FACIAL COMPARISON AS INTELLIGENCE: USING FACIAL BIOMETRICS ON SEXUALLY MOTIVATED SERIAL KILLER VICTIMS AS AN INVESTIGATIVE TOOL

By

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in

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Declaration

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

Signed: Sarah Bernadette Hackett
Acknowledgements

I would like to thank Brendan Chapman and David Keatley for their continuous support through this study and giving me the opportunity to build my skills in the fields of Forensic Science and Criminology. I would also like to thank Trent Willmott for the tremendous support and helping me with the calculations for the measurement of the victims faces, I could not have done this without you. I would also like to acknowledge the victims and their families used for this study.
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Part One

Literature Review

Face Similarity Linkage: A Novel Biometric Approach to Sexually Motivated Serial Killer Victims
Abstract

Some sexually motivated serial killers target victims on the basis of appearance. Therefore, multiple victims of a single serial killer are likely to have some facial features and geometries that are similar. The current research was undertaken to propose a technique, termed Face Similarity Linkage (FSL), to evaluate whether victims of a serial killer have statistically more similar facial measurements than a randomly chosen person of the same gender. To test this, three of Ted Bundy’s victims were randomly selected and anatomical landmarks were located and measured to produce proportionality indices of their faces. A random subject from an online database was used as a comparison. The results showed there were no statistically significant differences between the three of Bundy’s victims; however, there was significant difference between eleven of the seventeen facial measurements of Bundy’s victims when compared to a random person. This research serves as a proof of concept that, with more advanced means of data collection, FSL may be a useful tool for law enforcement for linking serial homicides. The current method is relatively novel, and in need of expert systems interfaces to improve speed and application, which is outlined in the current study.

Keywords
Serial Killer, Homicide, Biometric, Crime Linkage, Victim, Sexual Homicide, Face Similarity Linkage
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Introduction

Crime linkage can be difficult if there is no physical, genetic evidence left at a crime scene and therefore other techniques need to be used to link crimes to an offender (1). Determining the type of offender committing these crimes can be ascertained by assessing the crime scene and the victims and looking for distinguishing features that link crimes, and therefore the killer. This study focuses on the crimes of sexually motivated serial killers. Owing to the sexual motivation of attacks, some serial killers may have a particular “type” or appearance of prospective victims that they are drawn to. Therefore, similarities in facial biometrics of victims may be useful to help link multiple victims to a single offender. Being able to make the connection to a killer by linking the victim’s facial measurements stands as a useful investigative tool. Biometric approaches may be used as a means for crime linkage in the absence of physical evidence at a scene. The current study provides a background on crime linkage, typologies of serial killers and victimology in order to set the scene for the application of biometric methods as a novel linkage measure.

Crime Linkage

It is important in police investigations to understand and accurately determine crimes committed by the same offender (1). This process has been referred to as crime linkage, behavioural case linkage, comparative case analysis, and crime linkage analysis (2). With the presence of physical evidence (i.e., DNA or fingerprints), the crime can be connected to the offender, but even in their absence, it may be still possible to link the crime to a specific offender by analysing the decisions and behaviour shown by the offender at the crime scene (1), referred to as behavioural fingerprinting (3). Crime linkage is underpinned by two main assumptions; 1) consistency in behaviour and 2) distinctiveness between criminals committing crimes (4). The first assumption is that the offender maintains
consistency with their behaviour when they are committing crime (i.e., similar target, similar *modus operandi*, similar levels of violence, signature), which is known as offender consistency hypothesis (2, 4). The second assumption is based on the variation of the way the offender commits crime compared to other offenders (4). For clear crime linkage, there must be consistent behaviour that is distinctive from other criminals (4).

**Mass killer’s vs serial killers**

Mass killers are defined as those criminals that kill four or more victims in close temporal and geographic proximity creating a single crime scene (5). These offenders overlap in many ways with spree killers who go to more than one location to target and kill victims (6, 7). A mass killer is differentiated from a serial killer due to the temporal and geographic differences in their incidents (7). Mass killers tend to link their victims by social or contextual elements rather than choose their victims by more specific targeting\(^1\). A generally accepted definition of a serial killer is an offender who has two or more victims over a period of time with a “cooling off” period between each killing event (8, 9). Serial killers’ victims may have common traits such as; occupation, ethnicity, appearance, gender and social status (6, 9). It is the commonality of appearance that we aim to focus on in the current biometric approach. Due to the lack of forensic evidence in many cases, crime linkage is not always possible. In addition, variation and debate to what defines a ‘serial’ killer means the true number of serial killers may never be known (10). Another issue in defining the true number of serial killers may also be because commuter offenders travel from their local area to commit crime and have little or no overlap between the scene and

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\(^1\) However, there are cases of an individual being targeted by a mass killer, and others in close proximity also being killed alongside the primary target. In these instances, the surrounding people are targeted owing to opportunity, not selective planning and targeting or preference.
home. This makes linkage sometimes near impossible, especially if the travel is interstate and in different jurisdictions (11). For these reasons, new methods of linking crimes are needed.

**Typology of serial killers.**

One method of linking and understanding crimes is attempting to classify serial killers into typologies. These typologies are often the first step into the understanding of the reasoning for the killings (8, 12). Attempting to categorise and profile serial killers early-on can help make distinctions when trying to link crime. The most widely used typology of serial killers was developed originally by the United States Federal Bureau of Investigation (FBI): organised versus disorganised (8). This classification has been claimed as the foundation on the personality characteristics of the offender based on the crime scene information (8). The validity of this approach has raised concerns but, despite this concern, this approach can be seen as the underlying premise of the fivelfold model of serial killer typology by Holmes and Holmes (8).

Ressler, Burgess, and Douglas (1988) were the first researchers to divide serial killers into two separate categories; *disorganised* and *organised* offenders. They describe an organised offender to have high intelligence, socially adequate, sexually competent, living with partner, mobility (transportation) and has an average or higher intelligence quotient (IQ) (13). Their actions of the offence tend to show high level of planning and displaying control along with the avoidance of detection strategies in place such as moving the body of the victim or disposing the weapon (14, 15). Due to these qualities and high amounts of planning, these killers may target a particular type of victim that they choose due to appearance, even as specific as their facial features. It is this organised nature of victim
selection based on appearance that we intend to investigate with an approach that utilises facial biometrics for crime linkage. This appearance-based selection may be subtle and even subconscious to the offender. It may be based on an individual from their childhood or past such as a mother or ex-partner. It is not to say that this technique will apply to all organised offenders, nor any other particular typology. In fact, like other linkage tools, such as their *modus operandi*, it is possible that an appearance-based trend may occur for part of a series before changing or adjusting.

**Victimology**

Offenders usually choose victims based on three criteria: *a) availability*; offenders’ access to victims, *b) vulnerability*; circumstances in victims lives that allow offenders to victimise them, and *c) desirability*; the attractiveness in a potential victim. For this study, desirability is considered to be a main focus point for the offender when selecting their victim. The facial features, age, gender, ethnicity or body shape are likely to be important to the offender as enticements drawing them to the victim.

Disorganised offenders may know their victims since these offenders select victims of opportunity near their home or workplace (6, 13). The victims are seen as situational victims and essentially become a target due to crossing the path of the offender (6). When compared to victims of an organised offender, the offender may plan their crime to perfection, their victims are often strangers and are targeted due to the offenders careful stalking and surveillance of the location of these selected victims (13). Victims often tend to share common characteristics and the offender has a preference for a type of victim and may continue searching until this perfect victim is available (13).
For this study, sexually motivated serial killers will be the focus and more importantly, their victims. The typology of the researched serial killer will be those exhibiting organised behaviours with apparent sexual motivation. This is due to the main objective of their killings being sexual gratification and the attraction towards their victims.

**Biometrics**

Biometric characteristics can be used to distinguish one individual from another on the basis of body parts, personal characteristics or behaviour (16). Personal characteristics include those derived from; face, fingerprints, iris, voice, gait and ears (16). A biometric system is defined as a pattern recognition program that obtains biometric data from a particular individual, using these extracted features for comparison (17). These biometric patterns can be the physical, chemical, behavioural or physiological attributes of a person that individualise them from another person (18, 19).

**Biometric applications.**

The application of biometric systems has been increasingly used in commercial, government and forensic areas (17). Examples of commercial uses include computer and smart phone login and banking and medical record access. These are known as knowledge-based systems in which the person using the device or login must have knowledge of the biometrics used for that system, i.e. pre-set passwords or personal identification pins. Government applications include driver licenses and border control. These are known as token-based systems in which the person needs documentation as proof of identification for the operator to complete a one-to-one comparison (17). For forensic applications, biometric systems can be used to identify deceased individuals, criminals at large or missing
children. This application makes use of experts in the field of biometrics to compare and match the selected biometric features such as fingerprints or DNA (17).

**Facial biometrics: recognition.**

The human face is the most clearly visible trait to distinguish an individual and is how we recognise people easily and effectively. This makes facial characteristics ideal for use by a biometric system (20, 21). Using facial biometrics for recognition of an individual is becoming more popular owing to technology advances in applications such as authentication of a person in technology (i.e. smart phones) and social networks (21). The use of facial recognition in these areas allows identification of the person due to specific landmarks selected from the face and, once identified, verification of the person using previous images or databases (22). Facial recognition is considered the main application of biometric systems as it can be low cost, impermeable to intrusion and requires no physical contact (16). This allows measurements to be taken from sources like closed-circuit television or two-dimensional photographs and allows quick verification of the person without any physical contact (17, 21, 22).

**Facial biometrics: comparison.**

Facial comparison is an observation of two or more faces to determine similarities or dissimilarities and is the type of approach required to compare victims for similarities. This is in contrast to facial recognition whereby an individual’s facial traits are compared to a database of facial images in a biometric system (one-to-many) (23). The Facial Identification Scientific Working Group (FISWG) details guidelines of four main methods for facial comparison: holistic comparison, morphological analysis, photo-anthropometry and superimposition (24, 25).
Holistic comparison.

Holistic comparison exploits the human ability of assessing all facial features at the same time and comparing to another image or a face (24). Holistic comparison is part of a facial review process that is conducted between an image and subject/image sets for comparison (24). For this approach, the examiner cannot empirically explain the result. This comparison technique is somewhat subjective and therefore makes this approach limited for forensic use (24). Due to this limitation, it is recommended that holistic comparison is used only when other operation methods may be impossible (24, 25).

The advantages of using a holistic approach are that this type of comparison can be used on any image and does not require the subject to pose. It also requires no specialised equipment or training and the time taken for an examination is fast (24). The main disadvantages of a holistic comparison are there is not contemporaneous documentation of the comparison process and the comparison accuracy rates are low and variable (12). Megreya and Burton (26) showed that examiners found this method extremely hard to identify unfamiliar faces.

Morphological analysis.

Morphological analysis is based in the shape, appearance and location of facial features (24). The characteristics assessed include: the overall facial structure, anatomical structures and their components, and distinctive facial marks (scars, birthmarks) (24). This systematic approach allows the facial features to be compared and outcomes are interpretations from the examiner (21).

The image quality does not have to be high resolution to undergo morphological analysis. This method can be used to exclude subjects and is said to be more reliable than other
methods of comparison (24). Challenges, however, are that the subject and comparator must have a similar pose and angle and that there is no standardised feature and components for comparison. The time taken to examine images can be lengthy and there have been very limited studies to conclude the accuracy or reproducibility of the comparison (24).

**Superimposition.**

The method of using superimposition entails overlaying two images and comparing them visually (24). This technique has been used in conjunction with morphological analysis, but only when the two images have been taken from the same angle and viewpoint (24, 25). The three image transitions for the overlaying of images include: 

a) **wipe:** line appears across screen and gradually reveals image underneath,

b) **fade:** one image is gradually replaced with the other by changing the transparency of the second image,

c) **toggle:** each image is displayed for a fraction of a second for comparison (24).

The advantage of the using superimposition is that it can enhance morphological analysis when comparing shapes of facial features (24). Along with this technique advantage, there seem to be more disadvantages noted by FISWG. These disadvantages include the image quality and viewpoint need to be high and the same for each image for comparison (24).

**Facial photo-anthropometry.**

Facial photo-anthropometry is the metric approach of human facial traits for two-dimensional images, which can identify a person by comparing these images to reference images on a database known as forensic facial identification (27, 28). The first phase of photo-anthropometry involves the identification and placements of landmarks (or reference points) on the images that are to be measured for comparison (28). Once these
landmarks have been determined and identified, the measurements between these points are made to help with comparison (25). Due to the images not having a scale, the absolute size is not useable, and the measurements then need to be made in ratios and proportions to create indices for comparison (25). The only way to use precise measurements for images is to know the exact extrinsic and intrinsic factors at the time the photograph was taken.

In comparison to the other techniques, photo-anthropometry is an empirical approach using measurements, angles and ratios to compare faces, rather than just comparing images by just observing them and coming to conclusions that are based on the interpretations of the examiners. Photo-anthropometry has the potential to be used for linking of serial killer victims and may be automated with the right expertise. This method is repeatable, which can allow it to be used within large data bases (25). FISWG do state that photo-anthropometry should not be used as an independent comparison technique for positive identification or exclusion; however, this technique could aid in the filtering a large number of faces within a database and can have the potential to be useful for forensic laboratories and legal prosecutors in order to reduce the list of possible matches (25).

**Methods: Facial comparison and measurements**

We propose a simple, and hand-measured extension of facial photo-anthropometry for the extraction of facial features of serial killer victims. The proposed technique is currently limited in that it is not automated by an expert system and therefore data collection is restricted to manually collected measurements. We highlight this limitation in the hope that those with expertise in the development of expert systems may be able to progress this work beyond the scope of this proof of concept. To demonstrate the approach, we
compiled facial geometries of three victims of a single serial killer to explore similarities (and differences) between the victims. The aim was to see if there were trends that may inform investigators of the subconscious process of victim selection adopted by sexually motivated serial killers. The selection of these features for measurement was adapted from Tome et al. (29), Lee et al. (30) and Caple and Stephan (31). A demonstration of the process of landmark identification and measuring for comparison was conducted on three randomly selected victims of Theodore Robert Bundy (Ted Bundy). To test the hypothesis that these victims will have similarities compared to a randomly selected person from the population, a female control image was selected randomly from the publicly available database, Yale Faces B (32). Measurements were collected and compared within the pool of victims and also to the Yale subject.

Identification and Location of anatomical landmarks

Twenty-seven landmarks (ten of which were bilateral) were identified, with the definitions and abbreviations sourced from Lee et al. (2019) and Caple and Stephan (2016) (30, 31). These are presented in Table 1. These landmarks were chosen because of their ease in identification across all of the selected images by analysts and laypersons alike. References to the right side are that of the person’s right side rather than the right-hand side of the image as viewed.
Table 1. Anatomical facial landmarks used in this research and their definitions. Abbreviations with the prime (’) indicate the pairing with the right-hand side (and shown in Fig. 1)

<table>
<thead>
<tr>
<th>Landmark</th>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Trichion</td>
<td>tr</td>
<td>Midpoint of the hairline</td>
</tr>
<tr>
<td>2  Glabella</td>
<td>g</td>
<td>Most anterior midline point of the forehead</td>
</tr>
<tr>
<td>3  Superciliare centralis</td>
<td>scc, scc’</td>
<td>Centre of the eyebrow, highest point</td>
</tr>
<tr>
<td>4  Ciliare medialis</td>
<td>cm, cm’</td>
<td>Most medial and inferior corner of the eyebrow</td>
</tr>
<tr>
<td>5  Nasion</td>
<td>n</td>
<td>The deepest and midline point in the nasofrontal suture</td>
</tr>
<tr>
<td>6  Ciliare lateralis</td>
<td>cl, cl’</td>
<td>Most lateral extent of the corner of the eyebrow</td>
</tr>
<tr>
<td>7  Endocanthion</td>
<td>en, en’</td>
<td>The inner corner of the eye where the eyelids meet</td>
</tr>
<tr>
<td>8  Exocanthion</td>
<td>ex, ex’</td>
<td>The outer corner of the eye where the eyelids meet</td>
</tr>
<tr>
<td>9  Palpebrale superius</td>
<td>ps, ps’</td>
<td>Most superior point of the upper eyelid</td>
</tr>
<tr>
<td>10 Palpebrale inferior</td>
<td>pi, pi’</td>
<td>Most inferior point of the lower eyelid</td>
</tr>
<tr>
<td>11 Zygion</td>
<td>zy, zy’</td>
<td>The most lateral point of the zygomatic arch, breadth of face</td>
</tr>
<tr>
<td>12 Alare</td>
<td>al, al’</td>
<td>The most lateral point of the nasal ala</td>
</tr>
<tr>
<td>13 Pronasale</td>
<td>pn</td>
<td>The most protruded point of the nasal tip</td>
</tr>
<tr>
<td>14 Labiale superius</td>
<td>ls</td>
<td>Midpoint of the vermilion border of the upper lip</td>
</tr>
<tr>
<td>15 Cheilion</td>
<td>ch, ch’</td>
<td>Outer corners of the mouth</td>
</tr>
<tr>
<td>16 Labiale inferior</td>
<td>li</td>
<td>Midpoint of the vermilion border of the lower lip</td>
</tr>
<tr>
<td>17 Gnathion</td>
<td>gn</td>
<td>Lowest point in the midline on the lower border of the chin</td>
</tr>
</tbody>
</table>

These landmarks were mapped to the four subjects, shown in Figure 1. The subjects included three of Ted Bundy’s victims (subjects A, B, C) and one Yale Face (subject D). According to Tome et al. (29), these facial landmarks are seen as continuous features due to the use of real-valued numbers, which are definite numbers that can be measured and recorded from the face (i.e. nose height, forehead height etc.) rather than using discrete features that represent an indefinite number of categories and are not mathematically measurable (i.e. eyebrow shape; arched, rectilinear or sinuous) (29).
Measurement of Landmarks

The images used for the study were sourced from publicly accessible online sources (33-35). The Yale subject image is from the Yale University database, “Yale Faces B” (32). The Yale Face database contains grayscale images of 28 subjects’ faces each seen under 576 viewing conditions (9 poses and 64 illuminations). To illustrate this study, one female subject was selected randomly for comparison to the three victims as an outgroup. Images were printed onto A3 paper and the landmarks listed in Table 1 were identified and marked onto each image by hand and measured. To measure the facial traits, a 0–150 mm digital caliper (Craftright) was used with measurement accuracy to 0.01 mm.

Due to the images not having an identifiable scale, proportionality indices were determined. The indices were calculated by using the measurement definitions detailed in

*Figure 1. The anatomical landmarks illustrated in three of Ted Bundy’s victims (A-C) showing the abbreviations and a randomly selected Yale Face (D) subject. Roberta Kathleen Parks (A), Julie Cunningham (B), Denise Oliverson (C) and Yale Face B subject (D).*
Table 2. These values were then multiplied by 100 to give the proportion of that feature.

Regarding the angular (α) measurements, the horizontal lines shown in Figure 1 were used as a baseline to determine the α for the zygomatic arch and the eyebrow arch. To allow for differences in the angle of the images, measurements from left and right were averaged, on the assumption of approximate facial symmetry.

<table>
<thead>
<tr>
<th>Facial Trait</th>
<th>Measurement</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face</td>
<td>Face shape</td>
<td>$zy_L-zy_R/\text{tr-gn}$</td>
</tr>
<tr>
<td></td>
<td>Forehead</td>
<td>$\text{tr-g}/\text{tr-gn}$</td>
</tr>
<tr>
<td></td>
<td>Naso-labial length</td>
<td>$\text{pn-ls}/\text{tr-gn}$</td>
</tr>
<tr>
<td></td>
<td>Chin length</td>
<td>$\text{li-gn}/\text{tr-gn}$</td>
</tr>
<tr>
<td></td>
<td>Symmetry</td>
<td>$n-zy/zy_L-zy_R$&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Zygomatic arch angle</td>
<td>$\alpha(\text{al-zy})$&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td>Orbit</td>
<td>Horizontal opening</td>
<td>$\text{en-ex}/zy_L-zy_R$&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Eye height</td>
<td>$\text{ps-pi}/\text{g-pn}$&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Interocular distance</td>
<td>$\text{en-en}/zy_L-zy_R$</td>
</tr>
<tr>
<td></td>
<td>Eyebrow arch</td>
<td>$\alpha(\text{cm-scc})$&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td>Nose</td>
<td>Nose shape</td>
<td>$\text{al-l}/\text{g-pn}$</td>
</tr>
<tr>
<td></td>
<td>Nose Length</td>
<td>$\text{g-pn}/\text{tr-gn}$</td>
</tr>
<tr>
<td></td>
<td>Nose width</td>
<td>$\text{al-l}/\text{zy_l-zy_R}$</td>
</tr>
<tr>
<td></td>
<td>Naso-labial height (compared to nose length)</td>
<td>$\text{pn-ls}/\text{g-pn}$</td>
</tr>
<tr>
<td>Mouth</td>
<td>Mouth shape</td>
<td>$\text{ls-li}/\text{ch_l-ch_R}$</td>
</tr>
<tr>
<td></td>
<td>Mouth height</td>
<td>$\text{ls-li}/\text{tr-gn}$</td>
</tr>
<tr>
<td></td>
<td>Mouth width</td>
<td>$\text{ch_l-ch_R}/\text{zy_l-zy_R}$</td>
</tr>
</tbody>
</table>

<sup>*</sup>The average of both left and right region was made for these measurements.

**Statistical Analysis**

Z-scores were calculated for each subject’s facial trait, and the z-score was used to determine the $p$-value for each trait. A $p$-value of .05 was used to determine statistical significance ($p$-value >.05= not significant, $p$-value <.05= significant).
Results

With all facial trait indices calculated, along with the mean and standard deviation of each, statistical analysis allowed the comparison of the subjects A, B and C to the Yale subject D. Table 3 details the mean and standard deviation of the measurements of these subjects along with the significance of subject D measurement to that trait.

The standard deviations of the subjects A, B, and C were low (range from 0.14–6.81) which indicates that the data points for each image in the facial trait show little deviation from the mean for that trait. Comparing the z-scores and p-values of subjects A–C, it was observed there was no statistical significance between them (p-value >.05). Comparison of A, B and C to subject D p-values, showed traits that were statistically significant.

Table 3. The average and standard deviation of subject A, B and C facial trait measurements with comparison to subject D (Yale Face) p-value for significance to that trait. p-value <0.05 is significant and a p-value >0.05 is not significant.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Subject D Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face Shape</td>
<td>60.71</td>
<td>1.5</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>Forehead</td>
<td>35</td>
<td>0.9</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>Chin-length</td>
<td>15.58</td>
<td>1.08</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>Nose shape</td>
<td>63.44</td>
<td>2.73</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>Mouth height</td>
<td>10.78</td>
<td>0.14</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>Eyebrow arch angle</td>
<td>20</td>
<td>2.89</td>
<td>&lt;.00001</td>
</tr>
<tr>
<td>Naso-labial length</td>
<td>11.16</td>
<td>1.73</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>Interocular distance</td>
<td>28.13</td>
<td>0.57</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>Naso-labial height (compared to nose length)</td>
<td>41.41</td>
<td>6.81</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>Mouth shape</td>
<td>38.65</td>
<td>3.23</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>Mouth width</td>
<td>46.22</td>
<td>3.28</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>Symmetry</td>
<td>50.58</td>
<td>1.78</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>Horizontal opening</td>
<td>25.23</td>
<td>3.62</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>Eye height</td>
<td>26.34</td>
<td>4.03</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>Nose Length</td>
<td>27.01</td>
<td>0.92</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>Nose width</td>
<td>28.22</td>
<td>1.37</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>Zygomatic arch angle</td>
<td>32.67</td>
<td>4.4</td>
<td>&gt;.05</td>
</tr>
</tbody>
</table>
It can be seen in Table 1 that Subject D had statistically significant differences from Subjects A, B and C in face shape, forehead, naso-labial length, chin-length, interocular distance, mouth shape, height and width and eyebrow arch angle. Figure 2 plots the data to visually illustrate the averages for Subjects A, B and C in comparison to the indices of Subject D. This assists in demonstrating outliers for each trait and supports the $p$-values in Table 3. As a proof of concept, the proposed model has been able to identify subject D as geometrically more different in facial structure than A, B and C. We accept that this model is in its infancy and as such is a rudimentary approach. It is intended to be a demonstration of a concept that with additional expert software assistance, larger data sets may be explored, and the method validated.

![Proportional indices average of Ted Bundy's victims compared to proportional indices of Subject D](image_url)

**Figure 2.** Comparison between the Ted Bundy victim’s proportionality indices (average of all three) and the proportionality indices of Subject D. X-axis details the facial traits being measured; Y-axis is the proportionality indices.
Discussion

The aim of the current study was to provide a novel method for crime linkage based on victims’ facial biometrics. This method is underpinned by the theory that organised offenders, such as sexually motivated serial killers, often select their victims on the basis of common characteristics. This supports creating a profile for a particular victim type and continuing until they have found this person (13). Douglas et al. (2006) stated that the victims of these serial killers might have common traits such as occupation, appearance, gender, and social status; therefore, the current method focuses on appearance similarities and measures them in a scientific approach. Using basic measurements of facial landmarks, support was found for the hypothesis that sexual killers’ victims can be linked through facial similarity.

These results indicate that, by using this approach, three of Ted Bundy’s victims (subjects A, B, and C) exhibit similarity to each without any statistically significant differences in their proportionalities. Comparing these faces to a random Yale Face, the results indicate there are statistical differences between the victims and the random person including; face shape, forehead height, chin-length, nose shape, mouth height, and eyebrow arch angle.

Applications of the research

As described, crime linkage helps investigators determine if a crime has been committed by the same offender without the use of physical evidence looking at the crime scene and the behaviour of the offender committing the crime (1). Biometrics, and specifically facial biometrics, can be used as an investigative tool for crime linkage as the offender may have a facial type of victim, and the victim’s measurement may have a similarity that can only be noticed through measurement. This type of facial biometric method has been described
here using photo-anthropometry where landmarks and measurements of one image are compared to another to see if there are any similarities or dissimilarities (28). Using this biometric comparison technique, it may be a useful investigative tool to connect victims to one suspect or to guide in ruling out a certain suspect. This intelligence tool has scope for situations where there are known victims of a serial killer and other unattributed victims of unsolved homicides. It may be possible that collecting data from the faces of unsolved or unattributed victims will allow for connections to be drawn and investigations to be focussed or re-directed. As a tool for crime linkage, this technique could have application for crimes occurring across borders where a suspect is known in one area, but not known in another state.

An advanced application of facial biometrics was illustrated by Sero et al. (2019), where facial recognition from DNA can be established (36, 37). Sero et al. (2019) investigated situations where the DNA profile of the person of interest was unknown to the investigator, and the DNA sample did not match any DNA in the database. Using DNA phenotyping, it may be possible that the predictive output of the phenotype analysis may help reduce the number of potential candidates in a database and help further investigation into particular traits (36). The most desirable outcome would be the ability to infer the face shape from DNA; however, the face is a complex trait and is composed of distinct features and involves the environment and genetics for development (36).

Knowing that this research is active, not only could we use DNA to predict the facial shape of suspects/ persons of interest, but DNA could potentially help with cases where the victim is unknown and is a “Jane or John Doe” (especially decomposed or skeletal remains). Using
the DNA to predict the victims face shape may allow connection between other victims and therefore connection to a killer.

**Limitations and strengths of facial biometrics**

There are challenges in the use of facial biometrics that can make results unreliable. For example, changes in illumination, pose, facial expression and occlusion of an individual either in an images or in life form (21). Knowing these limitations of facial biometrics, caution should be exercised. Before large scale validation research is conducted, the application of these techniques should be limited to use as exclusionary or intelligence tools. Work is required to develop improved techniques for photo-anthropometry for future forensic investigation (27). When used cautiously, the use of facial biometrics in the context of serial killer victim linkage may have strengths allowing for its use as an intelligence tool to direct resources more effectively.

**Image quality and expressions.**

Using facial biometrics from images that have little detail and are captured at a low resolution can greatly affect the measurements of the face (38). A study conducted by Norell et al. (2015) examined 30 one-to-one facial images compared with one reference image and a questioned image (low, mid, or high-quality image). The participants that were used to test the comparison were split into trained and nontrained groups. The trained group was forensic experts (experienced in facial image comparison), and the nontrained subjects were students from the University of Texas at Dallas. The results from this study concluded that the image quality affected the comparison and there was an increase in noncommitted responses to whether the image was the same as the quality decreased...
from both groups (39). The images used in this research were from the 1970’s and therefore the quality of the images was deliberately low compared in order to test the capability of the approach.

Variations in facial recognitions can occur due to the expression portrayed on the person’s face and can degrade the recognition (40). The measurement of distances between facial features relies on the consistency of the surface of the skin and under facial expressions, the level of curves of the surface affect these distances and therefore affect facial recognitions and comparison (40). In Figure 1, all subjects had slightly different facial expressions, more prominent in their smiles. The action of smiling can affect the mouth shape (height and width) along with the eye height, as squinting may occur, zygomatic arch angle as the zygion (breadth of the face) may change due to raised cheeks making identification difficult.

**Occlusions and landmark detection.**

Obvious problems with facial comparison and facial recognitions involve occlusion of the face (41). Occlusions are whereby the face is blocked or covered by objects (41). These occluded sections can degrade the performance of facial landmark detection and therefore degrade the facial recognition and comparison (41). Occlusions can include glasses, hair, scarves, hands blocking the face or shadows covering the face (41).

Along with these occlusions, landmark placement is usually relatively high positioning since different examiners have different interpretation of where a certain landmark is located, and this is especially difficult with two-dimensional images where there is no three-dimensional reference (28). It should also be noted that in this study, landmarks and measurements were performed in singlicate, by a single researcher whereby future testing
should utilise at least two analysts. Examples of occlusions are visible in Figure 1 as the females in the images have their hair down making the location of the zygion difficult and maybe an inaccurate representation of the actual landmark.

**Investigative tool.**

The purpose of using facial biometrics and photo-anthropometry is as an extra tool for investigators to utilise when other resources are exhausted. The purpose of this research is not to solve every serial homicide. We suggest it be considered in the event of cases incorporating a new victim to many existing victims or to assist in the linkage of cases and victims. It should also be noted that an absence of significant facial landmark links between victims, is not necessarily an indicator of them not being associated with a single offender.

The decision-making process involved in serial killer victim selection is a complex and individual process that, like *modus operandi*, may change temporally or situationally.

The prospect that any investigator can use this method due its simplicity, low cost nature and speed is a great benefit. There is no need for extensive training or equipment—this research may be replicated with printed images, a ruler and pen. Clearly, the proposed method is a tool, not a complete solution. Other factors, including time and geography of potential victims should always be considered. However, as a relatively quick method of comparison, this method has potential for application to many unsolved and future crimes.

This potential may be further progressed by the adaption of the current manual procedure to an automated, in-silico solution with the assistance of software engineers and experts.
Conclusions

Sexually motivated serial killers tend to target victims based on their appearance and the possibility of their facial features being similar can be used for crime linkage investigation. The technique of Face Similarity Linkage (FSL) uses facial measurements to compare victims to each other to determine their similarity to each and to see if the serial killer is targeting these victims due to their facial measurements. More advanced means of data collection may be useful tool for investigation for linking serial homicides. The method described is novel; however, with expert systems, this technique can be improved and used in investigations.
References


Facial Comparison as Intelligence: Using Facial Biometrics on Sexually Motivated Serial Killer Victims as an Investigative Tool
Abstract
Studies have suggested that sexually motivated serial killers have a particular type of victim they target due to attractiveness. This current study is investigating whether this targeting of a victim is not only just their attractiveness to the killer, but if there is a subtle selection process of victims based on their facial features and geometries. Theodore Bundy, Dennis Rader, Edmund Kemper and Jerome Brudos where chosen for this research due to the nature of their crimes and victims. Their victims’ faces were printed, and anatomical landmarks were chosen and measured to create proportionality indices. The comparison subjects were four randomly selected females from Yale and Chicago face database (Subjects A–D). The same measures as the victims were taken on these images of the Subjects. Principle component analysis (PCA) scatterplots and heatmaps were utilized to observe if the measurements of the victims clustered and which characteristics created variances. Bundy’s and Rader’s victims show significant amounts of clustering, with a couple of outlier faces which could be explained due to research into each of those crimes. Kemper and Brudos victims were less clustered with the Subjects intertwined with the victims. The conclusion made from these plots were Kemper’s victims may have been random due to all being hitchhikers and Brudos had a shoe fetish and was more interested in their feet over their facial appearance. This research serves as a concept that may be a useful intelligence tool for law enforcement for linking serial homicides to a single offender.

Keywords
Serial Killer, Victim, Biometrics, Principle Component Analysis, Crime Linkage, Intelligence
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List of Abbreviations

PCA – Principle Component Analysis

PC – Principle Component

MO – Modus operandi

SD – Standard Deviation
Introduction

When presented with a series of crimes that share similar characteristics, this may indicate the offender may be the same person. This can be difficult when there is no physical evidence present at the scene and more non-conventional techniques can be used in assistance (1). The process referred to as crime linkage, behavioural case linkage and comparative case analysis, aids in investigation to link crimes to a single offender by analysing the characteristics of the crime, victimology and the crime scene (1, 2). The basis of this study is using facial biometrics of the victims to establish a link between the crime and the offender. Due to the nature of the serial killers observed in this study, the type of victim is chosen due to the killer’s attraction to them. Using facial biometrics as a crime linkage tool can support investigation by giving an alternative option when no physical evidence is provided (3). Therefore, investigating whether victims have similarities in facial biometrics may be useful to link victims to a single offender (3).

Serial Killer Typology and Victimology

A serial killer is commonly described as an offender who has two or more victims over a period of time with a “cooling off” period between each kill (4). Serial killers have been categorised into two typologies developed by the Federal Bureau of Investigation; *disorganised* and *organised* (4, 5). Organised offenders tend to take high amounts of planning before they commit their crime and show some amount of detection avoidance at their crime scene (6). With these high amounts of planning, they usually target a certain type and their victims may share common traits such as occupation, ethnicity, appearance, gender and social status (7). This research intends to investigate if this selection process can include the facial measurements of the victims and if this technique can be utilized for crime linkage in the future. The victim selection based on appearance or facial
measurement may be subtle and even subconscious to the offender to the point that the victim may resemble someone from their childhood, their family (mother) or an ex-partner (3). The four sexually motivated serial killers described below were chosen for this study.

**Theodore Bundy.**

Theodore Robert Bundy (“Ted Bundy”) was criminally active between 1974 to 1978 and has been convicted of killing and sexually assaulting at least 20 young females, all with similar physical appearance, across the states of Washington, Utah, Colorado and Florida (8, 9). Bundy possessed an above average intelligence, was traumatized as a child by his grandfather and displayed narcissistic traits (9). Bundy was notorious for impersonating authority figures and used a ruse of an arm in a sling or a broken leg to lure his victims (10). Bundy was incarcerated in February 1978 and sentenced to death and was executed in January 1989 (10).

**Dennis Rader.**

Dennis Rader’s (“BTK Killer”) active crime years were from 1974 to 1991 and has confessed and been convicted of murdering ten victims (four from one family, six females) (11) The alias “BTK Killer” was established due to the method of his murders; bind, torture and kill (11). Rader’s method of murder was ligature strangulation and stabbing with a knife and his characteristics are a sadist and fetishist (11). After 1991, the killing appeared to have stopped and all leads turned cold and no-one had been arrested, until 2004 when Rader resurfaced with communications to the media about his crimes (11). February 2005, Rader was sentenced to 175 years without the possibility of parole (12).
Edmund Kemper.

Edmund Kemper III ("Co-Ed Killer") was criminally active between 1964 to 1973 and is convicted of murdering ten victims. Kemper started his killing career at 15 years old by shooting and killing his grandparents after being sent to live with them by his mother (8). After serving eight years with no killings, six at which he spent at Atascadero State Hospital, a maximum security facility for mentally ill convicts, he began his series of murders in 1972 (13). From May 1972 to April 1973, he killed eight women, including his mother. His method of killing was stabbing, strangulation and sexual assault of the victims with the characteristics of necrophilia, cannibalism and dismemberment (13). After his last kill in 1973, Kemper fled to Pueblo, Colorado and confessed to the murders to the Santa Cruz Police Department, which led to a life sentence in November 1973 (13).

Jerome Brudos.

Jerome Brudos ("The Lust Killer", "The Shoe Fetish Slayer") had a criminal career between 1968 to 1969 which led to him being convicted for killing four young females. His fascination with women’s footwear began at the young age of five years old when he discovered a pair of women’s high heels in a junkyard and brought them home (8). From this age, he acquired a fetish for women’s feet/shoes and began stealing shoes for satisfaction (8). At 17 years old, Brudos was committed to Oregon State Hospital for luring a 17 year old girl into his car, beating her and making her strip off her clothes (8). Brudos was released, finished school and joined the armed services and eventually married and had a daughter. Brudos’ wife rebelled against his request for him to take nude photographs of her and Brudos became frustrated and eventually started sexually assaulting and strangling women (8). In June of 1969, Brudos plead guilty to three counts of first degree murder and received three consecutive life sentences, but was never convicted for his first
victim, even after he confessed, due to the body never being recovered (14). March 2006, Brudos died in prison due to liver cancer.

**Facial Biometrics**

The use of biometric systems is to be able to differentiate individuals from each other based on their characteristics derived from; face, iris, fingerprint, gait and voice (15). Biometrics systems gain biometric data from pattern recognitions which can be physical, behavioural, physiological or chemical attributes to an individual person to help distinguish them from the rest of the population (3, 16, 17). The most common characteristics that is used for biometric systems is obtained from the face (18). Facial biometrics is an increasingly large area of research due to the development of smarter technology (i.e. mobile devices) and high security biometrics systems (i.e. passport control) (18). Facial characteristics can be used in two major fields of biometrics; facial recognition and facial comparison. Facial recognition uses biometric systems to identify a person using specific landmarks and then verifies the person using image databases (3, 19). Facial comparison utilises the observation of two or more faces to identify any similarities or dissimilarities between them (3).

For this study, facial photo-anthropometry has been used for facial comparison of the serial killers’ victims. This technique uses a two-dimensional image of an individual’s face and reference points (or landmarks) are located on the image for comparison (20). Measurement between these points are conducted and due to the absences of a scale and the absolute size is not useable, proportional indices are created for the comparison (21). Using this metric approach instead of using the subjectivity of the analysts stating whether they are similar or not, allows an empirical result for comparison as the indices can actually be compared and measurements can be reproduced (3, 21).
Principle component analysis.

Once the measurements of the facial traits are completed for comparison, a statistical approach can be conducted to understand the similarities and differences. With increasingly large datasets being produced by facial biometrics, the results can become difficult to interpret and understand (22). PCA is a method that helps reduces the dimensionality of the data, increasing interpretability and also reducing data loss (22, 23). The way that PCA presents data is by using eigenvectors and eigenvalues to create the axis due to variance for scatter plot presentation. Eigenvectors display the direction of the variance and creates an axis through the cluster of data for PCA scatterplots to be created. Once the eigenvector has been established, the eigenvalues state the variance in the dataset, the principle components with the highest eigenvalues are then made to be the principle components of the plot due to the high variance (22).

These PCA plots allows the linear transformation of multivariate data into a set of these uncorrelated variables which are ordered due to their variance in the dataset (23). The information is presented in a scatterplot that visually compare two major components from the data by creating new uncorrelated variables that enables to maximum variance (22, 23). For the following research, a web tool called ClustVis (24) was utilised in displaying the scatterplot, with the addition of heatmaps of the data. These heatmaps are a data matrix that presents the values from research by using a colour gradient (23). The colour gradient allows analysts to have a good overview of the whole dataset from the smallest to largest values for each individual component (23).

Sexually motivated serial killers will be the main focus of this study. This typology of serial killer has been selected due to the organisation of victim selection and the main objective
of their crimes being sexual gratification and attractiveness towards their victims. This study intends to support the hypothesis that sexually motivated serial killers’ victims will have more statistically similar facial biometrics than those faces of randomly selected individuals.

Method and Materials

Sample Selection

Four sexually motivated serial killers and their victims were utilised for this study. These serial killers were selected on the premise that all have at least two victims, their targeted victims were majority female and the selected killers were male. The four serial killers were selected due to their victims’ images being available to the public, conviction for their crimes and the sexual nature of their crimes. All images of victims were obtained from news reports, online forums and websites. The four serial killers include; Theodore Bundy, Edmund Kemper, Dennis Rader and Jerome Brudos with a total of 41 victims faces were measured\(^2\). Victims that survived an attack from any of the killers were not include, only victims that are deceased were included. Only selection the deceased victim was due to access of images and respecting the surviving victim’s privacy. All images were of portraits, similar expression and the same lighting conditions.

Comparison Subjects

To measure and determine if the victim’s facial biometrics do resemble each other more so than randomly selected females from the population, four randomly selected faces of young females were taken from two database. The faces selected are of similar age and ethnicity to the victims to be able to compare the facial biometrics. Subject A and Subject

\(^2\) Two of Rader’s victims not included due to them not being the intended targets.
B (shown in Fig. 1) were randomly selected from “Yale Faces B” (25) which contains grayscale images of 28 subjects’ faces each seen under 576 viewing conditions (9 poses and 64 illuminations). Subject C and Subject D (shown in Fig. 1) were randomly selected from The Chicago Face Database (26). This database provides high-resolution photographs of male and female faces of various ethnic background between the ages of 17-65. All images selected from the databases were of portraits, similar expression and the same lighting conditions.

**Identification and Location of anatomical landmarks**

Twenty-one landmarks (seven of which were bilateral) were identified, with the definitions and abbreviations sourced from Lee et al. (2019) and Caple and Stephan (2016) (27, 28). These are presented in Table 1. These landmarks were chosen because of their ease in identification across all of the selected images by analysts and laypersons alike and due to the minimal impact of change with facial expressions, accessories or angled images. The paring of the right-hand side definition refers to the right-hand side of the person rather than the image.
Table 1. Anatomical facial landmarks used in this research and their definitions.

<table>
<thead>
<tr>
<th>Landmark</th>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Trichion</td>
<td>tr</td>
<td>Midpoint of the hairline</td>
</tr>
<tr>
<td>2 Glabella</td>
<td>g</td>
<td>Most anterior midline point of the forehead</td>
</tr>
<tr>
<td>3 Nasion</td>
<td>n</td>
<td>The deepest and midline point in the nasofrontal suture</td>
</tr>
<tr>
<td>4 Endocanthion</td>
<td>en, en’</td>
<td>The inner corner of the eye where the eyelids meet</td>
</tr>
<tr>
<td>5 Exocanthion</td>
<td>ex, ex’</td>
<td>The outer corner of the eye where the eyelids meet</td>
</tr>
<tr>
<td>6 Palpebrale superius</td>
<td>ps, ps’</td>
<td>Most superior point of the upper eyelid</td>
</tr>
<tr>
<td>7 Palpebrale inferius</td>
<td>pi, pi’</td>
<td>Most inferior point of the lower eyelid</td>
</tr>
<tr>
<td>8 Zygion</td>
<td>zy, zy’</td>
<td>The most lateral point of the zygomatic arch, breadth of face</td>
</tr>
<tr>
<td>9 Alare</td>
<td>al, al’</td>
<td>The most lateral point of the nasal ala</td>
</tr>
<tr>
<td>10 Pronasale</td>
<td>pn</td>
<td>The most protruded point of the nasal tip</td>
</tr>
<tr>
<td>11 Labiale superius</td>
<td>ls</td>
<td>Midpoint of the vermilion border of the upper lip</td>
</tr>
<tr>
<td>12 Cheilion</td>
<td>ch, ch’</td>
<td>Outer corners of the mouth</td>
</tr>
<tr>
<td>13 Labiale inferior</td>
<td>li</td>
<td>Midpoint of the vermilion border of the lower lip</td>
</tr>
<tr>
<td>14 Gnathion</td>
<td>gn</td>
<td>Lowest point in the midline on the lower border of the chin</td>
</tr>
</tbody>
</table>

*Abbreviations with the prime (’) indicate the pairing with the right-hand side (and shown in Fig. 1)*

These landmarks were mapped on all victims and the four Subjects seen in Figure 1. Facial landmarks which can be defined as continuous features (a definite number that can be measured and recorded) were utilised rather than using discrete features (indefinite number of categories, not mathematically measurable) such as eyebrow shape; arched, rectilinear or sinuous (29).
Measurement of Landmarks

The images selected for victims and comparison Subjects were high or large quality images, analysed in black and white and ideally to be frontal images. If face in the images were at an angle, measurements from left and right were averaged, on the assumption of approximate facial symmetry. Images were printed onto A3 or A4 paper, depending on the quality of image (due to dated crimes), and the landmarks listed in Table 1 were marked onto each image by hand and measured. To measure the facial traits, a 0–150 mm digital caliper (Craftright) was used with measurement accuracy to 0.01 mm.

Proportionality indices were utilised in this research due to the images not having an accurate scale for real-number measurements. These indices were calculated by using the
measurement definitions detailed in Table 2 and were entered into Excel for calculation. These values were then multiplied by 100 to give the proportion of that feature. Regarding the zygomatic arch angular ($\alpha$) measurement, the horizontal line shown in Figure 1 was used as a baseline to determine the $\alpha$. To deal with images of faces on an angle, measurements from left and right were averaged, on the assumption of approximate facial symmetry. These measurements and calculation were conducted on all 41 victims’ images and four database Subjects, making a total of 45 measured faces for this study.

Table 2. Facial biometrics and their mathematical definitions

<table>
<thead>
<tr>
<th>Facial Trait</th>
<th>Measurement</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face</td>
<td>Face shape</td>
<td>$zy_L:zy_R/\text{tr}-\text{gn}$</td>
</tr>
<tr>
<td></td>
<td>Forehead</td>
<td>$\text{tr}-\text{g}/\text{tr}-\text{gn}$</td>
</tr>
<tr>
<td></td>
<td>Naso-labial length</td>
<td>$\text{pn}-\text{ls}/\text{tr}-\text{gn}$</td>
</tr>
<tr>
<td></td>
<td>Chin length</td>
<td>$\text{li}-\text{gn}/\text{tr}-\text{gn}$</td>
</tr>
<tr>
<td></td>
<td>Symmetry</td>
<td>$n-zyL:zy_R$</td>
</tr>
<tr>
<td></td>
<td>Zygomatic arch angle</td>
<td>$\alpha(\text{al-zy})$</td>
</tr>
<tr>
<td>Orbit</td>
<td>Horizontal opening</td>
<td>$\text{en}-\text{ex}/zy_L:zy_R$</td>
</tr>
<tr>
<td></td>
<td>Eye height</td>
<td>$\text{ps}-\text{pi}/g-\text{pn}$</td>
</tr>
<tr>
<td></td>
<td>Interocular distance</td>
<td>$\text{en}_L-\text{en}_R/zy_L:zy_R$</td>
</tr>
<tr>
<td>Nose</td>
<td>Nose shape</td>
<td>$\text{al}_L-\text{al}_R/g-\text{pn}$</td>
</tr>
<tr>
<td></td>
<td>Nose length</td>
<td>$\text{g-pn}/\text{tr}-\text{gn}$</td>
</tr>
<tr>
<td></td>
<td>Nose width</td>
<td>$\text{al}_L-\text{al}_R/zy_L:zy_R$</td>
</tr>
<tr>
<td></td>
<td>Naso-labial height (compared to nose length)</td>
<td>$\text{pn}-\text{ls}/g-\text{pn}$</td>
</tr>
<tr>
<td>Mouth</td>
<td>Mouth shape</td>
<td>$\text{ls}-\text{li}/\text{ch}_L-\text{ch}_R$</td>
</tr>
<tr>
<td></td>
<td>Mouth height</td>
<td>$\text{ls}-\text{li}/\text{tr}-\text{gn}$</td>
</tr>
<tr>
<td></td>
<td>Mouth width</td>
<td>$\text{ch}_L-\text{ch}_R/zy_L:zy_R$</td>
</tr>
</tbody>
</table>

*The average of both left and right region was made for these measurements.*
**Statistical Analysis**

To compare the facial biometrics of the victims, a multivariate analysis of the data was performed using PCA. PCA plots were constructed that analyse each component (landmark measurements) and produce the variance of each feature. The two highest components with the largest variance (eigenvalue) would then be used to plot each victim and comparison samples. Heatmaps of each dataset were produced which gave comparison of each individual feature of each subject. ClustiVis (24) uses the data imported from Excel as calculated from the equations in Table 2. It compares the features of each face and produces PCA plot demonstrating the variance within the data. A heatmap is created which allows visualization of which features distinguish that subject from the other subjects (23).

**Results**

The figures below represent the results from the ClustVis (24) program producing PCA plots and heatmaps of each of the serial killers victims. In these figures, Subjects A-D are also featured and allow the comparison of the victims to randomly selected. Each victim is associated with a number which gives a timeline of the crimes (e.g. 1 = first victim, 2= second victim and so on) which may suggest a correlation between victim’s measurements and when they were killed. The scatterplots for PCA use principle component (PC) one and two (PC1 and PC2) which describe and display the variance within the data. PC1 will be a larger percentage than PC2 due to the large variation it shows. Both of the PC’s are the components with the highest amount of variance in the dataset.

For the heatmap, the gradient is dependent on the amount of standard deviations (SD) each individual is from the average of that facial trait. One standard deviation or more below the average results in a blue gradient and one standard deviation or more above the
average results in a red gradient. The victims and the Subjects are separated into clades (along the top) due to their similarities with other individuals. The facial traits are separated into clades also (along left-hand side) due to the similarities of each trait to one another.

Theodore Bundy

Figure 2 represents the victims of Bundy from one through to 20 and Subjects A–D. A cluster can be seen when looking at the victims and even some victims being in the same point as other victims. The comparison subjects are seen to lay below and to the left of the main cluster of the victims. Bundy’s victims Georgann, Denise N and Lynette, are also seen to be on the cusp of the cluster compare to Janice, Margaret, Melissa, Julia and Lisa, which can be described as the major clustering group.

![Figure 2. Principle Component Analysis (PCA) plot of Theodore Bundy victims and Subjects A-D.](image-url)
Figure 3 illustrates the features measured of each of Bundy’s victim’s and the Subject’s displayed in a heatmap form. This allows comparison of the individual features of each person and compliments the PCA plot in Figure 1 by helping to explain why some victim’s or Subjects are outside the cluster. When analysing the heatmap, Denise N and Georgann show high above average and below average features. The main feature that makes Denise N different is facial symmetry being the -3 SD away from the average along with below average traits in chin length, eye height and naso-labial height. Studying the features of Georgann, we can see the horizontal eye opening is very high above average (3 SD), along with nose shape. The other victims do not seem to show to many variations in the features with most being between -1 and +1 SD, below and above average respectively.

![Heatmap of Theodore Bundy victims and Subjects A-D](image)

**Figure 3. Heatmap of Theodore Bundy victims and Subjects A-D.**
**Dennis Rader**

Figure 4 represents the victims of Rader from one through to eight and Subjects A–D. A clustering effect can be seen when looking at the victims and with the Subjects being scattered in between the victims. The victim points can be seen to have mostly clustered above the PC2 axis at zero (i.e. positive side of PC2). Julie, Shirley and Kathryn can be described as outliers compared to the cluster group.

![Figure 4. Principle Component Analysis (PCA) plot of Dennis Rader victims and Subjects A-D.](image)

Figure 5 illustrates the heatmap of Rader’s victims and how each characteristic differs between each individual. The heatmap supports the findings that Julie, Shirley and Kathryn do show some facial biometrics that may be different to others. Julie displays below average (-1.5 SD) in the zygomatic arch, chin length and interocular distance. Shirley displays above average (+2 SD) in nose shape and below average (-2 SD) in nose shape and Kathryn have an above average (+2 SD) mouth width, nose width and horizontal eye opening. The other
victims seem to be constant or have some differences in characteristics, however not to the extent in the variations that Julie, Shirley and Kathryn show.

Figure 5. Heatmap of Dennis Rader victims and Subjects A-D

Edmund Kemper
Figure 6 represents the PCA plot for Kemper’s victims one through to nine and Subject’s A–D. The plot shows a cluster of victims in the top right of the axis with the Subject’s surrounding the cluster on the outside. There are three victim points that are not associated with the cluster, those being; Aiko, Cindy and Alice. Having these victims at such a vast range outside the trend cluster can suggest facial features of these victims are individual and do not correspond to the other victims.
Figure 6. Principle Component Analysis (PCA) plot of Edmund Kemper victims and Subjects A-D.

Figure 7 illustrates the heatmap for Kemper’s victims which can demonstrate the differences in features and explain why some victims were not among the clusters. Cindy can be seen to have four distinctive traits in the face shape (-2 SD), horizontal opening, face symmetry and mouth shape (+2 SD). Aiko and Alice both show distinct differences in similar traits; nose shape, chin length, eye height, naso-labial height (all below average, -1.5 to -2 SD) and nose length, interocular distance and mouth width (+1.5 to +2 SD).
Jerome Brudos

Figure 8 represents Brudos’ victims in a PCA plot. The points of data for each victim seem to have more variance than the PCA plots of the other serial killers. There does not seem to be a cluster of the victims, and the Subject to seem to be scattered outside the victim’s points. Explaining why these points are so scattered may be due to the typology or characteristics Brudos displayed and is explored in detail in later sections.
Figure 9 illustrates the heatmap for Brudos’ victims and it can be seen that all the victims and Subjects have more dissimilarities than similarities. This supports the evidence shown in Figure 8 where there is no real trend in clustering of victims, but the Subjects still tend to be on the outskirts of the victims. Comparing to previous figures, this heatmap may be able to explain what facial traits the victims have in common rather than what makes them different. At the 0 mark (white space) this is when that particular victim is meeting (or close to) the average measurement for that feature. For example, Linda Salee and Karen have reached the average on their mouth shape compared to Subject B and Linda Slawson who are on the opposite side of the average for face symmetry.
Discussion

This study was conducted to determine if facial biometrics for sexually motivated serial killers’ victims can be used to determine if serial killer’s target victims due to not only a particular characteristic (gender, appearance, occupation, age, ethnicity or social status), but also select victims with similar facial structure and measurements. Using facial biometrics for these victims may contribute to investigation as an intelligence tool for crime linkage. The results from this study give confidence that this could potentially be a useful tool as the victim’s measurements tend to cluster in PCA plots (see Figure 2, 4, 6 and 8). The heatmaps for each serial killer (Figures 3, 5, 7 and 9) also allows visualisation of where a particular feature may result in that victim being outside the cluster. This directs future research into that particular victim to discover why they are dissimilar in those traits.

Figure 9. Heatmap of Jerome Brudos victims and Subjects A-D.
Distribution of PCA Plot

As described in Section 3, all metric information obtained from measurements was uploaded for PCA which allows the data to be condensed into a simple scatterplot of all measurements based on the variance within the facial traits. This plot can be easily read and interpreted rather than having individual scatterplots comparing each individual to each other. The PCA plots do show clustering with the victims and subjects, although there are a few victim points that are outside the cluster and investigation into why was conducted.

Investigating Figure 2, Bundy PCA plot, there are three victims that fall outside the cluster of the other victims. Looking at Figure 3, Georgann Hawkins is distinguished from other victims due to her above average nose shape and horizontal eye opening. Conclusions about why she may be outside the cluster could be due to her being abducted from an alley behind her sorority which could possibly mean this victim was opportunity and random rather than meticulously planned like the others (10). Another victim, Denise Naslund, is seen outside the cluster in Figure 2 due to the below average face symmetry. A reason for Denise being on the outskirts could be due to another opportunity kill. Denise was abducted and killed four hours after Janice Ott in the same park, Lake Sammamish State Park (10). The last victim to discuss of Bundy is Lynette Culver. Lynette was Bundy’s youngest victim at 12 years old. In Figure 3, it can be seen that Lynette did not have significant similarities or dissimilarities with any other victims. The reasoning for why Lynette is on the outside may be due to her facial features being smaller or less developed than the other victims due to her age (30).
Analysing Figure 4, the PCA plot of Rader’s victims is similar to Bundy in relation to his victims clustering, with a couple of outlier victims. The three victims for discussion and possible explanation as to why they are outside the cluster are Julie Otero, Kathryn Bright and Shirley Vian. Julie was one of the four victims of the ‘Otero Family Murders’, her son, daughter and husband all fell victim too. A possible explanation for Julie not clustering with the other victims may be due to her ethnicity. The Otero’s were from a Hispanic background and studies comparing facial structure of Hispanic to Caucasians saw there is a significant difference between the two groups with 14 features being significantly larger in Hispanics than Caucasians (30). The next victim that is analysed is Kathryn Bright, seen at the higher end of the PC1 axis. The explanation for Kathryn being different may be due to Rader changing his modus operandi (MO). Rader changed his method of murder and may have changed his targeted victim so the police could not link him to any previous crimes. Kathryn is seen to have an above average mouth width in Figure 5, but this is due to her larger smile in the image used compared to other victims. Shirley Vian was his next victim after Kathryn. Shirley is closely grouped with Julie and Subject A. The reasoning for Shirley being outside the cluster is due to Rader confessing that Shirley was a completely random kill as his potential target was not home when he went to commit his crime (31, 32). Once Rader discovered his target was not home (Anne Dillion), he continued through the neighbourhood, found another house and went inside and proceeded to kill Shirley (31).

The PCA plot for Kemper’s victims can be seen in Figure 6 with little clustering of his victims. Kemper did target young females, but along with this he also targeted women who were hitchhiking (13). His victims were all around the same age and college (except for his grandparents and mother), but their facial biometrics were not as similar to each other as a serial killer who would stalk and chose particular targets (i.e. Ted Bundy). Even though his
victims are distant, there is still two victims that fall outside the vague cluster and that is Alice Liu and Aiko Koo. Both of these victims were of Asian ethnicity in comparison to all his other victims being Caucasian. Studies have suggested that Asian facial structure is significantly different in 16 dimensions compared to those of Caucasian ethnicity (30). Asians are seen to have larger faces, increased width of face and increased in nose shape which can be supported by Figure 7 (30).

The last PCA plot to be analysed is Figure 8 of Brudos victims. Comparing this plot to the other serial killers is almost impossible. Very little, if any, victims are similar to each other. Figure 9 shows the heatmap and there are very few faces that align with the average for any feature. A possible explanation for why their facial traits were largely different may be due to the type of serial killer Brudos was. Brudos from a young age was obsessed with women’s footwear and feet (14). He would dress his victims up after death in high heels or even amputate their feet so he could place high heels on them as trophies. Brudos gained his sexual gratification from the women’s feet, making the facial appearance of the victim non-defining. Brudos did target young females, but their appearance was not necessarily important for him to commit his crimes.

Limitations and Research Gap

Using facial biometrics on two-dimensional images can create challenges and limitations including image quality, expressions and occlusions in the images. The time era of the cases chosen for this research does increase these limitations but knowing these limitations and challenges can help improve techniques dealing with these types of images.

The criteria for the image selection for this study was high or large quality images that would be able to be printed in a large scale to measure the landmarks. Due to these cases
being from the 1970’s, 80’s and 90’s, access to high quality images were possible, but limited. Most images found were of large or high quality, but some images developed pixelization when printed as a large image. Research has discovered that image quality highly effects the comparison of images with the increase of undetermined results (33). An additional limitation that arose with the victim’s facial measurements was occlusions of their faces. Occlusions are whereby the face is blocked by accessories (i.e. scarves, glasses), shadows or hair (34). The areas of the face that are occluded can interfere with the location and detection of landmarks for comparison (34). Occlusions can greatly change the appearance of an original image of the face and can largely distort what the face looks like and the accuracy of the measurements (35). The images used in this study did present a problem as some victims did have glassware on in the images making eyebrow arch angle impossible to measure and therefore being removed as facial trait to measure. Another occlusion was fringes on some of the victims. This occlusion blocked the location of the trichion landmark (midpoint of hairline) and estimation by continuing the curve of the face around through the fringe was conducted to measure this point.

The facial trait with the most variance in measurements was the mouth shape, mouth height and mouth width. When investigating into why there is such a variance, it was concluded that expressions or more importantly smiling was the main factor effecting the measurements. The measurement of facial features relies on the surface of the skin to be consistent and with expressions the curves in the face are altered and may affect the distances and hinder comparison (36). Most images of the victims were smiling (due to being family photographs), but images that did not have the victim smiling had a lower proportional index for all three mouth measurements. These measurements could
unintentionally make one victim an “outlier” not due to their facial measurements, but the
factor of smiling could be the only discrepancies between the victims.

The research gap and an area for future research would include increasing the sample size
by increasing the amount of serial killers’ victims to measure. By increasing the dataset, this
would give more confidence to support the hypothesis that the victims are more similar to
each other than to randomly selected individuals. Along with increasing the sample
population, increasing the number of analysts measuring the faces would create a more
realistic database as each analyst would have their own definition of where each landmark
would be located. With increased measurements, the average of each measurement would
more accurately represent that feature.

Investigative and Intelligence Tool

The purpose of this study was to understand the methods behind facial biometrics to see
if it could be put into practice as an investigative and intelligence tool when physical
evidence is absent, or resources are exhausted. To use this research as an investigation
tool, it potentially could be useful when new victims are being associated with one
convicted offender by comparing their facial measurements to previous victims (3). This
study does not suggest this method will solve every crime but can be a tool investigators
can fall back on. With this investigative tool in mind, if a victim cannot be lined to other
victims, this does not indicate that it is not associated with the one offender (3). The victim
selection is based on the preference of the offender and the availability of victims when
they committed the crime. The process is complex and the targeted victims can change due
to opportunity or MO (3).
An example of facial biometrics being an intelligence tool is comparing the facial characteristics of Rader’s victims with Bundy’s victims. Figure 10 shows the heatmap when the victims of Rader and Bundy are combined into one along with the Subjects; Rader victims marked in red boxes, Bundy’s victims in yellow boxes and subjects in green boxes. These two victim datasets had the closest variance in PC, which would enhance the comparison between the two groups. Figure 10 shows the heatmap separating the data into two clades and when looking at the victims in each clade, the division between Rader and Bundy is nearly exclusively to one killer. The left-hand clade groups 13 out of the 20 victims for Bundy with only two of Rader’s victims included. The right-hand groups the remaining six of Rader’s victims, the remaining six of Bundy’s victims and all four the
comparison Subjects. This grouping of the Subjects in the right-hand clade (similar to Rader victims than Bundy) can be supported when looking at Figure 2, which shows the Subjects more entwined with Rader’s victims than Bundy’s victims as seen in Figure 4.

This heatmap could prove that facial biometrics of victims could potentially be used as an intelligence tool by giving the investigators evidence that victims of sexually motivated serial killers group together and separate for each killer. Even though there is a cross over with victims in each other’s clade, this does not suggest that this technique does not work. It may suggest that these serial killers may have had a similar type of victim or the geographical and temporal situation prevented the killer targeting that particular victim.

**Conclusion**

The aim of the current study was to provide a method for crime linkage based on victims’ facial biometrics. This aim was not to produce a system that would solve every case, but to be utilised when other sources are exhausted. This technique can be developed and possibly be used as an intelligence tool for investigators of serial homicide cases. The method of this research relies on the understanding of organised offenders, such as sexually motivated serial killers, and how these offenders often target victims with particular characteristics. This study suggests that facial biometrics of these victims can be a potential tool for crime linkage with this type of offender.

Four sexually motivated serial killers were chosen for this study to help support the hypothesis that victims of these serial killers will be more similar to each other compared to a randomly selected victim of the same profile. The results from this study do support the hypothesis with the victims showing similar facial biometrics to each other illustrated using PCA plots and heatmaps. Although these serial killers have the same motivation to
kill (i.e. sexual), the assumption that every sexually motivated serial killer target their victims based on their facial appearance is false. It was seen when reviewing Jerome Brudos’ victims as their facial biometrics did not have similarities and this may be due to Brudos not being attracted to the victim’s facial appearance, but rather their footwear and feet. This proves that even though these four serial killers are classified as sexually motivated, understanding the sexual motivation to offend is critical for this technique. Comparing Brudos to Theodore Bundy demonstrates that facial biometrics is a useful tool for serial killers that target victims based on facial appearance as Bundy’s victims clustered and are very similar appearance than Brudos.

Image quality and facial expressions produce a limitation for this method, and overcoming these limitations include choosing landmarks that are not affected by expression to give analysts a more accurate measurement. The future for this technique, as mentioned above, is to become an intelligence tool when investigators have a new victim that may possibly be from an offender with known victims. This approach is still novel, however with exploration into reducing limitations and an extensive research into the serial killer’s motivation, this technique has the potential to be an alternative intelligence tool.
References


