved.

4.2.2 Collecting Data

The participants were first asked to have their right shoe and outsole photographed and subsequently to leave their footwear impression. Ultimately, they were to fill in a form to provide some additional information about the shoe and its wearer. To achieve traceability each form was stapled together with its test impression and assigned a unique number. Additionally, the digital photo numbers, assigned by the cameras, were recorded on each form to refer its residing photographs.

4.2.2.1 The Set-Up

A “photo-studio” device, constructed to facilitate photography and illumination of the outsole and shoe, was placed in the centre with two external flashes, F1 and F2, and two cameras, C1 and C2, strategically positioned around it. See fig. 4.1.

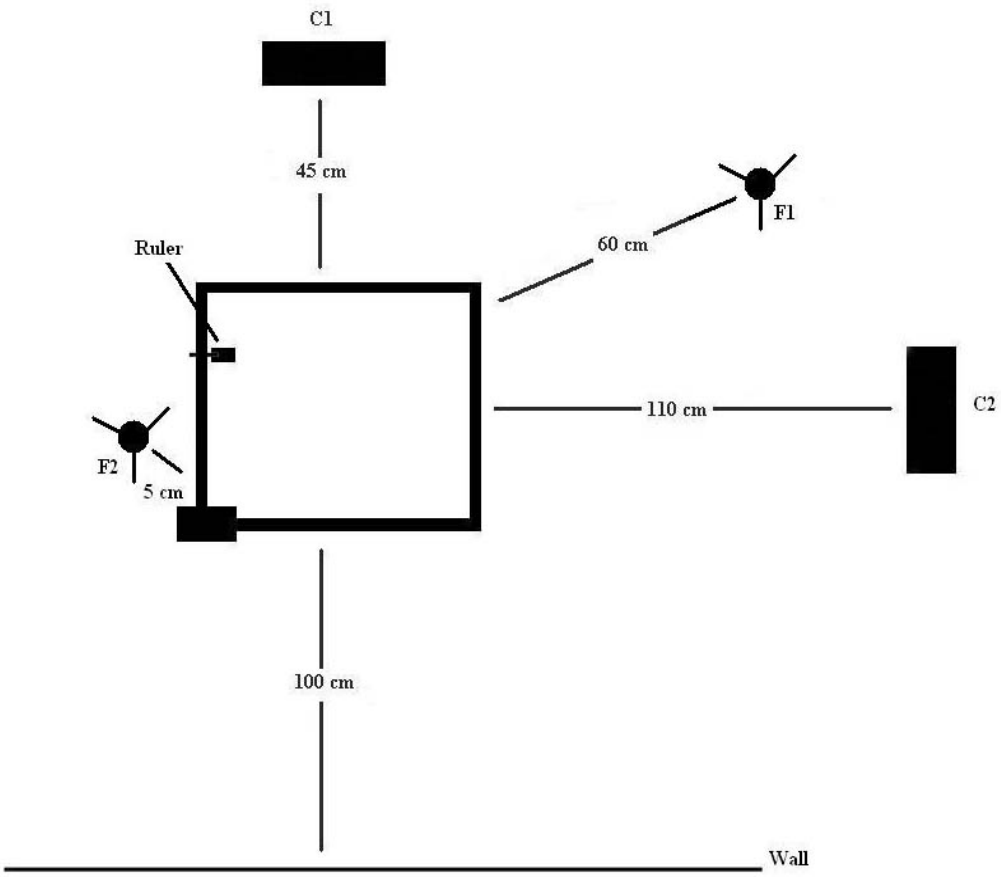

Fig. 4.1 A sketch with approximate distances illustrating the photography set-up. C1 and C2 represents the cameras while F1 and F2 represents the flashes.

The reason for using two flashes was to obtain photographs with maximum outsole details and to diminished potential background disturbance, while the reason for using two cameras was to facilitate the actual photography procedure. In order to achieve high quality photos, in the means of our purpose, the proper photography arrangement was determined at the set through repeated tryouts.

Adjacent to the photography device an inkless foot/shoe print kit was placed where the participants of the survey were asked to leave their footwear impression.

4.2.2.2 Photography

Each participant in the survey had their shoe photographed from two different angles: one showing the outsole and another showing the outside of the shoe. The photograph taken of the outsole of the shoe was primarily to verify the origin of the footwear impression and its internal characteristics. However, it is also used to estimate the prior and future features of the sole. The additional photographs taken of the shoe were to establish a link between the outsole and a specific shoe type.

As the photographs taken of the outsole required a high resolution in order to obtain all minute details, the more advanced system camera NIKON D80 was used. The photographs of the shoe were only required to show the type and consequently the amount of details became

negligible. Thus, the less advanced digital camera NIKON COOLPIX 5400 was used. Both cameras used have eleven different modes whereof seven are so called shooting modes (Digital Vari-Program) and five are advanced modes (exposure modes). In the shooting modes the adjustments are optimized automatically to fit a certain scene while the advanced modes enables for the user to have a complete control over the camera adjustments. In this project both cameras were set on the advanced mode P, Programmed automatic, where the camera automatically selects the shutter speed and aperture to provide for an optimal exposure. All other adjustments, for instance distance, are controlled by the user.

To obtain a maximum amount of details from the outsole and by other means high quality photographs with non-disturbing background, the proper exposure compensation was to be set for each photograph.

4.2.2.2.1 Cameras

4.2.2.2.1.1 NIKON D80

The NIKON D80 is a semi-professional D-SLR (digital single lens reflexion) camera with a resolution of 10,2 million effective pixels and replaceable objectives. The objective used in this project is SIGMA ZOOM 18-50mm 1:3,5-5,6 DC.

Camera adjustments:
- Image format: JPEG FINE
- Image size: 3872x2592/10,0 M (LARGE)
- ISO rating (sensitivity): 100 (STANDARD)
- Focus: Automatic AF-A (STANDARD)
- Exposure: Automatic
  - Compensation: +2,0-4,0 EV
- Flash: Commander mode
  - Built in: Unreleased (--, only triggering flashes)
  - External:
    - Flash 1: TTL-mode, compensation +1,3
    - Flash 2: TTL-mode, compensation –1,0

All other adjustments are set on standard (NORMAL) for the P mode.

4.2.2.2.1.2 NIKON COOLPIX 5400

The NIKON COOLPIX 5400 is an easily applicable prosumer digital camera with a resolution of 5,2 million effective pixels and two types of built in zooms, optic or digital. In this project the full 4x optic zoom is used in order to achieve as high resolution as possible.

Camera adjustments:
- Image format: JPEG FINE
- Image size: 3872x2592/10,0 M (LARGE)
- ISO rating (sensitivity): Automatic
- Focus: Automatic AF-A (STANDARD)
- Exposure: Automatic
  - Compensation: +0,0-1,0 EV
- Flash:
  - Built in: Unreleased
  - External: TTL-mode, compensation +1,3

All other adjustments are set on standard (NORMAL) for the P mode.

4.2.2.2.2 External Flash

4.2.2.2.2.1 SB-600

SB-600 is an advanced flash that can be used as a wireless head unit if the camera is compatible with Nikon's Creative Lighting System. In order to obtain a balanced illumination of the image and background and, also, minimize eventual shadows, the flash has a built in wide- angle adaptor that softens the illumination. In this project two wireless SB-600 flashes, F1 and F2, were used.

4.2.2.3 Collecting Footwear Impressions

To collect the footwear impressions several methods can be applied. However, in order to avoid any inconvenience a simple and non-destructive method like the inkless was preferred.

4.2.2.3.1 Inkless Foot/Shoe Print Kit LE-25

The Inkless Foot/Shoe Print Kit, supplied by ARMOR FORENSICS, provides a clean and simple method for the collection of footwear impressions, which neither damages nor leaves visible residues on the footwear, i.e. is non-destructive. Each kit contains a chemical coater and 100 chemically sensitized sheets that are large enough for an average shoe. By pressing the shoe on the coater and then stepping on the sensitized sheet a black impression immediately will appear. The sheet size is large enough to fit most shoes and dries almost immediately after treaded and leaves no visible residue on the sole.

4.2.3 Establishing the Database

First all collected footwear impressions were scanned (with a resolution of 400 dpi) while the photographs were revised in Photoshop Elements in order to diminish any disturbing background. The footwear impressions and their residing pictures were then put together into a folder assigned the number of the impression which was implemented into SIMSALAPIM. Subsequently, the information obtained from the form residing each footwear impression were recorded in the database. Ultimately, each impression was coded by following the guidelines apprehended by the system.

Each collected outsole pattern was coded in regard to its own observable characteristics. Still, additional coding could be legitimate if the outsole photograph was to acknowledge more minute details. In case a specific outsole pattern occurred more than once all copies were coded the same. By studying the characteristics of the outsole, its original features could be imagined and also its future features anticipated, which was also coded for.

The establishment of the database was probably the most time consuming stage in this project. In total, 687 impressions were scanned and coded and 1374 (2x687) pictures revised.

4.2.4 Evaluating the Database

In order to present any results and evaluate the database some test and illustrative cases were set-up. To access the raw data, tabulate and establish diagrams that present the results appropriately, Microsoft Access and Excel were used.

By applying Bayes' theorem likelihood ratios could be calculated and in some cases standard statistical methods like the χ^2-test provided for some additional calculation of significance.

5 Results and Evaluation

In order to obtain any results from the database the questioned footwear impression first needs to be coded whereupon a subsequent comparison with the already existing data can be made. The retrieved matches will be listed and their raw data may be viewed. By comparison of the residing photographs of the questioned impression and the suggested match, real matches can be recognized.

5.1 Results

To enable the subsequent evaluation of the database, especially its applicability and reliability, descriptive comparisons and illustrative cases were used.

5.1.1 Descriptive Comparison

To acknowledge any limitations as well as possible areas of application of the database some descriptive comparisons were made and the results evaluated.

5.1.1.1 Outsole Pattern Prevalence

This descriptive test was performed in order to determine the prevalence of each outsole pattern present in the selected population and, subsequently, compare the result with the Irish survey analogue (Hannigan *et al*., 2006). By retrieving the occurrence of each type of outsole pattern from the database the prevalence could be obtained. In addition, also the number of brands sharing the exact same outsole pattern was determined.

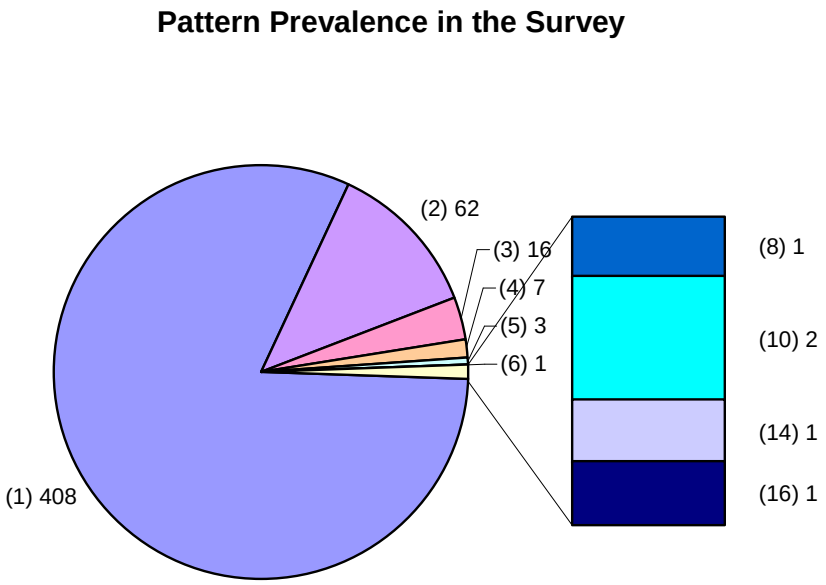

Fig. 5.1a A breakdown showing the prevalence of the 502 different outsoles patterns present in the database. ‘(x)y’ indicates x examples of y different outsole patterns.

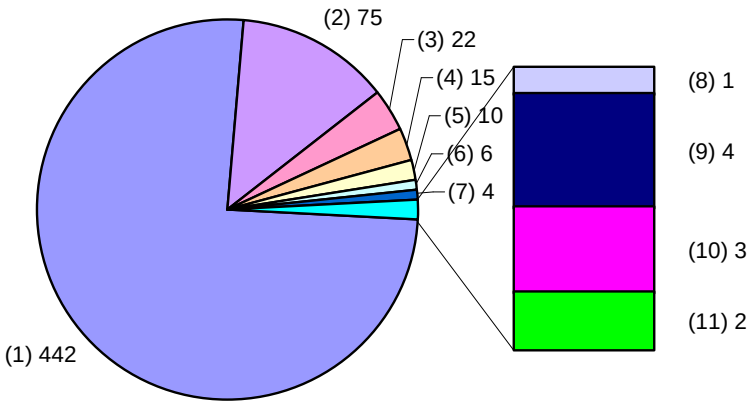

Fig. 5.1b A breakdown showing the prevalence of the 584 different outsoles patterns present in the Irish survey. '(x)y' indicates x examples of y different outsole patterns.

From the results, shown in fig. 5.1a, it can be concluded that most outsole patterns only occur once in the survey and, consequently, the most common prevalence is 0.15 % (1/687). Further more, the most frequent pattern occurs 16 times, i.e. has a prevalence of 2.33 % (16/687), and belongs to an Adidas sport (tennis) shoe which outsole pattern is shown in fig. 5.9.

Knowing that the general outsole pattern prevalence (59.39 %, i.e. 408 patterns out of 687) in the survey is one and figuring that this is a trend, an expansion of the database would imply reduced prevalence frequencies and, consequently, increased evidence values. When comparing the recognized pattern prevalence in this survey with the one presented in the Irish survey, see fig. 5.1b, a major resemblance can be observed. Thus, it can be acknowledged that a specific outsole pattern, in fact, may serve as significant forensic evidence as they to a great extent can diminish a suspect population.

5.1.1.2 Prevalence of Brands

To be able to acknowledge the most common pattern among the brands present in the survey a descriptive test was made. By retrieving the occurrence of each pattern and then the brand name residing the shoes in each group of patterns from the database, the pattern distribution among the brands could be obtained.

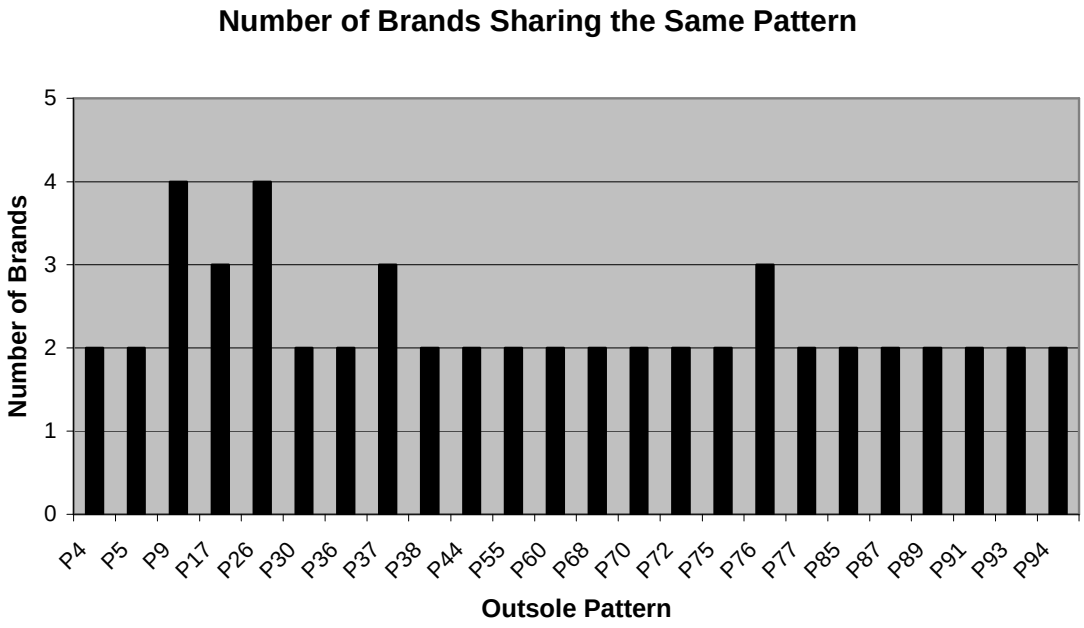

Fig. 5.1c The number of different brands that share the same outsole pattern.

The results in fig. 5.1c show that if not a unique shoe pattern, the general number of brands sharing the same outsole pattern is two. Furthermore, pattern P9 and P26 are the most common among the different shoe brands present in the survey.

In order to facilitate a criminal investigation it would be desirable to be able to associate a specific outsole pattern to a specific brand. Given the results above it may be established that this cannot be absolutely realizable, still, a fairly enough suggestion can be made.
Additionally it should be conveyed that different models of the same brand may also share the same outsole pattern.

5.1.1.3 Shoe Size Prevalence

In order to recognize the most common shoe size among the participants a descriptive test was set up. By retrieving the occurrence of each shoe size from the database the shoe size distribution in the selected population could be obtained. In addition, the average shoe size was calculated.

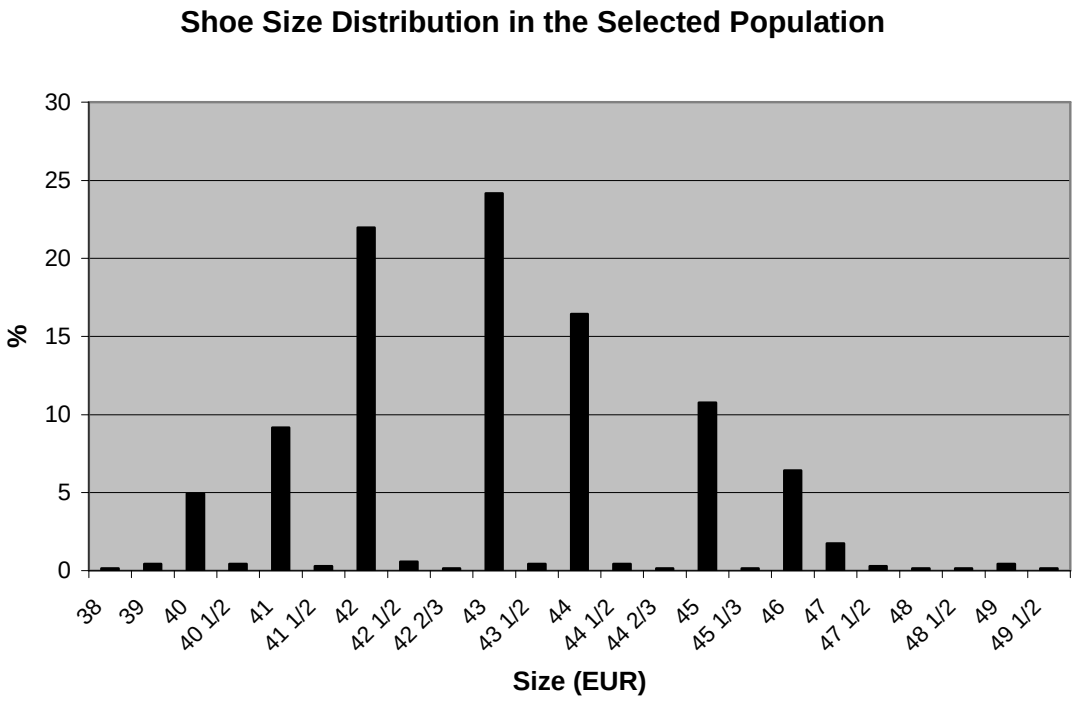

Fig. 5.2 The shoe size distribution of the participants.

Fig. 5.2 indicates that the general participant has size 43 (EUR) and by calculation, see 9.4.1 in appendix, the average size was estimated to be within the interval $\bar{x} = (43{,}125 \pm 0{,}254)$ with 95% confidence.

Class characteristics such as shoe size may be crucial parameters in the criminal investigation as well as in the evidence evaluation. By knowing the shoe size distribution in a population the value to ascribe a footwear impression made by a shoe of a certain size could be estimated. For instance, the distribution in fig. 5.2 implies that a footwear impression made by a man with a shoe size greater than 46 or smaller than 40 would be assigned a much higher evidence value than a footwear impression made by a shoe of size 43.

5.1.1.4 Age Distribution

This test was performed in order to find out if the age distribution in the database is similar to the age distribution in the male Swedish population. By retrieving the raw data of all footwear impressions from the database, a plot of the age distribution of the participants in the survey could be made. Subsequently, a comparison with the true age distribution of the male Swedish population was made. The comparison was restricted to males in ages between 18 and 47as the number of participants older that 47 in the study were quite few.

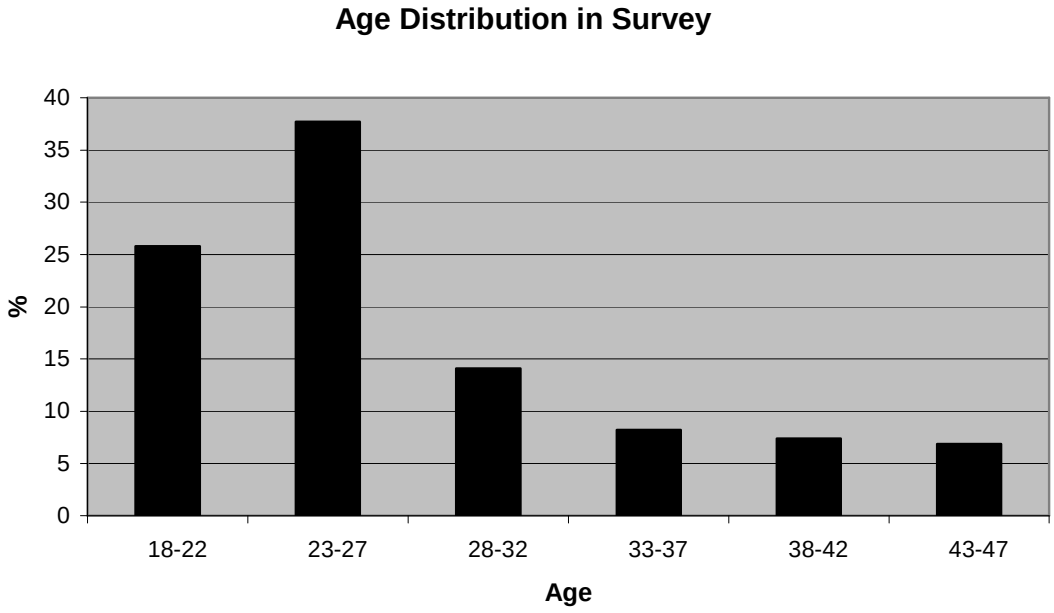

Fig. 5.3a The calculated age distribution of the participants in the survey.

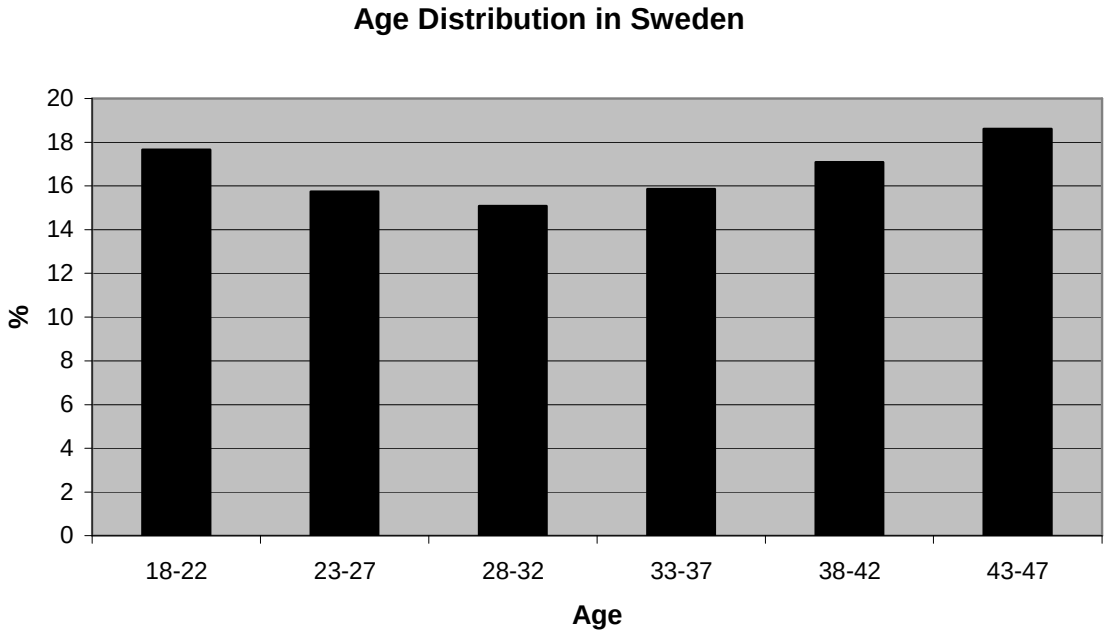

Fig. 5.3b The calculated age distribution in Sweden.

The unmistakable dissimilarities observed when making a comparison between the age distribution in the survey, shown in fig. 5.3a, and the corresponding age distribution in Sweden, shown in fig.5.3b, strongly indicate that the database does not represent the male Swedish population over the age of 18. This is to be seen as a major fault as "true" prevalence frequencies required in the forensic evidence evaluation can only be achieved when the reference database extends to a greater population. As this survey, evidently, is much to reduced to provide "true" frequencies from the database, all calculated evidence values are somewhat inaccurate.

5.1.1.5 Relation between Variables

These tests were set-up in order to identify associations of significance between some of the variables present in the database. First the raw date of all footwear impressions from the database was retrieved whereupon the parameters could be plotted against each other. In case a possible relationship was observed a χ^2-test at the 5 % level was performed to determine the significance.

5.1.1.5.1 Age of Participant vs. Shoe Type

In this test the age of participants was plotted against the shoe type in order to observe a possible association of significance. Also an age dependent shoe type breakdown was made to enable a comparison with the Irish survey presented in Hanningan, T.J. *et al* (2006).

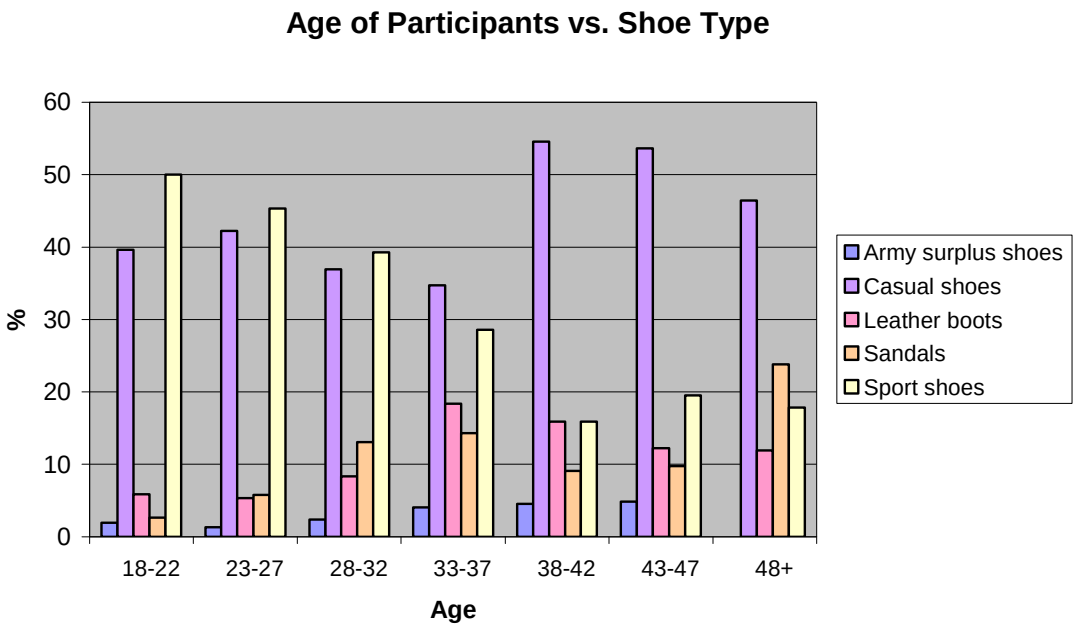

Fig. 5.4a The age of participants vs. shoe type.

From fig. 5.4a it can be interpreted that the shoe type to some extent is dependent of the age of the participant and, thus, in order to establish the significance a χ^2-test was performed. See appendix 9.4.2.1. The χ^2-test points out that there is, in fact, a significant association between the age of the participants and shoe type. For instance, fig. 5.4a gives that men at the age of 18-27 are most likely to wear sport shoes while men over 38 are expected to wear casual shoes.

By acknowledging significant associations between variables the recovery of one variable at the crime scene would indirectly provide information about its associative variables. For instance, a recovered footwear impression known to have originated from a sport shoe would based on this survey indicate a younger wearer.

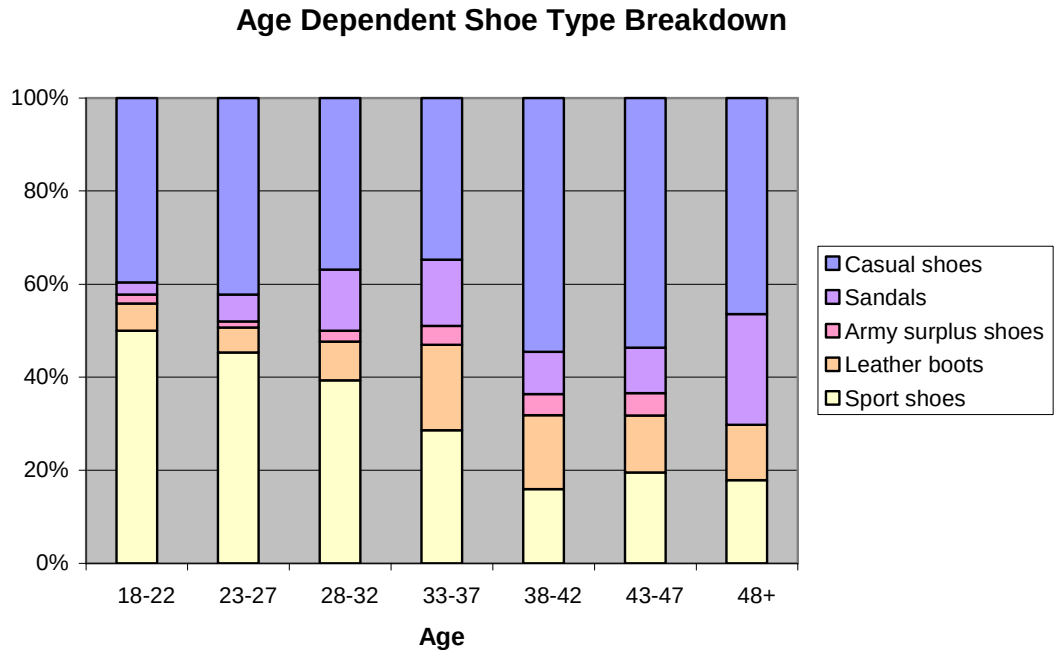

Fig. 5.4b The age dependent shoe type breakdown to be compared with the analogue of the Irish survey.

When comparing the age dependent shoe type breakdown in fig. 5.4b with the results of the Irish survey some similarities can be recognized. However, the shoe type classifications are somewhat different between the surveys and therefore it may only be valid to compare observable patterns. The most apparent pattern similarity is that the tendency to wear sport shoes decreases with an increased age of the participants.

5.1.1.5.2 Age of Participant vs. Age of Shoe

In this test the age of participants was plotted against the age of shoe in order to examine the presence of a significant association. In addition, also the average shoe age was calculated.

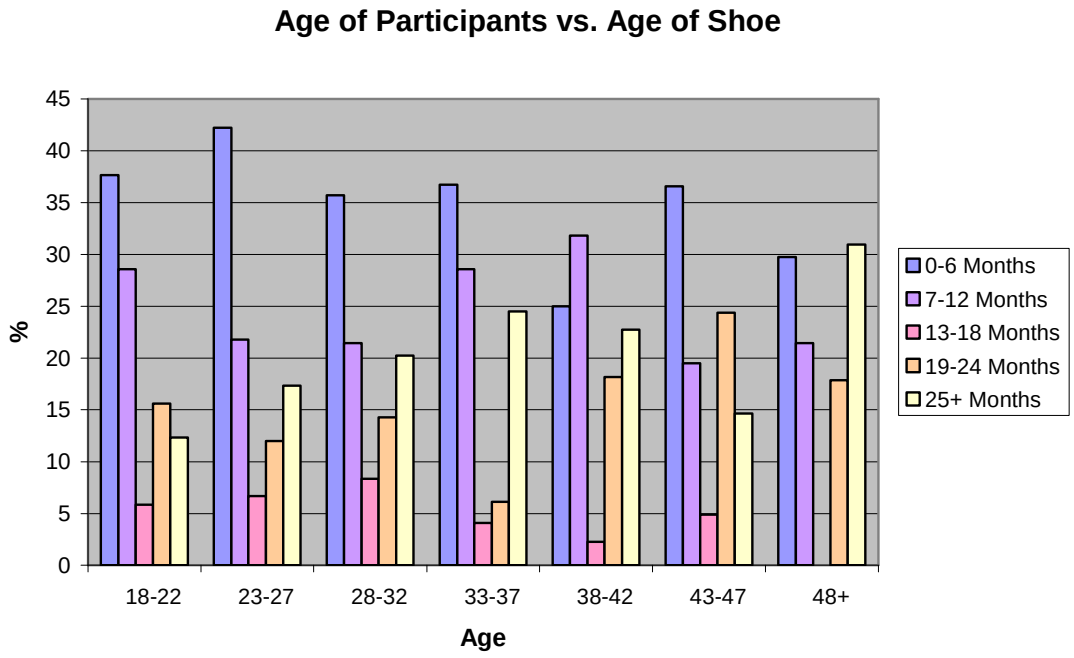

Fig. 5.5 The age of participants vs. shoe age.

Fig. 5.5 indicates an association between the age of participant and age of shoe and, thus, in order to establish the significance a χ^2-test was performed. See appendix 9.4.2.2. The result obtained from the χ^2-test does not support the indicated association and, consequently, no parallels between the parameters can be drawn.

5.1.2 Cases

To illustrate the limitations as well as possible areas of application of the database, cases, both real and fictive, were set-up.

5.1.2.1 Real Cases

The database was applied in two real cases during this project and a positive result was achieved in one of them.

5.1.2.1.1 Case I: Shoe Size Comparison

In this case there was a question of whether or not a footwear impression could have been made by the questioned shoe regarding to size. Given the outsole pattern of the suspect shoe the database was searched resulting in the retrieval of one outsole with the same pattern but in another size. As the information residing this outsole comprised its shoe size it enabled for a subsequent comparison.

From the shoe size comparison it was established that the footwear impression was unlikely to have originated from the questioned shoe resulting in a changed value of evidence. This, without a doubt demonstrates the great use of the database.

5.1.2.1.2 Case II: Partial Impression Identification

This case consisted of a number of partial impressions that needed to be linked to a specific brand or at least a specific shoe type. By searching the database some similar footwear impressions were found.

Unfortunately, none of the retrieved impressions were consistent with the questioned partial footwear impressions. Still, some of the partial impressions could have originated from a sport shoe and if so, it most likely was a tennis or basketball shoe.

5.1.2.2 Fictive Case

These cases are made-up, simply, to illustrate the evidence value of a footwear impression, i.e. its weight/strength.

5.1.2.2.1 Evidence Value/Likelihood Ratio

Imagine three different cases where different footwear impressions without any individual characteristics have been found at the crime scenes. Then, in each case the question to ask is: to what strength would the evidence support the hypothesis that the suspect shoe is the source? To allow for the answer to this question each footwear impression was searched for in the database in order to receive a frequency of prevalence in the population.

5.1.2.2.1.1 Case I: Infrequent pattern

In this case the database was searched for a random specific outsole pattern, shown in fig. 5.6, whereupon 1 matched impression was retrieved. Subsequently, the frequency and likelihood ratio was calculated.

Fig. 5.6 On the right is one of the most infrequent outsoles and on the left its residing footwear impression. The footwear impression on the left is laterally transposed as it facilitates comparison.

A frequency of 0.15 % (1/687) and a likelihood ratio within the interval $(0:687+1346)$, at 95% confidence, were obtained. See table in appendix 9.4.3. Thus, the likelihood ratio would, according to Evett *et al.* (2000), be verbally denoted “The evidence provides moderately

strong support for H_P against H_D" where H_P: The suspect shoe is the source and H_D: The suspect shoe is not the source. See chapter 3.4.

5.1.2.2.1.2 Case II: Moderately frequent pattern

In this case the database was searched for a random specific outsole pattern, shown in fig. 5.7, whereupon 8 matched impressions were retrieved. Subsequently, the frequency and likelihood ratio was calculated.

Fig. 5.7 On the right is one of the moderately common outsoles and on the left its residing footwear impression. The footwear impression on the left is laterally transposed as it facilitates comparison.

A frequency of 1.16 % (8/687) and a likelihood ratio within the interval (86 ± 59), at 95% confidence, were obtained. See table in appendix 9.4.3. Thus, the likelihood ratio would, according to Evett *et al.* (2000), be verbally denoted "The evidence provides moderate support for H_P against H_D" where H_P: The suspect shoe is the source and H_D: The suspect shoe is not the source. See chapter 3.4

5.1.2.2.1.3 Case III: Frequent pattern

In this case the database was searched for a specific outsole pattern, which was thought to be the most common one, shown in fig. 5.8. From the search 16 matched impressions were retrieved, whereupon the frequency and likelihood ratio were calculated.

Fig. 5.8 On the right the most common outsole and on the left its residing footwear impression. The footwear impression on the left is laterally transposed as it facilitates comparison.

A frequency of 2.33 % (16/687) and a likelihood ratio of within the interval (43 ± 21), at 95% confidence, were obtained. See table in appendix 9.4.3. Thus, the likelihood ratio would, according to Evett *et al.* (2000), be verbally denoted "The evidence provides moderate support for H_P against H_D" where H_P: The suspect shoe is the source and H_D: The suspect shoe is not the source. See chapter 3.4.

The specific outsole pattern above was in fact acknowledged as the most frequent in the survey. Therefore it would be of further interest to the forensic examiners if its shoe size prevalence also was established.

As seen in fig 5.9 the most common shoe size for this outsole pattern is 42 which differs somewhat from the general, see fig 5.2.

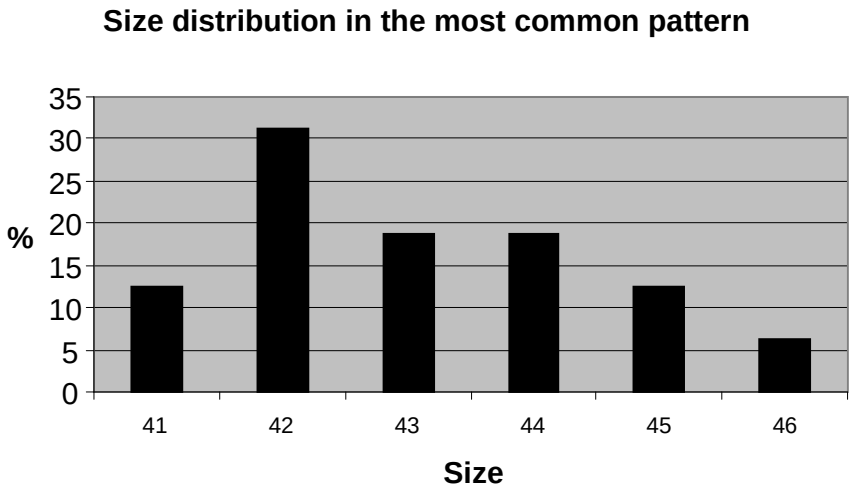

Fig. 5.9 The size distribution for the most common outsole pattern.

5.2 Evaluation

Given the results of the survey the use and limitations of footwear impression as forensic evidence and an additional reference database can be acknowledged.

5.2.1 Footwear Impression as Forensic Evidence

A lot of information can be retrieved from a footwear impression as the shoe outsole possesses an amount of different class, individual and wear characteristics. Thus, the footwear impression may constitute a powerful piece of evidence in criminal investigations.

5.2.1.1 Prevalence

Even though this survey comprises a diminished population the obtained results still indicate that the prevalence of any specific outsole pattern in the selection group is low enough for the residing footwear impression to constitute evidence of value. Studying the likelihood ratios more closely and using the scale of Evett *et al.* (2000) the outsole patterns present in the database can be divided in two groups; the evidence provides moderately strong support to the proposition put forward by the prosecution, or the evidence provides moderate support to the proposition put forward by the prosecution, in regard to their strength as evidence. The general outsole pattern prevalence in the database is one (408 patterns out of 687) and figuring that this is a trend, an expansion of the database would imply increased likelihood ratios and, consequently, evidence values.

5.2.1.2 Characteristics

As the class characteristics, among other things, constitute the outsole pattern it is evident that a combination of different class characteristics would reduce the prevalence of a specific shoe further. However, in crime investigations, generally, the only footwear evidence recovered is the impression and therefore the prevalence is that of the outsole pattern. Instead, by examining the minute details, i.e. the individual characteristics, of an outsole pattern one may reduce the prevalence to such extent that the outsole can be individualized.
When studying the photographs and footwear impressions of outsoles sharing the same pattern several detail distinctions could be observed. This implies that if a thorough forensic examination of a crime scene footwear impression and a questioned shoe is performed, one could either exclude or recognize the shoe. Furthermore, different wear characteristics could be observed which, ultimately, may contribute to individualization.

5.2.1.3 Evidence Value

Considering the footwear impression it is to be regarded as evidence of significance. Exactly how much strength it provides to a proposition put forward by the court is analogous to its likelihood ratio. The likelihood ratio is generally inferred from an estimated frequency of occurrence that is based on experience and therefore, it comprises some inaccuracy. By the establishment of a reference database the prevalence will be recorded and, consequently, the "true" frequency and likelihood ratio can be far more accurately estimated.

5.2.2 Database

By establishing a reference database the search for a specific outsole pattern, or any other characteristic of interest in the comparison and identification process, may be facilitated. Subsequently, the prevalence can be calculated from the retrieved data and, thereby, aid the evidence evaluation process.

5.2.2.1 Reliability

Even though it may seem convenient to obtain a likelihood ratio inferred from an estimated frequency, the question of inaccuracy still remains due to unreliability of the database. Apart from potential errors in recording the data, the major part of inaccuracy originates from the reference data itself. In general, it is very difficult to collect the exact desired data especially when it comes to reference data that is to represent a greater population. For instance, to establish a more exact frequency of occurrence of outsole patterns, a survey that extends to the whole population would be required. This would not only be time consuming but also imply great cost for the forensic laboratories and therefore, the collected data, typically, only constitutes the data available, i.e. the data collected in the survey.

As this survey only extends to the voluntarily participants in the male population over the age of 18 in Linköping the established database is most likely to compromise some inaccuracy. One possible error in the reference data material was acknowledged by the comparison between the age distribution of the participants in the survey and that of the whole population, i.e. Sweden, see chapter 5.1.1.4. The obtained result indicates that there is a great difference which implies that the database cannot be thought to represent the whole male population unless the age distribution is proved to be insignificant to the outsole pattern prevalence.

6 Concluding Remarks

Regardless of the nature of the crime, footwear impressions are most likely present at the crime scene. Occasionally, a questioned impression can be recognized to originate from a specific shoe resulting in a high value of evidence. However, more frequently the source cannot be identified and the pattern prevalence may solely provide the value of evidence. The value of evidence is analogous to its likelihood ratio, which is generally an estimated frequency of occurrence.

In order to calculate the frequency of occurrence of a specific outsole pattern one needs to collect the appropriate data which extends to the whole population. Unfortunately, this survey only considers 687 voluntarily males over the age of 18 in Linköping, Sweden, and may therefore be somewhat fallacious. Despite the diminished population, the result still indicates that the outsole pattern prevalence constitutes a significant value of evidence. In general, it may exclude the evidence, i.e. provide a negative evidence value, or provide a positive evidence value.

A database of outsole patterns may not only provide the pattern prevalence but also more specific and minute characteristics such as type, size, common wear patterns and individual damages, which could be used in different comparison procedures. Thus, an established reference database could be of great assistance to the crime investigations as it could, for an example, indicate what type of shoe to look for and also link different crime scenes.

7 Prospectives

As the results of this survey indicate that a reference database facilitates the footwear impression identification process and evidence evaluation, it has the potential to become a basic tool in criminal investigations. However, in order to be acknowledged by the forensic scientists, the concept of a footwear impression reference database first has to encounter some major problems. For instance, in order to achieve a high accuracy the database is required to comprise appropriate data that extend to the whole population, at any season of the year, which would imply managing extremely extensive data. By the implement of an international footwear impression database, a linkage of the already existing databases all around the world, the inaccuracies could be diminished. However, as there are several concurring database systems available one needs to agree on the most pre-eminent to apply. Furthermore, in order to facilitate the evidence evaluation of footwear impressions one important action to take is to implement a universal scale of statement. This would most certainly aid the communication and collaboration between the national forensic laboratories.

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9 Appendices

9.1 Form

Reference number:

Footwear Impression as Forensic Evidence

Prevalence, Characteristics and Evidence Value

Master Thesis in Forensic Science at Linköping University

Date: _____ Photo number:

Time: _____ Camera 1: _____

Place: _____ Camera 2: _____

Shoe type: Sport Casual Boot Sandal

Please fill in the box!

Age:	18-22	23-27	28-32	33-37
	38-42	43-47	48+	
Shoe size:	39	40	41	42
(EUR)	43	44	45	46
	47	Other: _____		

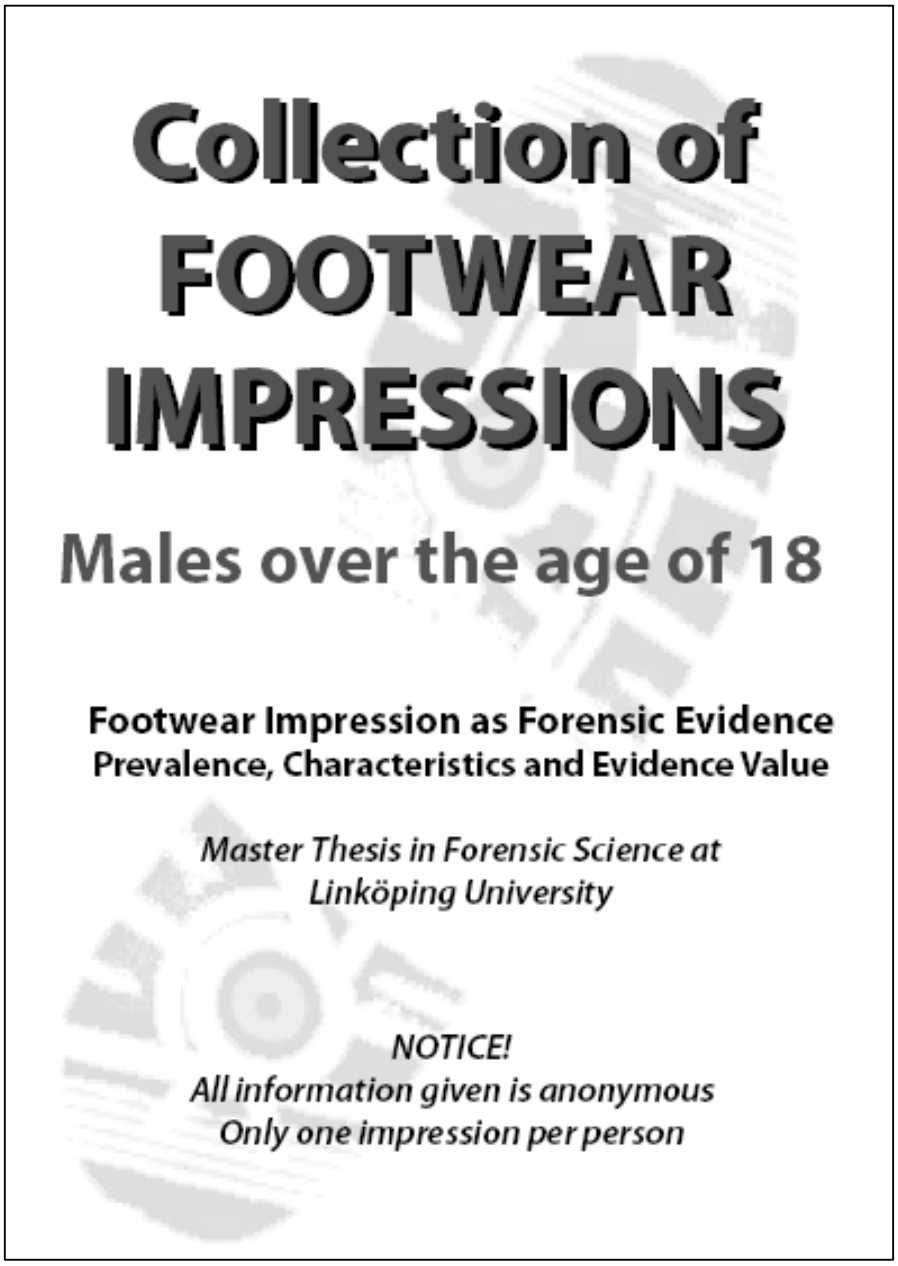
Approximate age of the shoe: _____
(Years/Months)

Brand: _____

Model: _____

Comments: _____

9.2 Poster


Collection of
FOOTWEAR
IMPRESSIONS
Males over the age of 18
Footwear Impression as Forensic Evidence
Prevalence, Characteristics and Evidence Value
Master Thesis in Forensic Science at
Linköping University
NOTICE!
All information given is anonymous
Only one impression per person

9.3 Tables

9.3.1 Pattern Prevalence

Pattern Prevalence	Number of Patterns	Total
1	408	408
2	62	124
3	16	48
4	7	28
5	3	15
6	1	6
8	1	8
10	2	20
14	1	14
16	1	16
Total	502	687

9.3.2 Sole Pattern vs. Brand

Solepattern	P4	P5	P9	P17	P26	P30	P36	P37	P38	P44	P55	P60	P68	P70	P72	P75	P76	P77	P85	P87	P89	P91	P93	P94	Totalt Antal
Unknown		1	1					2					1		1								1		6
360																				1					1
Adidas					2																				1
Arbesko												1													1
Attitude																			1			1			2
Bagheera									1																1
Best	1						2																		2
Björn Borg																				1					1
Cheap Monday			1																						1
Cheapo						3																			1
Blamno						1																			1
Converse All Star			11																						1
Coop																								1	1
Dets					1																				1
Din sko															1		2								2
Firefly				1																					1
Front Page													1												1
Geytop																					1				1
Jack & Jones																	1								1
Lacoste																		4							1
Le coq sportif										1															1
Lejon					1									1					2			1			4
Levis			1																						1
Lion																		1							1
Maks					1																				1
Moonlai				1																					1
Nike														1									2		2
Puma										1															1
Seaside											1														1
Skokanonen																								1	1
Skopunkten	1	1						1													1				4
Stålex												1													1
Taxi																1									1
Vans				8																					1
Warp									2																1
Wedins							1	1			1						1								4
Zack																1									1
Totalt	2	2	4	3	4	2	2	3	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	37

9.3.3 Age Distribution

Age Distribution in Survey

Age	Number	%
18-22	154	25,8
23-27	225	37,7
28-32	84	14,1
33-37	49	8,2
38-42	44	7,4
43-47	41	6,9
Total	597	100

Age Distribution in Sweden

Age	Number	%
18-22	324447	17,6
23-27	289265	15,7
28-32	277205	15,1
33-37	291446	15,9
38-42	314018	17,1
43-47	341937	18,6
Total	1838318	100

9.3.4 Age of Participants vs. Shoe Type

In Numbers

Shoe Type	18-22	23-27	28-32	33-37	38-42	43-47	48+	Total
Army surplus shoes	3	3	2	2	2	2	0	14
Casual shoes	61	95	31	17	24	22	39	289
Leather boots	9	12	7	9	7	5	10	59
Sandals	4	13	11	7	4	4	20	63
Sport shoes	77	102	33	14	7	8	15	256
Total	154	225	84	49	44	41	84	681

In percent

Shoe Type	18-22	23-27	28-32	33-37	38-42	43-47	48+	%
Army surplus shoes	1,9	1,3	2,4	4,1	4,5	4,9	0,0	2,0
Casual shoes	39,6	42,2	36,9	34,7	54,5	53,7	46,4	42,5
Leather boots	5,8	5,3	8,3	18,4	15,9	12,2	11,9	8,6
Sandals	2,6	5,8	13,1	14,3	9,1	9,8	23,8	9,5
Sport shoes	50,0	45,3	39,3	28,6	15,9	19,5	17,9	37,4
Total	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0

9.3.5 Age of Participants vs. Age of Shoe

In Numbers

Age of Shoe	18-22	23-27	28-32	33-37	38-42	43-47	48+	Total
0-6 Months	58	95	30	18	11	15	25	254
7-12 Months	44	49	18	14	14	8	18	169
13-18 Months	9	15	7	2	1	2	0	36
19-24 Months	24	27	12	3	8	10	15	99
25+ Months	19	39	17	12	10	6	26	129
Total	154	225	84	49	44	41	84	**687**

In percent

Age of Shoe	18-22	23-27	28-32	33-37	38-42	43-47	48+	%
0-6 Months	37,7	42,2	35,7	36,7	25,0	36,6	29,8	37,0
7-12 Months	28,6	21,8	21,4	28,6	31,8	19,5	21,4	24,6
13-18 Months	5,8	6,7	8,3	4,1	2,3	4,9	0,0	5,2
19-24 Months	15,6	12,0	14,3	6,1	18,2	24,4	17,9	14,4
25+ Months	12,3	17,3	20,2	24,5	22,7	14,6	31,0	18,8
Total	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0

9.3.6 Shoe Size Distribution of Participants

Size	Total	%
38	1	0,15
39	3	0,44
40	34	4,95
40 ½	3	0,44
41	63	9,17
41 ½	2	0,29
42	151	21,98
42 ½	4	0,58
42 ⅔	1	0,15
43	166	24,16
43 ½	3	0,44
44	113	16,45
44 ½	3	0,44
44 ⅓	1	0,15
45	74	10,77
45 ⅓	1	0,15
46	44	6,40
47	12	1,75
47 ½	2	0,29
48	1	0,15
48 ½	1	0,15
49	3	0,44
49 ½	1	0,15
Total	687	100,00

9.4 Calculations

9.4.1 Shoe Size Distribution of Participants

Mean value: $\bar{x} = 43{,}125$

Standard deviation: $s = 1{,}730$

$\sqrt{n} = 26{,}211$

$X \pm 1{,}96 \times \left(s / \sqrt{n} \right)$

$43{,}125 \pm 1{,}96 * 0{,}1294$

$X_1 = 43{,}379$

$X_2 = 42{,}871$

9.4.2 χ^2

9.4.2.1 Age of Participants vs. Shoe Type

Shoe Type	Unknown	18-22	23-27	28-32	33-37	38-42	43-47	48+	Total
Army surplus shoes	0	3	3	2	2	2	2	0	14
Casual shoes	3	61	95	31	17	24	22	39	292
Leather boots	0	9	12	7	9	7	5	10	59
Sandals	2	4	13	11	7	4	4	20	65
Sport shoes	1	77	102	33	14	7	8	15	257
Total	6	154	225	84	49	44	41	84	687

χ^2 adjusted

Shoe Type	18-22	23-27	28-32	33-37	38+	Total
Army surplus shoes	3	3	2	2	4	14
Casual shoes	61	95	31	17	85	289
Leather boots	9	12	7	9	22	59
Sandals	4	13	11	7	28	63
Sport shoes	77	102	33	14	30	256
Total	154	225	84	49	169	681

$$E_{ij} = \frac{(R_i * C_j)}{n}$$

Shoe Type	18-22	23-27	28-32	33-37	38+	Total
Army surplus shoes	3,166	4,626	1,727	1,007	3,474	14,0
Casual shoes	65,354	95,485	35,648	20,794	71,720	289,0
Leather boots	13,342	19,493	7,278	4,245	14,642	59,0
Sandals	14,247	20,815	7,771	4,533	15,634	63,0
Sport shoes	57,891	84,581	31,577	18,420	63,530	256,0
Total	154,0	225,0	84,0	49,0	169,0	681,0

$$q_{ij} = \frac{((O_{ij} - E_{ij})^2}{E_{ij}}$$

Shoe Type	18-22	23-27	28-32	33-37	38+	Total
Army surplus shoes	0,009	0,571	0,043	0,978	0,080	1,681
Casual shoes	0,290	0,002	0,606	0,692	2,459	4,050
Leather boots	1,413	2,881	0,011	5,325	3,698	13,328
Sandals	7,370	2,934	1,342	1,343	9,780	22,769
Sport shoes	6,307	3,587	0,064	1,061	17,697	28,716
Total	15,389	9,975	2,066	9,399	33,714	70,543

From χ^2 table

f $= 16$ and $\alpha = 0{,}05 \Rightarrow$ Q $= 26{,}30$

Q $= \sum$ q$_{ij}$ $= 70{,}543 \approx 70{,}54$ and $\alpha = 8{,}01514$ E $- 9$

9.4.2.2 Age of Participants vs. Age of Shoe

Age of Shoe	Unknown	18-22	23-27	28-32	33-37	38-42	43-47	48+	Total
0-6 Months	2	58	95	30	18	11	15	25	254
7-12 Months	4	44	49	18	14	14	8	18	169
13-18 Months	0	9	15	7	2	1	2	0	36
19-24 Months	0	24	27	12	3	8	10	15	99
25+ Months	0	19	39	17	12	10	6	26	15
Total	6	154	225	84	49	44	41	84	687

χ^2 adjusted

Age of Shoe	18-22	23-27	28-32	33-37	38-42	43-47	48+	Total
0-6 Months	58	95	30	18	11	15	25	252
7-12 Months	44	49	18	14	14	8	18	165
13-18 Months	9	15	7	2	1	2	0	36
19-24 Months	24	27	12	3	8	10	15	99
25+ Months	19	39	17	12	10	6	26	129
Total	154	225	84	49	44	41	84	681

$$E_{ij} = \frac{(R_i * C_j)}{n}$$

Age of Shoe	18-22	23-27	28-32	33-37	38-42	43-47	48+	Total
0-6 Months	56,987	83,260	31,084	18,132	16,282	15,172	31,084	252
7-12 Months	37,313	54,515	20,352	11,872	10,661	9,934	20,352	165
13-18 Months	8,141	11,894	4,441	2,590	2,326	2,167	4,441	36
19-24 Months	22,388	32,709	12,211	7,123	6,396	5,960	12,211	99
25+ Months	29,172	42,621	15,912	9,282	8,335	7,767	15,912	129
Total	154	225	84	49	44	41	84	681

$$q_{ij} = \frac{((O_{ij} - E_{ij})^2}{E_{ij}}$$

Age of Shoe	18-22	23-27	28-32	33-37	38-42	43-47	48+	Total
0-6 Months	0,018	1,655	0,038	0,001	1,713	0,002	1,191	4,618
7-12 Months	1,198	0,558	0,272	0,381	1,046	0,376	0,272	4,104
13-18 Months	0,091	0,811	1,475	0,135	0,756	0,013	4,441	7,721
19-24 Months	0,116	0,997	0,004	2,387	0,402	2,738	0,637	7,280
25+ Months	3,547	0,308	0,074	0,796	0,333	0,402	6,396	11,855
Total	4,970	4,329	1,863	3,700	4,250	3,531	12,936	35,578

From χ^2 table

$f = 24$ and $\alpha = 0{,}05 \Rightarrow Q = 36{,}42$

χ^2 calculated

$Q = \sum q_{ij} = 35{,}578 \approx 35{,}58$ and $\alpha = 0{,}0608$

9.4.3 Likelihood Calculations

$$LR = \frac{\Pr(E \mid H_P)}{\Pr(E \mid H_D)}$$

$$\Pr(E \mid H_d) = \frac{(f * x - 1)}{x - 1}$$

f : *frequency*

x : *population*

Pattern Prevalence	Frequency	$Pr(E\|H_p)$	$Pr(E\|H_d)$	LR	Var(LR)	√Var(LR)	z	LR±z√Var(LR)
1	0,0014556		0,0014555	687	471282	686		687±1346
8	0,0116448	1	0,0116447	86	911	30	1,96	86±59
16	0,0232897		0,0232896	43	113	11		43±21

Note 1. The variance (Var(LR)) is calculated from a linearization of the likelihood ratio.
Note 2. The numerator probability ($Pr(E|H_p)$) has been set to 1 in the calculations for sake of simplicity. Occasionally it might however be less than 1.

9.5 Scale of conclusions at SKL

Below is the current English translation of the scale of conclusions used at Statens Kriminaltekniska Laboratorium, Sweden (SKL, 2007).

Scale of conclusions

(Draft I)

A forensic report from SKL is a statement of the findings from an examination.
The results have been tested against both an advanced hypothesis and at least one alternative hypothesis.
The examiners' evaluation of these findings will be reported using one of the conclusions detailed as follows.

In cases when the examiners can state a fact other terms are used, such as "it is", "it isn't" or "it can be excluded that".

Level +4 **The results of the examination support with certainty that …**
The possibility that these results could be found if an alternative hypothesis is true can in practice be excluded.

Level +3 **The results of the examination strongly support that …**
The possibility that these results could be found if an alternative hypothesis is true is considered to be very unlikely.

Level +2 **The results of the examination support that …**
The possibility that these results could be found if an alternative hypothesis is true is considered to be unlikely.

Level +1 **The results of the examination support to some extent that …**
There is somewhat more support for the advanced hypothesis than the alternative hypothesis.

Level 0 **Inconclusive**
It is not possible to determine whether the advanced hypothesis or an alternative hypothesis is true.

Level -1 **The results of the examination support to some extent that … was not …**
There is somewhat more support for the alternative hypothesis than the advanced hypothesis.

Level -2 **The results of the examination support that … was not …**
The possibility that these results could be found if the advanced hypothesis is true is considered to be unlikely.

Level -3 **The results of the examination strongly support that … was not …**
The possibility that these results could be found if the advanced hypothesis is true is considered to be very unlikely.

Level -4 **The results of the examination support with certainty that … was not …**
The possibility that these results could be found if the advanced hypothesis is true can in practice be excluded.