8-2016

The effects of scarring on face recognition

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Graduate School Form
30 Updated 12/26/2015

PURDUE UNIVERSITY
GRADUATE SCHOOL
Thesis/Dissertation Acceptance

This is to certify that the thesis/dissertation prepared

By Kevin J. Chan

Entitled
THE EFFECTS OF SCARRING ON FACE RECOGNITION

For the degree of Master of Science

Is approved by the final examining committee:

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THE EFFECTS OF SCARRING ON FACE RECOGNITION

A Thesis

Submitted to the Faculty

of

Purdue University

by

Kevin J. Chan

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

August 2016

Purdue University

West Lafayette, Indiana

ACKNOWLEDGEMENTS

I would like to thank my Committee Chair and Advisor Prof. Stephen Elliott for guiding me through my graduate studies and keeping me from getting lost in the rabbit holes. I would also like to thank Prof. Richard Guest for his help and expertise, not just this thesis but for all projects that helped me grow. In addition, I would like to thank Prof. Joel Ebarb for his knowledge and assistance, in the classroom or on the dance floor, from the earliest years of undergraduate till now.

Beyond the classroom I would like to thank Prof. Yuehwern Yih for her guidance and counseling in both dance and academia; Two-Time US Champion Kimberley Mitchell for always believing in me; and Bas van der Zanden, who taught me that with enough practice and conviction, it is possible to win.

Much gratitude to my support system; Esther “Foosters” Foo, Shadow “Dou Dou” Zhao, and Dr. Ziqing “Sergeylicious” Lin. Special thanks to Dr. Cory “Unicory” Nguyen for being my graduate school Sherpa, and Johnson Char for giving me a place to live. Significant recognition to Natasha Shevchenko, Olivia “Kid Mambo” Hardebeck and Sylvia “French Toast” Lefebvre for always listening.

Last, but certainly not least; my partner Roxanne Schroder and my good friend Bridget "The Loofah" Kilbride. Because of these ladies, my last year at Purdue will be the most memorable.

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ABSTRACT

Chan, Kevin J. M.S., Purdue University, August 2016. The Effects of Scarring on a Face Recognition System. Major Professor: Stephen Elliott.

The focus of this research is the effects of scarring on face recognition. Face recognition is a common biometric modality implemented for access control operations such as customs and borders. The recent report from the Special Group on Issues Affecting Facial Recognition and Best Practices for their Mitigation highlighted scarring as one of the emerging challenges. The significance of this problem extends to the ISO/IEC and national agencies are researching to enhance their intelligence capabilities. Data was collected on face images with and without scars, using theatrical special effects to simulate scarring on the face and also from subjects that have developed scarring within their lifetime. A total of 60 subjects participated in this data collection, 30 without scarring of any kind and 30 with preexisting scars. Controlled data on scarring is problematic for face recognition research as scarring has various manifestations among individuals, yet is universal in that all individuals will manifest some degree of scarring. Effect analysis was done with controlled scarring to observe the factor alone, and wild scarring that is encountered during operations for realistic contextualization. Two environments were included in this study, a controlled studio that represented an ideal face capture setting and a mock border control booth simulating an operational use case.

CHAPTER 1. INTRODUCTION

Face recognition is a routine social interaction that has been increasingly automated (Li & Jain, 2005). Technological developments create new opportunities and new challenges for the future, which means that face recognition as a science will have an ever-changing landscape. This chapter defined one of the recent additions to the body of knowledge of face recognition, the impact of scaring (ISO/IEC JTC 1/SC 37, 2010). This problem, and the purpose of this study will also be defined, along with associated limitations and scope of research. This study examined the scarring problem and overcame comparison factors with the use of theater arts to replicate scarring on the face, and create a realistic dataset for performance analysis. By analyzing the impact of scaring with realistic recreation, solutions can be developed in future research. This chapter also presents the framework of this thesis, which comprises of the following: Statement of the Problem, Significance of the Problem, Statement of Purpose, Research Questions, Assumptions, Limitations, Delimitations, and Definitions.

1.1 Statement of the Problem

Scarring of the face have an effect on face recognition performance and image quality (ISO/IEC JTC 1/SC 37, 2015). With the advent of the machine-to-machine interface for border control, human operators are being replaced, or reduced in number

(Foster, 2016). This border control operational setting creates challenges for face recognition systems; problems such as pose, illumination, and expression need to be systematically addressed to ensure proper identification (Jain, Ross, & Nandakumar, 2014). The face is a social organ and the way humans contextualize the face allows for a certain robustness in recognition capabilities (Delac & Grgic, 2004; Landis, 1929). The human visual system can make adjustments to visual stimuli that allow correction of processed images. These adjustments and corrections lead to the invariance of factors such as isometric deformations, texture changes, and even occlusions (Landis, 1929; Proctor & Van Zandt, 2008). Machines have performance issues when it comes to this robustness to face changes, and ongoing research is done along all avenues of potential variance (Li, 2012). Research in image manipulation in machine interface in face recognition include pre-processing (Hsu, Shah, & Martin, 2006; Sang, Lei, & Li, 2009), cosmetic makeup (Dantcheva, Chen, & Ross, 2012), plastic surgery (Dantcheva & Dugelay, 2011; Singh, Vatsa, & Noore, 2009), occlusion (Samal & Iyengar, 1992), expression (Bronstein, Bronstein, & Kimmel, 2003), and illumination (Jain, Klare, & Park, 2011). The presence of scarring on the face, one would intuitively conclude that there would be an impact; the physical changes would transcend into performance changes. However, there is currently no information regarding the pre- and post-scarring of faces on a face recognition system. Jain and Park (2009) presented evidence that scarring can be detected and used as a soft biometric (Jain & Park, 2009), but have yet to study the effects of matching between pre and post scarring. Factors such as standardized pre and post scarring images, general information, and performance analysis of scarring effects limit this development.

1.2 Significance of the Problem

Face recognition is a popular and widely used modality of biometric authentication (Jain, Ross, & Nandakumar, 2014). The effects of facial scarring have unknown effects on machine interfaced face recognition (Jain & Park, 2009); testing pre- and post-scarring has not been done yet, but was classified as "potential issues" by the Special Group on Issues Affecting Facial Recognition, also known as SG-IFR (ISO/IEC JTC 1/SC 37, 2015). Scarring has been used as an auto-detect soft biometric within face recognition (Jain & Park, 2009). Due to the constant and social use of the face as an identifier, human to the human interface is not degraded by scarring unless the scarring is extreme (Samal & Iyengar, 1992). Scarring occurs commonly and in varying magnitudes, almost all individual will have some scarring on their body (Bayat, McGrouther, & Ferguson, 2003), making it a particularly hard to control as a variable. Furthermore, scarring is further factored in three types: atrophic, hypertrophic, and keloid scarring. Scarring, like all physical changes, is hypothesized to cause matching performance changes (Gao, Li, Liu, & Zhang, 2007).

On the surface, ISO/IEC JTC 1/SC 37 is a technical group within the ISO; a typical subcommittee of technical professionals representing their various national standards organization (ISO/IEC JTC 1/SC 37, 2010). ISO/IEC members write, report, and vote on various standards; acting as an extension of intent for national bodies (ISO General Secretariat, 2015). However, membership of the SG-IFR report, the participants came from Australia, Canada, New Zealand, the United States, and Italy. Also, the Australia and New Zealand SmartGate referral rate only had five countries listed: Australia, Canada, New Zealand, the United States, and the United Kingdom (ISO/IEC JTC 1/SC

37, 2015). It is apparent the Five Eyes intelligence community, known as FVYE, are making advancements to improving their network. It would not be outlandish to assume that the FVYE are taking careful consideration of ISO/IEC standards on face recognition, as standards information can help bolster their intelligence integrity between their alliance members. The FVYE have previously done such data and network-centric activities, even activities of covert and espionage nature (Parson, 2015). This exclusive intelligence sharing alliance was born out of Cold War and has remained significant to the national interest of member countries. The dynamic nature of terrorism and the new adaptive policy initiatives by governments has placed increasing reliance on the FVYE (Cox, 2012). With the presence of the FVYE countries in the SG-IFR report, this research would have an impact on future national interests that include but not limited to security implications, intelligence gathering and sharing, and counter-terrorism applications.

1.3 Statement of Purpose

This study collected face image data that is ISO-19795-5 compliant, with the factor of scarring for biometric research. Scarring will be simulated using liquid latex in a theater arts application. The preliminary investigation will statistically compare both image quality and performance metrics using Detection Error Tradeoff Curves. Biometric stability analysis was also done with the Dunstone and Yager Zoo Menagerie and will be used as supplemental analysis to add granularity and context to the overall performance analysis.

1.4 Research Question

What is the impact of scarring in image quality and performance of a face recognition?

1.5 Assumptions

The assumptions for this research will include the following:

- The matching algorithm of Megamatcher 9.0 was in good working order
- The image quality analysis algorithm of PreFace 4.2 was in good working order
- Image capturing hardware met industry standards of shutter speed between 1/60th to 1/250th of a second
- Image capturing hardware met industry standards of at least two pixels per millimeter
- The 18% gray background was subject to typical shadow and reflectance variations from subjects
- Liquid latex scars applied to the subject were identically constructed from the same mold
- The color of liquid latex is sufficiently different from subject skin pigmentation
- Scars that subjects have before the data collection were uncontrolled and developed uniquely

1.6 Limitations

The limitations for this research will include the following:

- The study was limited to using only Megamatcher 9.0

- The study was limited to using only Aware Preface 4.2
- The study was limited to controlled full frontal lighting scheme specific ISO/IEC FCD 19794-5 photo studio, operational use case scenarios will not be controlled
- The data collection was limited to 60 subjects that do not reflect the population at large, due to collection from local participants
- The data collection was done with non-occluded face images
- The data collection was limited to a Boolean style, yes or no, factor of scarring

1.7 Delimitations

The delimitations for this research will include the following:

- Testing different locations of face scarring was beyond the scope of this study
- Testing different shapes of scars was beyond the scope of this study
- The study did not include keloid scarring, raised scars that spread beyond wounds
- The study did not include high definition makeup techniques, which utilizes illumination manipulation in tandem with makeup effects
- The study did not include airbrushing or facial tattooing techniques of makeup application, which are permanent changes to subject skin characteristics
- The study will not include the use of Kryolan Tuplast scar polymer, a relatively new and unconventional method for prosthetic scar construction

1.8 Terms & Definitions

The following key terms for this research are defined as:

- Atrophic Scars: “are flat and depressed below the surrounding skin.” (Bayat, McGrouther, & Ferguson, 2003, p. 89)
- Biometrics: "is the automatic identification of an individual based on his or her physiological or behavioral characteristics." (Dunstone & Yager, 2008, p. 99)
- Biometric System: “a pattern recognition system that operates by acquiring biometric data from an individual, extracting a feature set from the acquired data, and comparing this feature set against the template set in the database.” (Jain, Ross, & Prabhakar, 2004, p. 4)
- Detection Error Trade-off (DET) Curves: “summarizes system performance by plotting false match rate vs. false non-match rate pairs for a range of match thresholds.” (Dunstone & Yager, 2008, p. 105)
- Equal Error Rate (EER): “The error rate at which the false accept rate equals the false reject rate. The EER can be used to summarize the performance of a system, as it contains both false match and false non-match information.” (Dunstone & Yager, 2008, p. 104)
- False Acceptance Rate (FAR): “proportion of verification transactions with wrongful claims of identity that are incorrectly confirmed” (ISO/IEC 19795-1:2006)
- False Rejection Rate (FRR): "proportion of verification transactions with truthful claims of identity that are incorrectly denied" (ISO/IEC 19795-1:2006)

- Genuine match: “A match between two instances of the same biometric characteristic from the same person.” (Dunstone & Yager, 2008, p. 101)
- Hypertrophic Scars: “are raised scars that remain within the boundaries of the original lesion, generally regressing spontaneously after initial injury” (Bayat, McGrouther, & Ferguson, 2003, p. 89)
- Impostor match: “A match between two different biometric characteristics. This is usually a match between two different people, but also includes a match two different characteristics of the same person, such as matching between the left iris and right iris.” (Dunstone & Yager, 2008, p. 101)
- Keloid Scars: “are raised scars that spread beyond the margins of the original wound and invade the surrounding normal skin in a way that is site specific.” (Bayat, McGrouther, & Ferguson, 2003, p. 89)
- Performance: “which refers to the achievable recognition accuracy and speed, the resources required to achieve the desired recognition accuracy and speed, as well as the operational and environmental factors that affect the accuracy and speed.” (Jain, Ross, & Prabhakar, 2004, p. 4)
- Sample: “user’s biometric measures as output by the data capture subsystem” (ISO/IEC 19795-1:2006)
- Scars: “wound healing is evolutionarily optimized for speed of healing under dirty conditions, where a multiple redundant, compensating, rapid inflammatory cascades allow the wound to heal quickly to prevent infection and future wound breakdown.” (Bayat, McGrouther, & Ferguson, 2003, p. 88)

1.9 Chapter Summary

This chapter introduced the research question of the effects of scarring on face recognition. The purpose, assumptions, limitations and delimitations, as well as pertinent definitions, were conferred to establish the research boundaries. This chapter provided an overview of this research and secured a foundation for its significance and importance.

CHAPTER 2. LITERATURE REVIEW

2.1 Biometrics

Biometrics is a multidisciplinary field that incorporates natural sciences, mathematics, and humanities. The magnitude of biometrics can span from a simple house door to vast national borders (Dunstone & Yager, 2008). Biometrics uses physiological and biological characteristics for automated recognition and is selected for their universality, distinctiveness, permanence, and collectability (Jain, Ross, & Prabhakar, 2004).

Biometric measurements should be universal in that the general population can be included in the system. The measurements of between one another are distinct and discernable and practically invariant over time. Biometrics should also account for collection methodology for consistent and effective extraction as complicated methods can be time-consuming or uncomfortable to the users. Many modalities are offered for biometrics, with the three dominant ones being iris, fingerprint, and face recognition (Dunstone & Yager, 2008).

Secret and token based identification systems rely on a representation of identity, such as PIN numbers or credit cards. Secrets and tokens have the risk of being lost, stolen, or acquired by impostors. Biometrics is a natural alternative because biometric characteristics are inherently possessed by the user. The risk of forgetting and stealing identifiers are lower compared to secrets and tokens (Jain, Ross, & Nandakumar, 2014).

2.2 Face Recognition

Face recognition is using the unique characteristics and features of the face to identify an individual's identity. Located on the frontal portion of the head, the face is the foremost part of personal interactions with the outside world, making it a very social organ that is engaged in daily use (Jain, Ross, & Nandakumar, 2014). Humans perform face recognition routinely and effortlessly many times a day. The digital boom created a means of computerizing this innately human process. Face recognition is non-intrusive, natural, can be collected at a distance, and the face is always apparent (Li & Jain, 2005).

The first use of the face as an identifier was a comparison of photographs in an 1871 British Court hearing (Jain, Klare, & Park, 2011). In 1882, Dr. Alphonse Bertillon created the first set of metrics for the face during his tenure at the Parisian Prefecture de Police (Bertillon, 1896). The Bertillon system would be implemented across the world, and becoming the first de facto face recognition standard (Finn, 2009).

The first automated face recognition system was by Takeo Kanade in 1973, in research for his doctorate dissertation (Li & Jain, 2005). Since then, research in automated and computerized face recognition systems have spread to answer many challenges of face recognition. Face recognition developed into one of the most common modalities in biometrics and having highly visible implementation in border security and law enforcement.

Face recognition does have its roots in law enforcement with the Bertillon system, and its automation widened the scope of application. In addition to mugshots and photographic evidence, face recognition evolved into operations such as missing person identification (Park & Jain, 2005), forensics (Jain, Klare, & Park, 2011), surveillance, and watchlists (Li & Jain, 2005). A result of globalization and technological advances is increased traffic through customs and borders (Woodward, 1997). Automated face recognition has found operational use in global entry programs and machine readable travel documents (Li & Jain, 2005).

2.3 Face Recognition Algorithms

Being the primary focus of attention in social intercourse, the identity and emotion of individuals are conveyed with the face (Landis, 1929). The human ability to recognize and analyze faces is robust, adjustable, invariant to factors such as aging or environment, and can even filter out distractions and uneven conditions. The face is a complex and multi-dimensional stimuli, thus developing algorithms for automated face recognition is complicated (Turk & Pentland, 1991).

2.3.1 Principle Component Analysis

Principle Component Analysis, commonly referred to as PCA, is one of the most commonly used face recognition algorithms. The algorithm decomposes the face into small sets of characteristics called eigenfaces and is analyzed separately. PCA has earned favor among many biometric researchers for its speed, simplicity, learning capacity, and invariance to minor changes (Turk & Pentland, 1991).

2.3.2 Linear Discriminant Analysis

There are many other face recognition algorithms, some having evolved from PCA while others evolved as a compliment to it. Linear Discriminant Analysis, referred to as LDA, uses class discrimination to minimize intra-class variations and maximize interclass variations. Variation of differences between the face enrollments of an individual is minimized while the variation of the difference between two individual is maximized (Li, 2012). LDA can be expected to provide improved accuracy over PCA because of this class discriminant learning. The accuracy improvement does require sufficient face enrollments into the system. Whereas PCA can be deployed more rapidly, LDA will have more enrollment requirements (Jain, Ross, & Nandakumar, 2014).

2.3.3 Independent Component Analysis

Independent Component Analysis, abbreviated as ICA, is a more generalized version of PCA (Jain, Ross, & Nandakumar, 2014). ICA aims to make resulting components as independent as possible, instead of looking at the face components interdependently like PCA or LDA (Li, 2012). This lack of dependence on components allows ICA to make recognition processes with independent source components (Liu & Wechsler, 1999). Liu and Wechsler would continue to improve ICA with the inclusion of Gabor Feature Analysis as a supplemental process. Gabor wavelets capture the properties of spatial localization, orientation, and dimensions making it a good approximation to filter images for decomposition of discriminating features (Liu & Wechsler, 2003).

2.3.4 Local Binary Pattern and Texture-Based Algorithms

PCA, LDA, and ICA are appearance-based face recognition algorithms. Another type of face recognition algorithm is texture based. A popular texture based algorithm is Local Binary Pattern, abbreviated as LBP, due to its success not only in face recognition but object recognition as well. LBP works by extracting features from a localized pixel area and making matching comparisons to neighboring localized pixel areas. LBP encodes pixels of the face image in 8-bit binary strings and outputs a histogram of local binary patterns. Though the encoding and binary pattern histograms are localized, they will be put together to generate a global histogram in a final normalized vector. This normalized vector is then used for matching, by computing the distance between the local feature vectors (Jain, Ross, & Nandakumar, 2014). This process is similar to PCA, but the analysis is done on a pixel basis rather than a component basis. PCA, LDA, and LBP offer a holistic representation of the face and are sensitive to changes such as occlusions and topographical variance. The compartmentalized process allows these algorithms to sort through features or localized areas, as some are considered redundant or irrelevant to overall matching process (Li, 2012). Li refers to these redundancies and irrelevancies to as “junk features”.

2.4 Image Quality

Face image quality has a systematic effect on the enrollment and reliability of face recognition performance. If poor quality images enroll into the system, then the result would be poor quality performance. Standards for scenery, photographic aspects, and digital requirements are established by ISO/IEC-19794-5 (Sang, Lei, & Li, 2009).

Due to the multitude of use cases and operational settings of face recognition, there are many standards enacted for face image quality. The benefit of ISO/IEC-19794-5 is the comprehensive measurement of many different metrics. The ISO Frontal Best Practices profile measures face image quality along 23 image quality metrics. ISO Frontal Best Practices profile is used to ensure passport photos comply with a certain image quality. Though NIST Mugshot Best practices use 24 image quality metrics, most of which overlaps with ISO Frontal Best Practices, the use case is specific to law enforcement mugshots (Chan & Elliott, 2015). Ergo compliance to such stringent standards may not apply to general use of face recognition.

Image quality analysis, as a preprocess face recognition, can supplement the overall system and solicit better discrimination from the processing algorithms. Gao et al. (2007) describe the quintessential example, where some image quality preprocessing occurs before the matching, thereby normalizing the face image before feature extraction, and then the matching algorithm can set appropriate threshold based on the preprocessing quality assessment (Gao, et al., 2007). Figure 2.1 show Gao et al.'s framework for integrating image quality to supplement biometric recognition.

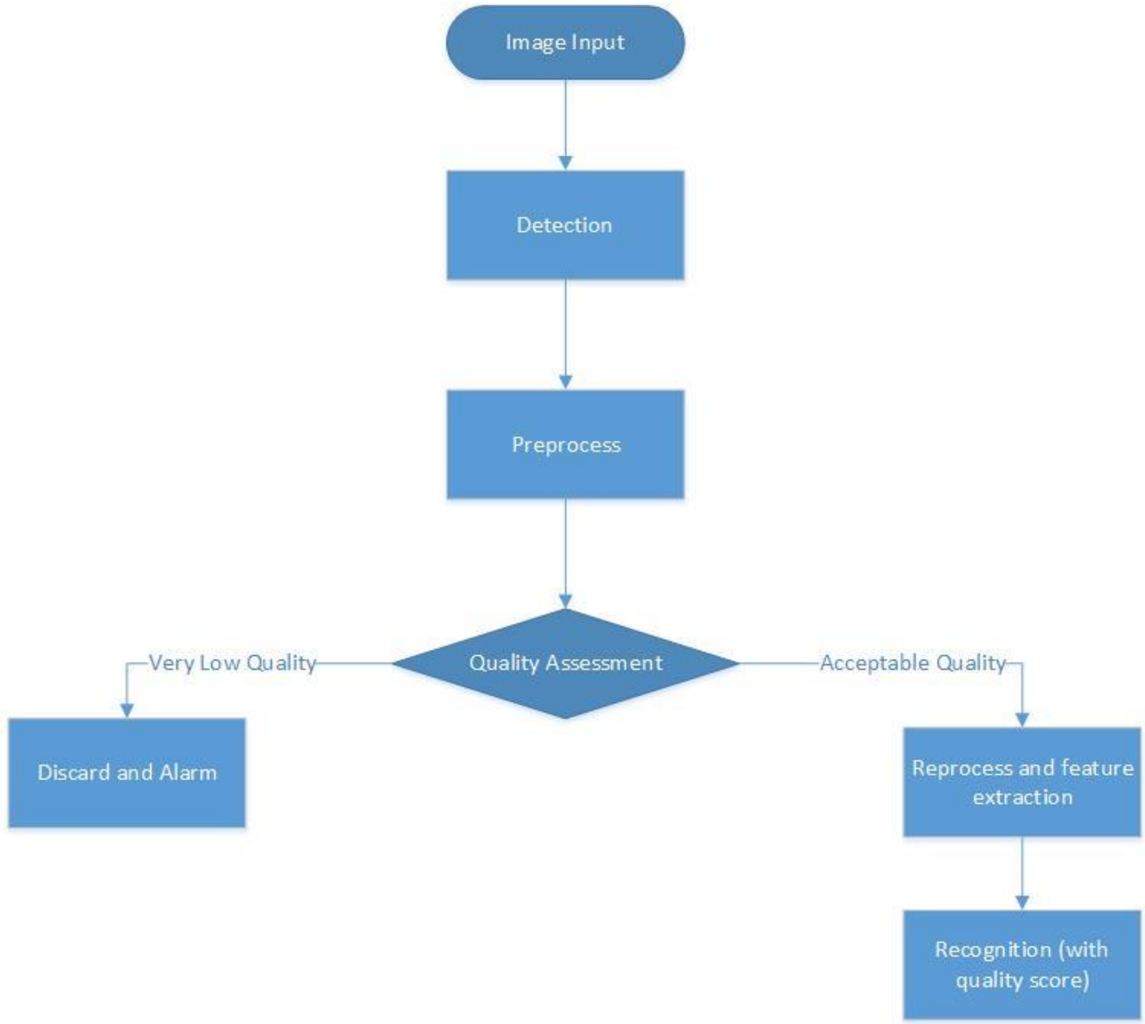

Figure 2.1: Gao et al.'s framework of biometric recognition with image quality assessment (Gao, et al., 2007)

2.5 Biometric Performance

In biometric recognition systems, the Detection Error Tradeoff curve referred to as DET curve, is used to represent performance. The DET curve is used to great effect in biometrics because of its presentation using tradeoff of error types. In biometrics, single or finite performance indicators will not reflect the overall capabilities of a system. Biometric recognition system can operate on a vast scale of thresholds and security parameters, ergo biometric system performance is best represented by a curve (Martin, et al., 1997; Schuckers, 2012).

2.5.1 Receiver Operating Characteristic Curves

Traditionally, the Receiver Operating Characteristics curve, abbreviated as ROC curve, is used for performance analysis with error ratings (Martin, et al., 1997). ROC curves have been used in a wide array of fields including biometrics, image processing, data mining, machine learning, and human factors (Dunstone & Yager, 2008). The principle operation behind the ROC and DET curves is the optimization of tradeoffs across system performance. If the response criterion, which is match threshold in the case of biometrics, increases or decreases then the tradeoff curve will change. The ROC and DET curves help represent all possible combinations of tradeoffs at different response criterion, and can indicate acceptable operational characteristics (Dunstone & Yager, 2008). ROC curves are commonly plotted by correct detection rate over false alarm rate; biometric applications will occasionally use true accept rate over false accept rate (Schuckers, 2012), within a variable response criterion or threshold set at τ.

$$TAR = \int_{\tau}^{\infty} f_1(x)dx \qquad \text{(Equation 2.1)}$$

$$FAR = \int_{\tau}^{\infty} f_0(x)dx \qquad \text{(Equation 2.2)}$$

ROC curves provide information regarding system sensitivity (Proctor & Van Zandt, 2008). The response criterion is dependent on the system, ranging from generic aspects like background noise level to biometric specific criterion like false match rates.

Though the ROC is utilized for biometric performance analysis, the DET curve has become the preferred and common practice in biometrics.

2.5.2 Detection Error Tradeoff Curves

The DET curve is a variant of the ROC curve that plots errors on both axes, giving uniformed treatment to both error types. Scaling both error types gives the DET curves more discriminating presentations of different systems, not only showing better-performing systems but also in which error scale the performance is better (Martin, et al., 1997). The DET curve is a plot of False-Match Rate over False-Non Match Rate.

$$FMR_l(\tau) = \int_0^\tau \Psi_l(x)dx \qquad \text{(Equation 2.3)}$$

$$FNMR_C(\tau) = \int_\tau^\infty \Psi_C(x)dx = 1 - \int_c^\tau \Psi_C(x)dx \qquad \text{(Equation 2.4)}$$

Based on the above equations, we can compute the DET curve as shown below. From the FMR and FNMR, we can construct genuine and impostor distributions based on derivatives from the gathered matching results (Adler & Schuckers, 2005).

$$impostor(\hat{x}) = -\frac{dFMR_l}{d\hat{x}} \qquad \text{(Equation 2.5)}$$

$$genuine(\hat{x}) = \frac{dFNMR_C}{d\hat{x}} \qquad \text{(Equation 2.6)}$$

The clearer differentiation of performance makes the DET curve preferable as a biometric performance analysis tool; the DET curve can show the overall compromise of the system in regards to the combination of error rate tradeoffs (Schuckers, 2012). Figure 2.2 shows the differences between DET and ROC curves. The Equal Error Rate, abbreviated as EER, is shown on the DET curve as the point where both error rates are equal. At the EER, where both error rates are equally frequent, the tradeoff is considered optimal, and the combination represents the most balanced system response criterion (Kajarekar, et al., 2008). The EER is significant because, from that point, the threshold can be set for decreasing certain error rates while assessing the cost of the other. The mathematical elaboration for the EER is as follows (Dunstone & Yager, 2008).

$$\tau_1 = \max_{\tau}\{\tau | FNMR(\tau) \leq FMR(\tau)\} \qquad \text{(Equation 2.7)}$$

$$\tau_2 = min_{\tau}(\tau | FNMR(\tau) \geq FMR(\tau)) \qquad \text{(Equation 2.8)}$$

$$[EER_{low}, EER_{high}] = \begin{cases} [FNMR(\tau_1), FMR(\tau_1)] \\ [FNMR(\tau_2), FMR(\tau_2)] \end{cases} \qquad \text{(Equation 2.9)}$$

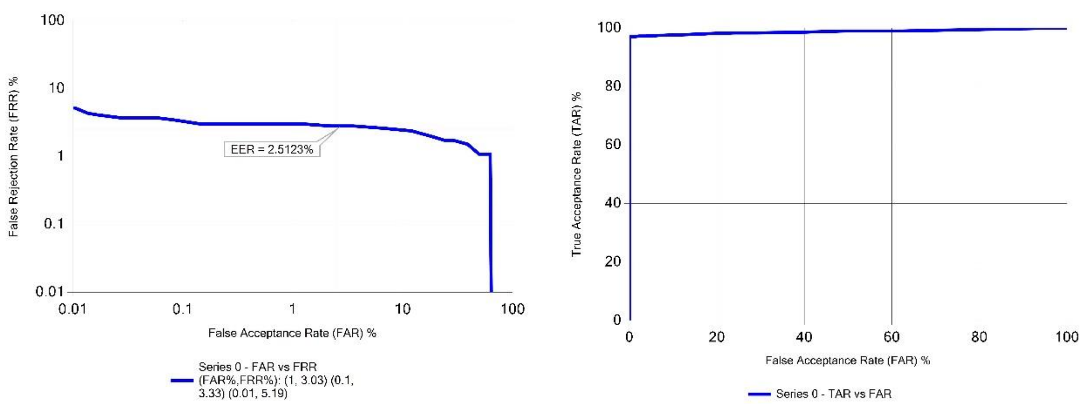

Figure 2.2: Comparing DET curve on the left and ROC curve on the right

As a result of the DET curve's distinguishing characteristics, Martin et al.'s report concluded that the DET curve should be standard for performance reporting in biometric speaker recognition. The DET curve has been used in a variety of biometric systems testing across many modalities (Fierrez & Ortega-Garcia, 2008; Himaga & Kou, 2008; Kajarekar, et al., 2008).

When overlaying ROC or DET curves, a way to compare different systems is analyzing the Area Under the Curve, abbreviated as AUC. The AUC gives an overall performance indicator but is not specific on which facet of performance is better or worse (O'Connor, et al., 2015). O'Connor et al. (2015) described the curve as simply a "snapshot" (O’Connor, et al., 2015, p. 46) of system performance, but performance variability can be attributed to many factors not seen from a general point of view. For this research, the DET curve will be used to assess overall performance between baseline and scar datasets. The performance curves of the two datasets will be overlaid to observe how the curves behave and the general AUC of the datasets. The application will be similar to Martin et al.’s example in Figure 2.2, where the AUC of the DET shows the system behavior in more detail than the ROC.

2.5.3 Zoo Menagerie

Zoo Menagerie has the advantage of showing performance on an individual user basis while ROC and DET curves show the system tradeoff in its entirety (O'Connor, et al., 2015). Inherent differences in recognizable features between individuals create intra-class variation. Individual performance ergo is dependent on individual behavior within the biometric system (Doddington, et al., 1998).

2.5.3.1 The Doddington Zoo

Doddington et al. (1998) noticed a “striking performance inhomogeneity” (p. 1) among users. Poor performance by an individual can manifest itself in overall system performance. Doddington et al.’s Zoo Menagerie are important for generalization and overall system robustness across a wide population, as it adds granularity to individual performance effects in the system performance. Doddington's zoo classifies users in four animals: sheep, goats, lambs, and wolves. Sheep are the default user type, those who are observed to behave normally within the biometric system. Goats are particularly difficult to recognize and account for a statistically disproportionate amount of failed detections. Goats as biometric system users are not reliably accepted. Lambs are users who are easy to impersonate and account for a statistically disproportionate amount of false alarms. Lambs reveal compromises in the system, like vulnerability through trial and error attacks or biometric characteristics that are subject to algorithmic anomalies. Wolves are users who are successful in impersonation and are exceptionally likely to be accepted as someone else. Wolves, like lambs, account for a statistically disproportionate amount of false alarms. Unlike lambs, wolves reveal potential system threats as they possess features and characteristics that can defeat security measures (Doddington, et al., 1998).

The Doddington et al. method analyzed verification performance when users matched against themselves and with others. Dunstone and Yager (2007) presented another method for the zoo menagerie based on a user's relationship between genuine and impostor match score. Like the Doddington et al. method, the Dunstone and Yager zoo seeks to answer performance consistency problems by observing the user (Dunstone & Yager, 2007). For the Dunstone and Yager model, consistently poor performance is key. It is not enough that a user suffers poor performance, but also has to suffer it outside random variation (Dunstone & Yager, 2007).

2.5.3.2 The Dunstone and Yager Zoo

The Dunstone and Yager zoo menagerie looks at the relationship between genuine and impostor scores and classifies users in fours animals: chameleons, phantoms, doves, and worms. Chameleons appear similar to others, hence the classification name, and have high match scores in both genuine and impostor. Chameleons have very generic features that weigh heavily by matching algorithms. Phantoms have low match score in both genuine and impostor. Doves are the best users of biometric systems with high genuine scores and low impostor scores, and they match well with themselves and poorly with others. Suffering little verification error, Doves can have uncommon or very distinctive characteristics that are easily discerned (Dunstone & Yager, 2007). The antithesis to Doves, worms has low genuine scores and high impostor scores, making them the worst users for a biometric system. Dunstone and Yager (2007) calls them “lowly creatures” (p. 3), due to their few distinguishing features. Worms cause a disproportionate number of system errors. The effect on worms on the biometric system performance is described as parasitic, as their poor performance can improve other users when matched against them. Worms are important as they expose flaws in matching algorithm (Dunstone & Yager, 2008). An example of this zoo methodology is shown below in Figure 2.3.

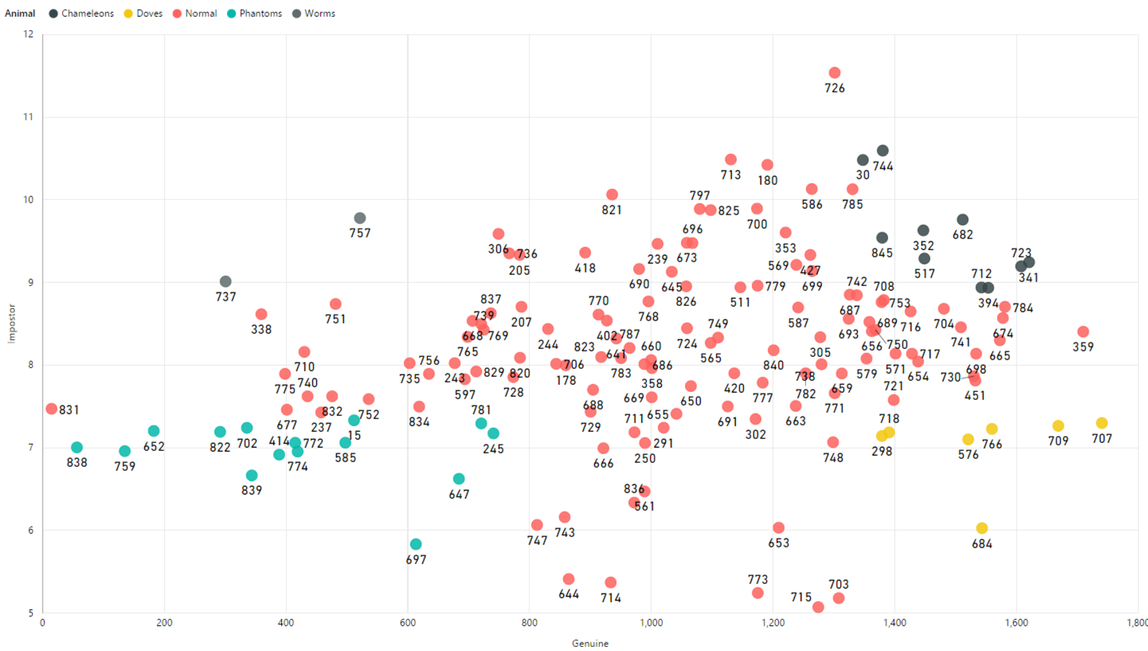

Figure 2.3: An example of a Zoo Plot using the Dunstone & Yager Methodology

2.5.3.3 Schucker's Critique and the Existence of Zoo

Doddington et al. do not conclude that individual users are within a zoo classification by virtue of their biometric qualities and characteristics. Users manifest certain wolf-ish or lamb-ish qualities with certain causal dependencies (Doddington, et al., 1998). A weakness of this zoo method is presented by Dunstone and Yager (2007), calling attention that isolated instances of failed verification does not warrant classification. Some users will have more matching difficulty while others less so, all in part of normal variation (Schuckers, 2012). Schuckers (2012) describes this phenomenon as "the nature of any measurement process with noise" (p. 300). Noise and variation, being integral to signal process in both human and machine (Proctor & Van Zandt, 2008), can bring doubt to the existence of the zoo menagerie (Schuckers, 2012). Schuckers

(2012) asked if a goat is a goat for all systems or just one particular one, which brings to question the universality of animal classifications. This changes the dependency dynamics from individual based on a system based, and also calls into question several issues such as human factors and environmental effects (Schuckers, 2012).

Zoo analysis can be used as a method to find the cause of weakness in biometric systems. A change in the number of worms can cause algorithmic bugs to the surface as the system population will always have a certain number of worms that should not deviate beyond statistical normality. Environmental and human factor issues could be revealed through poor quality results from poor quality captures. Data integrity issues such as ground truthing and duplicate enrollments can also be revealed in the zoo (Dunstone & Yager, 2007). For this study, zoo menagerie will be used for analysis of user stability across the factor of scarring. The Stability Score Index, referred to as SSI, was coined to address movement from one animal classification to another. User movement tendencies cannot be seen in an aggregate graphical analysis, but is apparent when comparing two or more zoo plots of the same population. Stability score is scaled from 0 to 1, where 0 is stable and does not move at all (O'Connor, Elliott, Sutton, & Dyrenfurth, 2015).

$$SSI_i = \frac{\sqrt{\left(x_{i_2}-x_{i_1}\right)^2+\left(y_{i_2}-y_{i_1}\right)^2}}{\sqrt{(x_{max}-x_{min})^2+(y_{max}-y_{min})^2}} \qquad \text{(Equation 2.10)}$$

2.6 Challenges to Face Recognition Performance

The quintessential problems with face recognition are described with the acronym PIE: Pose, Illumination, and Expression (Li & Jain, 2005). Though as the technology developed, new problems are encountered. Aging (Park & Jain, 2005), image quality (Gao, Li, Liu, & Zhang, 2007), and processing artifacts such as printing and scanning (Ferrara, Franco, Maltoni, & Sun, 2013) are all being researched to find solutions for the face recognition shortcomings. Research in occlusions; such as glasses, hair, and head wear; have been researched, but are still being actively explored (Li S. Z., 2012).

2.6.1 Pose and Illumination

Face recognition can be on par with a fingerprint regarding performance within given controlled conditions (Phillips, et al., 2003). What stands as an obstacle is pose and illumination, which have become standardized through ISO/IEC frameworks (Gao, et al., 2007; ISO/IEC 19795-1:2006, 2006; ISO/IEC JTC 1/SC 37, 2010). Algorithms have been researched to provide geometric alignment between images being matched. Research done by Beymer showed evidence of 98% recognition rate on a database of 62 individuals with geometric alignment, consisting of 930 modeling views and 620 test views of varying poses (Beymer, 1994). Template based matching has already achieved success during Beymer’s research, to which Beymer extended to a multi-dimensional template matching model (Brunelli & Poggio, 1993). Poses ranged from -30°to 30° yaw and from -20° to 20° pitch. Beymer achieves success by taking a feature locating model to correlate with templates for the best match result. This method of feature selection and matching is similar to PCA by Turk & Pentland using eigenface as a matching algorithm for face recognition (Turk & Pentland, 1991).

The three-dimensional structure of the face creates shadows of varying intensity, which can accentuate or diminish face features used for matching. Shadowing is what leads to pose and illumination problems being analyzed in tandem, as both contribute to the direction and intensity of light impacting the face (Gross, et al., 2005). Shadowing variation from pose and illumination can cause a drop in face recognition performance. Adini, Moses, and Ullman (1997) conducted 107 different face matching operations, such as edge mapping and Gabor filtering, under illumination variance. Every operation missed and failed at least 20% of matching; missed being the system could not recognize and failed being the system confused one face for another (Adini, Moses, & Ullman, 1997). Adini, Moses, and Ullman's research would continue into Zhao and Chellappa's work on shape-from-shading algorithms for illumination invariance in face recognition (Zhao & Chellappa, 1999).

Despite the ongoing research for pose and illumination, there is still one aspect of photometry that lies at the root of pose and illumination variance. Lambertian reflectance, a property which gives an object a matte look, is assumed for face recognition systems (Zhao & Chellappa, 1999; Jacobs, Belhumeur, & Basri, 1998). Lambertian reflection of light off an object or face, the system perceives and treats the lighting conditions as equal through all components (Jacobs, Belhumeur, & Basri, 1998), or purposefully ignores certain shadows cast by facial features (Basri & Jacobs, 2005). We know this intuitively as not true, as the human vision system may receive the information similar to automated machine systems, the human perception can process metadata on the spatial dimensions of the face and adjust the recognition process accordingly (Patterson & Baddeley, 1977). Ergo pose and illumination can create variance on shadowing and reflectance, yet the machine system cannot adjust to a person's vision system.

2.6.2 Expression

Following on from Landis (1929) and Patterson and Baddeley (1977), the human vision system also can discern identity with expression. Expressions cause isometric deformation, which with a Lambertian reflectance input in face recognition, can cause problems for matching performance (Bronstein, Bronstein, & Kimmel, 2003). Isometric deformations created from expressions have a similar effect to pose and illumination on the face, being that it can create strong shadowing and illumination inequalities. Bronstein, Bronstein, and Kimmel (2003) utilized three-dimensional face recognition to achieve expression invariance for matching. The algorithm proposed by Kimmel allowed for the extraction of intrinsic geometric features and applied PCA type composition (Bronstein, Bronstein, & Kimmel, 2003). The results from Bronstein, Bronstein, and Kimmel (2003) showed that the three-dimensional models outperformed the traditional two-dimensional approach, but this still left to question the expression invariance of two-dimensional face recognition in common use.

The human visual system is robust to expressions as noted by Samal and Iyengar (1992), and it is proving quite challenging to incorporate this human robustness into machine-based recognition. Pose, illumination, and expression cause shadowing and reflectance variance that may trouble machine base recognition face recognition can still generate good performance with sufficient enrollments and template updating (Samal & Iyengar, 1992). Multiple inputs and repetitive visual contact on a face build familiarity, and it is even observed in the human visual system enhance performance (Samal & Iyengar, 1992; Patterson & Baddeley, 1977).

2.6.3 Aging

Aging creates complications for face recognition; as we age our bodies undergo a change which undoubtedly includes the face. The intra-class variations caused by aging is challenging for age invariance face models as it manifests itself differently across demographics (Park & Jain, 2005). Genders (Koehler, et al., 2006), ethnicities (Shirakabe, Suzuki, & Lam, 2003), different age groups (Sugata, et al., 2011), and even nutrition will change age manifestations (Cosgrove, et al., 2007); the derivative of the change magnitude is more dynamic than other variables.

Aging creates challenges for many face recognition applications such as missing children identification, law enforcement watch lists (Park & Jain, 2005), and image retrieval (Ling, Soatto, Ramanathan, & Jacobs, 2007). A study conducted by Ling et al. (2007), showed evidence that aging reduced face recognition performance where the age difference of enrollments is greater than four years. Ling et al. (2007) also tested face recognition using gradient orientation pyramid algorithms instead of the traditional Bayesian techniques and presented evidence of improvement by 0.1% EER. Park, Tong, and Jain (2010) also tested three dimensional age invariant face recognition and found that cumulative accuracy can increase by as much as 10%. Three-dimensional face recognition has the capability to compensate for aging (Park, Tong, & Jain, 2010), in a similar method to expression invariant modeling (Bronstein, Bronstein, & Kimmel, 2003). Though Park et al. and Ling et al. have both showed evidence of performance deterioration effects of aging in biometrics, the effects of illumination and expressions till surpass regarding effect magnitude (Park, Tong, & Jain, 2010).

2.6.4 Image Manipulation and Cosmetics

A growing concern for face recognition is image manipulation, both digitally and physically (ISO/IEC JTC 1/SC 37, 2015). Digital pre-processing have been studied before (Sang, Lei, & Li, 2009), and is a regular aspect of face recognition for improving image quality and performance (Gao, et al., 2007). Physical alterations such as cosmetic makeup and plastic surgery remains a challenge for researchers to investigate (ISO/IEC JTC 1/SC 37, 2015).

Figure 2.4: Subjectivity and variance of makeup across individuals (See Appendix C).

Scholarly investigation of cosmetic makeup is difficult due to its prevalence in certain demographics, its subjectivity in metrics, and its variance dependencies by individual users. Figure 2.4 shows six different individuals and their different applications of cosmetic makeup. Even the human visual system is affected by cosmetic makeup changes (Ueda & Koyama, 2010). Dantcheva et al.'s research showed evidence of increasing EERs with the addition of makeup across four datasets and three algorithms

(Dantcheva, Chen, & Ross, 2012). Guo, Wen, and Yan (2014) performed correlation mapping on makeup and no makeup faces using a local binary approach. It was concluded that makeup effects have variation in and of itself, where different components of makeup can vary the performance effect for a multitude of factors (Guo, Wen, & Yan, 2014). Among the two researchers the only definitive conclusions are eye makeup, such as eye shadow and mascara, have the greatest contributors of error and obfuscate identity the most (Dantcheva, Chen, & Ross, 2012; Guo, Wen, & Yan, 2014). Within Ueda & Koyama, Dantcheva et al., Guo et al., the discrepancy in metrics and factorization of makeup makes quantification of this subject difficult.

Cosmetic plastic surgery also stands as a similar challenge for face recognition (Singh, Vatsa, & Noore, 2009). Singh et al.'s preliminary findings show that face recognition cannot handle global facial plastic surgery like skin resurfacing and face lifts. Any change in one region can affect the performance overall, especially for texture based algorithms like LBP. Texture based algorithms yield lower accuracy for cases involving cheek and forehead changes. Surgeries like liposhaving or facial sculpting severely degrade performance of any algorithm, because it removes fat from facial regions and significantly changes appearance (Singh, Vatsa, & Noore, 2009). Overall, non-surgery dataset performed 30-35% better in identification accuracy than their surgery counterparts across six algorithms (Singh, et al., 2010). While the convention of PCA is performing with error rates lower than 10% in controlled settings (Gross, Baker, Matthews, & Kanade, 2005), plastic surgery can deteriorate this performance down to 30% EER (De Marsico, et al., 2011).

The subjectivity that affects cosmetic makeup is also apparent in plastic surgery. Plastic surgery creates changes in geometry and texture to varying magnitudes, ergo gathering pre- and post-surgery data is problematic (Singh, et al., 2010). Exacerbating the data problem is medical confidentiality; surgery data is secured under law, which adds an additional obstacle to the investigating (Singh, et al., 2010). Plastic surgery also shares a problem similar to aging, where repeat face captures will not enhance the system performance. This creates a special challenge different from the other uncontrollable settings; occlusion, pose, illumination and expression can be corrected and standardized (De Marsico, et al., 2011).

2.6.5 The Emerging Challenge of Scarring

Scarring is a normal function of mammalian tissue repair, optimized to heal wounds quickly under less sanitary conditions (Bayat, McGrouther, & Ferguson, 2003). There are three types of scarring: atrophic, hypertrophic, and keloid. Atrophic and keloid are less common compared to hypertrophic. Atrophic may occur as frequently as hypertrophic, but most often a result of acne (Alster & West, 1996). Keloid scarring is similar to hypertrophic scarring as they are a response to cutaneous injury, but the repair tissue grows beyond the confines of the original wound area (Tanriverdi-Akhisaroglu, Menderes, & Oktay, 2009). Keloid scarring is also not apparent in all humans, as it predominantly affects darker skinned ethnicities and between the ages of 10 to 30 years (Alster & West, 1996).

Scarring and facial marks have been used within biometrics as a soft form of feature detection (Jain & Park, 2009), which presents evidence that scarring may have an effect on performance and image quality. Face scarring can change the texture and color of the skin (Bayat, McGrouther, & Ferguson, 2003), both of which can affect face recognition algorithms as they are common factors analyzed in machine vision (Martinkauppi, Hadid, & Pietikäinen, 2005).

Color sensitivity is often interlinked with illumination problems. Machine vision algorithms used in face recognition aim to cancel out the effect of illuminant color and defining skin color as a function of reflectance (Martinkauppi, Hadid, & Pietikäinen, 2005). The human visual system still has the advantage over automated systems as the human eye and brain processes can associate light stimuli with context (Martinkauppi, Hadid, & Pietikäinen, 2005; Patterson & Baddeley, 1977; Proctor & Van Zandt, 2008).

The challenges of scarring in face recognition are multifaceted; color, illumination, texture, and metric variances create uncontrollable settings for face recognition operation. A universally accepted method of measurement for scarring has yet to emerge, as Alster & West noted that the Vancouver scar scale and the Manchester Scar Proforma are still widely used, but not interchangeable. Both scaling methods are dependent on observer subjectivity for calculating the characteristics of the scarring.

Table 2.1: An example of Vancouver scarring metrics (Draaijers, et al., 2004).

Vancouver Scar Scale			
1. Vascularity		2. Pigmentation	
Normal	0	Normal	0
Pink	1	Hypopigmentation	1
Red	2	Mixed	2
Purple	3	Hyperpigmentation	3
3. Pliability		4. Height	
Normal	0	Flat	0
Supple	1	<2mm	1
Yielding	2	2-5mm	2
Firm	3	>5mm	3
Ropes	4		
Contracture	5		

Table 2.1, there are quantifiable numbers associated with the characteristics of scarring metrics, but interpretations of these metrics are still subject to observer perspectives. The Vancouver scar scale still has the weakness of being qualitative in nature (Alster & West, 1996). Though converted to a numerical scale, the measurability is depended on human observation, things like surface texture and pliability may differ between observers. At best, the current scar scaling paradigm provides a description rather than a measurement of scarring, which suits its intention as a subjective evaluation of the effectiveness of scar therapies (Draaijers, et al., 2004).

2.7 The Face in Theater Arts

In both theater arts and biometrics, the face is identified and based on the measurement of various characteristics. In the theater concept of *Prosopon*, the Greek word for person/face/mask is a common theme where a mask or makeup is applied to the face to identify and give qualities to certain characters (Zeitlin, 1985). The three-dimensional dynamics and the relationship of lighting and shadow require makeup artists and theater technicians to design and develop solutions around a controlled environmental setting (Corson & Glavan, 2001), similar to biometric scientists. Makeup artists design around the face and environment to create certain effects; color hues, texture changes, and feature size.

The use of makeup could be used by biometric researchers to simulate changes to the face with hyper-realistic results (Corson & Glavan, 2001). The use of liquid latex for the simulation of scarring can provide face recognition systems with a way to uniformly assess scarring while controlling various natural factors. Liquid latex can be cast into a silicone mold (Corson & Glavan, 2001); scars that are identical in texture, size, topography, and reflectance can be constructed for a controlled study. Application to the face can be done with liquid latex, spirit gum, or Pros-Aide®, and would be secured on the face with realistic appearance (Corson & Glavan, 2001). Additional powdering and color blending can be done to create the realistic natural appearance, only noticeable on extreme sensitivity levels (Sartor & Pivovarnick, 2001). The use of liquid latex for both realistic and fantasy effects have been successfully implemented in film and media. Oscar winner Tami Lane used liquid latex techniques for her work in *Lord of the Rings*, *The Hobbit*, and *The Chronicles of Narnia: The Lion, the Witch, and the Wardrobe* for which she won her Academy Award for (Debreceni, 2013).

2.8 Literature Review Summary

This literature review summarized the current knowledge that was significant to the field of biometrics and the face as a modality of recognition. It reflects on the different face algorithms used by contemporary industry professionals and progresses made by researchers past and present. It also reflects on the significance of image quality as a factor to recognition system quality and health. Performance metrics and methodologies, both historical and au courant, are exhibited. Finally, the challenges of face recognition are conferred and how the inclusion of fine arts could provide innovative solutions. By assimilating the current research and conclusions, there is context and justification for this research. Furthermore, this literature review conveys how this research on scarring effects is salient to the current knowledge base.

CHAPTER 3. METHODOLOGY

This chapter gives an overview of the different procedures for this research. Sequential details of data collection and statistical analysis methods will be elaborated.

3.1 Data Collection

The first half of this research was the data collection procedure. The data collection was comprised of three parts: participants and recruitment, subject characteristics recording, and face image capture.

3.1.1 Participants & Recruitment

Test subjects were recruited for this research. A total of 60 test subjects were recruited through self-selection, volunteer efforts, or through advertising response. A group of 30 test subjects had no facial scarring, and the second group of 30 had preexisting. The second group with preexisting facial scarring supplements the data collection with scarring from a wild and uncontrolled source. As scarring develops differently between individuals (Bayat, McGrouther, & Ferguson, 2003), an absolute controlled dataset will have a little inference to the population.

3.1.2 Subject Characteristics

Subject demographics were recorded at the beginning of each subject data capture. The four demographics recorded are age, race, ethnicity, and gender

3.1.3 Face Image Capture

The last part of the data collection was the face image capture. The face capture adhered to standards set by ISO/IEC JTC SC 37 in the 3rd FDC for 19794-5. Each subject had three baseline face images captured, and then three face images with prosthetic scarring makeup applied. This was done in two environments, a controlled studio and a mock booth simulating the operational environment. For subjects with facial scarring, no prosthetic makeup will be needed.

3.1.3.1 Prosthetic Scar

The prosthetic makeup scar was made of simple latex construction. For the purpose of uniformity and universality, the scars were cast in the same linear hypertrophic mold. The scars were made by applying liquid latex to a silicone mold. The liquid latex dried and develops a solid yet soft flesh like texture. When dried, the latex scar is ready for application to the face (See Appendix A).

For sanitation and health purposes, each molded scar was considered disposable, and discarded after use with a single subject. For allergen and dermatological sensitivity purposes, subjects were asked if they have latex allergies. Two options of bonding agents are offered to subjects: liquid latex as the typical adhesive, or hypoallergenic Pros-Aide® adhesive (See Appendix B).

As scarring manifestations are subject to many factors, this study only analyzed scarring in a yes or no Boolean scheme. For uniformity, all latex scars were directly applied to the subject’s left cheek. This set scar location was chosen for being rich in face features (Ding & Wang, 2005). Face feature points are as shown in Figure 3.1. Since the subject was not required to remain expressionless for long periods of time, the risk of the prosthetic scar falling off was low.

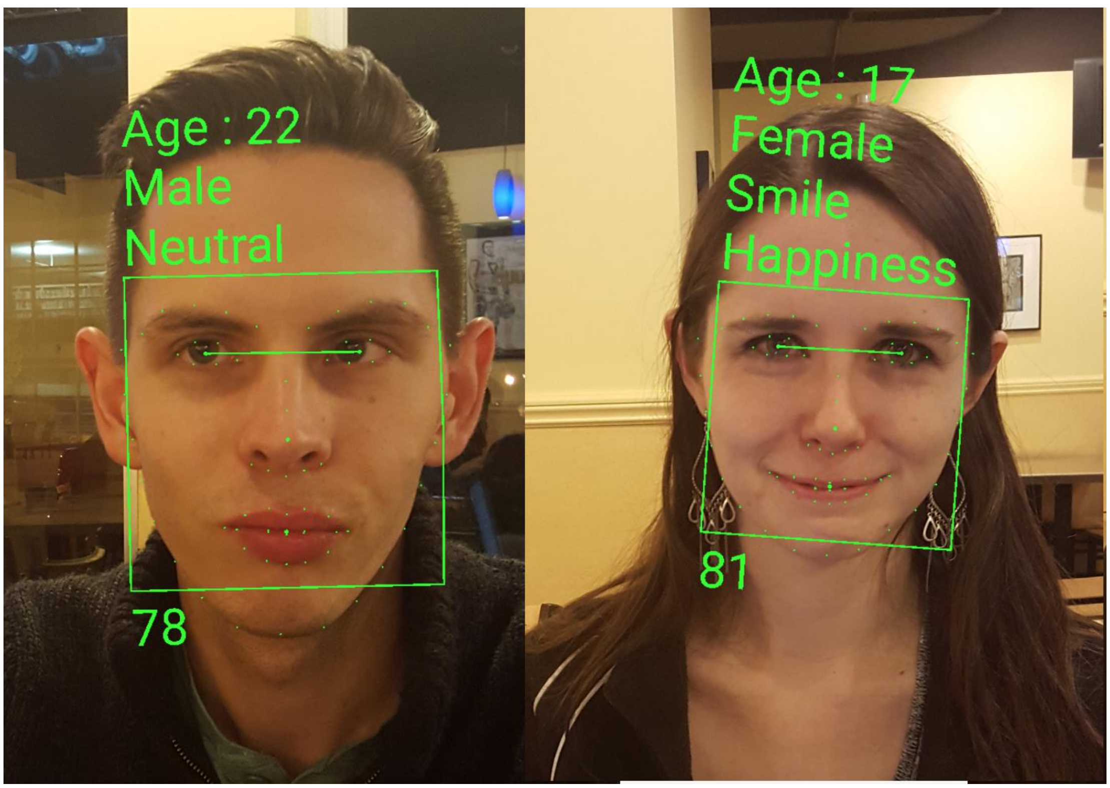

Figure 3.1: Map of face features for biometric recognition (See Appendix C).

3.1.3.2 Standards for Face Image Capture

Outlined are imperative specifications for an ISO/IEC JTC SC 37 compliant face image capture (ISO/IEC JTC 1/SC 37, 2010):

- B.2.3 – Frontal pose off with head rotation not more than ±5° in any direction (roll, pitch, and yaw)
- B.2.4 – Neutral expression (non-smiling)
    - Not raised eyebrows, smiling, looking away, squinting, frowning
- B.2.6 – If normally wear glasses, then keep glasses on. Should be photographed without tint or and lighting artifacts (avoided by increasing angle between lighting for 45° or more)
- B.3.1.1 – Optimal human examination and permanent storage, preferred minimum of spatial sampling of full image of at least:
    - 240 pixels for head width
    - 120 pixels in between eye centers
    - Max width of 420 pixels and Max height of 525 pixels
- C.2.1.1 - Camera-to-subject distance within 1.2-2.5 meters
- C.2.1.3.1 – light source places 35° above line of sight of camera-to-subject, and 45° horizontally, reflector panels used to softly and uniformly reflect light onto subject

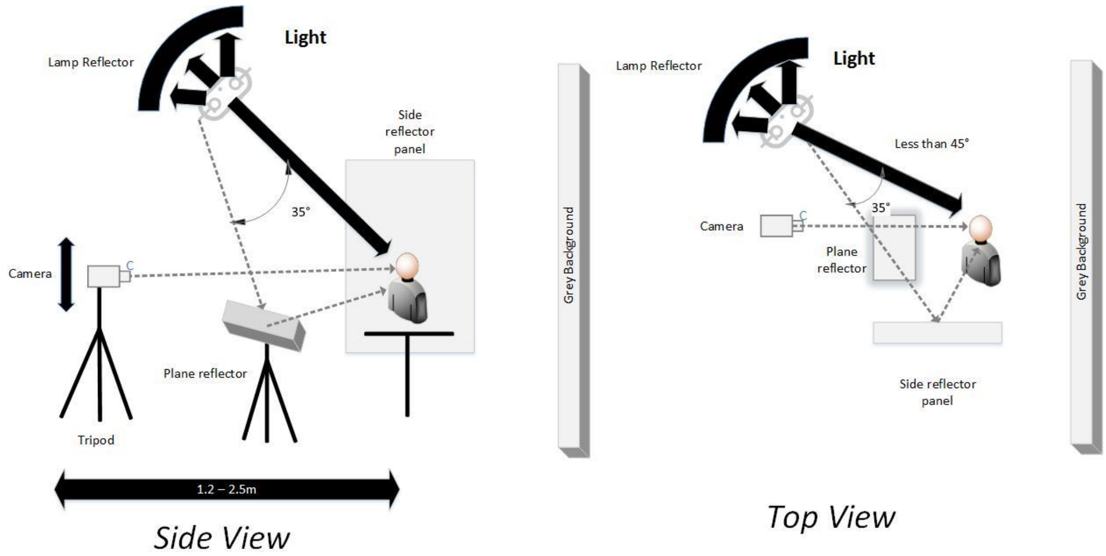

Figure 3.2: ISO/IEC JTC SC 37 compliant face image capturing arrangement (ISO/IEC JTC 1/SC 37, 2010)

3.1.4 Testing Procedure

The testing procedure followed the two sequences listed below. The first sequence was for the non-scarred subjects that participated in this study. The second sequence was for subjects that had preexisting face scarring before the time of the study.

3.1.4.1 Subjects Without Preexisting Scars

1. Subject entered the face data capturing studio and was be briefed by test administrator
2. Consent form was provided for subject to read and sign
3. Once the consent form was signed the test administrator saved it and recorded the subject's demographic information
4. Test administrator began video recording of the data capture session

5. Subject took a seat in front of the gray background, and the test administrator made any height and angle adjustments necessary to identify the Centerline Location using the iPhone wireless camera controller
6. Test administrator also adjusted the camera position within the 1.2 - 2.5m boundary to ensure 120 pixels between the subject's eyes
7. Subject removed any occlusions from the face (such as glasses or hair)
8. Test administrator captured three images of the subject's face
9. Test administrator applied a small amount of face powder for data capture preparations (pretreat the face for liquid latex application and negate specular reflectance)
10. Test administrator captured three images of the subject's face with face powder
11. Test administrator applied the prosthetic scar on the subject's left cheek with liquid latex adhesive and foundation blending (if needed)
12. Test administrator captured three images of the subject's face with a prosthetic scar
13. Subject moved to the mock border control booth and had three images captured with a prosthetic scar in a booth setting
14. Test administrator then removed the prosthetic scar and captured three additional baseline images in the booth environment
15. Test administrator recorded the subject's participation in the human subject log and asked the subject for one last signature
16. Once the subject signs the human subject log, the subject was paid for their participation a sum of $10 and exited the face image capture area

3.1.4.2 Subjects With Preexisting Scars

1. Subject entered the face data capturing studio and was be briefed by test administrator
2. Consent form was provided for subject to read and sign
3. Once the consent form is signed the test administrator saved it and recorded the subject's demographic information
4. Test administrator began video recording of the data capture session
5. Subject took a seat in front of the gray background, and the test administrator made any height and angle adjustments necessary
6. Test administrator also adjusted the camera position within the 1.2 - 2.5m boundary to ensure 120 pixels between the subject's eyes.
7. Subject removed any occlusions from the face (such as glasses or hair)
8. Test administrator captured three images of the subject's face
9. Test administrator applied a small amount of face powder
10. Test administrator captured three images of the subject's face
11. Subject moved to the mock border control booth and had three images captured in a booth setting
12. Test administrator recorded the subject's participation in the human subject log and asked the subject for one last signature
13. Once the subject signed the human subject log, the subject was paid for their participation a sum of $10 and exited the face image capture area

3.1.5 Equipment

Table 3.1: Equipment Density List outlines the equipment used for face image data collection and statistical analysis:

Table 3.1: Equipment Density List

Description	Type	Quantity
18% Gray ABS Plastic Background	Scenery	1
Canon PowerShot SX600 HS Digital Camera	Photographic	1
iPhone 5	Photographic	1
Logitech 920 Webcam	Photographic	1
Ben Nye Liquid Latex	Makeup	16 oz
MiniTab 17	Software	1
Windows 8.1 Enterprise	Software	1
Ben Nye Theatrical Crème Kit TK3	Makeup	1
Impact SP-UM Lighting System	Scenery	1
Plane deflector	Scenery	2
Microsoft Power BI	Software	1
Oxford Wave Research Bio-Metrics 1.5	Software	1
Megamatcher 9.0	Software	1
Aware PreFace 4.2	Software	1
VeriLook 8.0	Software	1

3.1.6 Confidentiality

Name and personal information of the subject were recorded for payment purposes. Subjects remained anonymous, and were identified throughout the research with an issued subject identification number. Subject demographic information was the only personal information used for statistical analysis. Other information such as contact phone number, full name, and email were not be used for research. All records were stored in a local database using secure cloud server. A consent form outlying the human subject confidentiality can be found in Appendix F.

3.1.7 Data Cleaning and Segregation

Upon completion of face image data collection, the data was cleaned and segregated for subsequent statistical analysis. The raw face image data was stored on the digital camera's SD card, and extracted into the database for segregation into two samples. Each subject's baseline and scarred image was stored in respective folders for sample type. For the mock booth, the data was stored on its local computer drive and manually transferred, as the booth camera will be the installed webcam.

3.2 Statistical Analysis

The second half of this research was the statistical analysis procedure. The statistical analysis was comprised of three main parts: image quality and performance output, image quality analysis of variance, and finally the zoo analysis.

3.2.1 Image Quality and Performance Output

Once the data collection was finished, and the data was cleaned and segregated, the datasets will be processed using PreFace 4.2 and Megamatcher 9.0. Preface outputted the image quality results in a spreadsheet under the ISO Frontal Best Practices face profile. The image quality will be recorded on an image by image basis before transference to an online database, and example is shown in Table 3.2. Megamatcher 9.0 will process the performance for the eight different datasets: baseline, powder, and prosthetic scarred; for both controlled studio and operational booth settings. Wild scarred faces as is and with some setting powder in both controlled studio and operational booth settings.

Table 3.2: Example of Image Quality information table

Setting	Scar	Image	EYE_SEP	EYE_SEP	EYE_AXI	EYE_AXI	EYE_AXI	EYE_AXI	CENTERI
Studio	No	Chan_Face_F_001_1_1.JPG	Ok	648.1111	Ok	-1.06091	Ok	0.542245	FailHigh
Studio	No	Chan_Face_F_001_1_2.JPG	Ok	685	Ok	0	Ok	0.550637	FailHigh
Studio	No	Chan_Face_F_001_1_3.JPG	Ok	666.1835	Ok	0.876882	Ok	0.542796	FailHigh
Studio	No	Chan_Face_F_002_1_1.JPG	Ok	687.0262	Ok	1.741611	FailLow	0.463226	FailHigh
Studio	No	Chan_Face_F_002_1_2.JPG	Ok	690.7757	Ok	1.856594	FailLow	0.472567	FailHigh
Studio	No	Chan_Face_F_002_1_3.JPG	Ok	673.2431	Ok	3.487413	FailLow	0.463767	FailHigh

3.2.1.1 DET Curves

Once performance results are outputted from Megamtcher 9.0, it was visually rendered through Oxford Wave Research Bio-Metrics 1.5. Oxford Wave generated DET curves to performance observation of FMR, FNMR, as well as the EER. Ten DET curves were generated and compared against each other; baseline with prosthetic scar in studio setting, baseline with prosthetic scar in booth setting, baseline and preexisting scar in studio setting, baseline and preexisting scar in booth setting, enroll on baseline and match on prosthetic scar in studio setting, and finally enroll on baseline and match on prosthetic scar in booth setting. Two additional DET curves were made to observe the performance of the face with setting powder applied, and provided supplementary data. Key performance indication points were 0.1, 0.01, and 0.001 FAR.

3.2.2 Analysis of Image Quality

The outputted measurements from Preface 4.2 will be processed through Microsoft Power BI. The various measurements will be graphed on their compliance with the ISO full frontal face image standards (ISO/IEC JTC 1/SC 37, 2010), as well as raw values statistically compared. Below is a diagram of measurements and coordinates that PreFace 4.2 will analyze, see Figure 3.3.

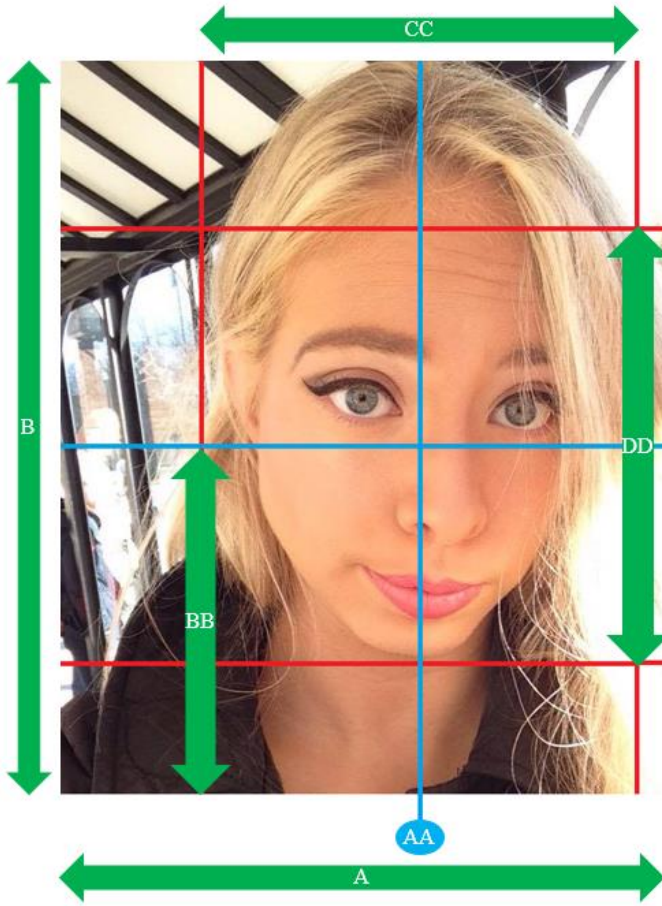

Figure 3.3: PreFace 4.2 output of face area and associated measurements analyzed.

PreFace 4.2 analyzed all face images captured during data collection and grade them along the ISO Frontal Best Practices profile. The profile consisted of the 23 out of 37 possible image quality metrics, listed in Appendix D (Aware, Inc., 2007). PreFace 4.2 outputted all 37 metrics in raw values, but only determined compliancy for the 23 pertinent metrics to ISO Frontal Best Practices.

A conventional two-sample t-test was performed using a significance level of $\alpha = 0.05$. This significance level was chosen out of conventional practice, as comparison of biometric image quality usually follows a simple Boolean compliant or incompliant dimension. Image quality does output in numeric values, ergo if we choose to deviate from the compliant incompliant dimension a common and traditional significance level would be appropriate (Ableson, 1995).

The t-test had one factor that separated the samples, presence of scarring. Scarring was measured in two levels, if it was or was not applied to the face during the face image capture. The two environments, the studio and the booth, were exclusively tested to ensure variance from one environment did not bleed over to the other. Equation 3.1 shows the statistical model for the image quality t-test.

$$H_0: n_{unscarred} = n_{scarred}$$

$$H_a: n_{unscarred} \neq n_{scarred} \qquad \text{(Equation 3.1)}$$

While

The same t-test statistical model from image quality shown in $Ha: n_{unscarred} \neq n_{scarred}$ (Equation 3.1 was applied to VeriLook. The age estimation from VeriLook was used to calculate age difference from the exact age that was reported by the subject. Then the age difference of each sample were compared via t-test to evaluate and compare age estimation with the effect of scarring.

The categorical comparison of gender estimation to the actual sex reported by the subject was evaluated with a Pearson's chi-squared good ness of fit test. The chi-squared allowed us to examine the frequency distributions of correct and incorrect gender estimations under the conditions of pre- and post-scarring.

3.2.3 Stability Analysis

The final statistical analysis was using Oxford Wave Research Bio-Metrics 1.5 to render the Zoo Menagerie on the two different datasets. This is done to supplement the performance results of the DET curves, as it added context and granularity to the different EERs. Zoo characteristics were connected to subject demographics information. Combining the information of the DET curves and Zoo Menageries highlighted where performance changes occur and what conditional causes for performance changes. The information from the matcher and the zoo plot were recorded, and example table is shown in Table 3.3.

Table 3.3: Matching and Zoo data recording

		Studio		Booth	
Subject ID	Powder	Before Scars	After Scars	Before Scars	After Scar
1	Doves	Normal	Doves	Normal	Normal
2	Normal	Doves	Normal	Normal	Doves
3	Normal	Normal	Normal	Normal	Normal
4	Normal	Phantoms	Normal	Normal	Phantoms
5	Normal	Normal	Phantoms	Normal	Normal

The two zoo analysis result outputs from Oxford Wave can then be compared to observe the stability of individual subject performance. Subject zoo characteristics can be evaluated between the baseline and scarred images, and will give direction to the subject movement. The magnitude of stability was calculated using the Stability Score Index, and used to determine the minimum and maximum of genuine and impostor distributions.

3.3 Methodology Summary

This chapter reviewed the data collection and statistical design utilized to carry out this research. It laid out the testing design and the materials needed for completing the data collection. Lastly, the statistical analysis and graphical summary methods are presented to evaluate the data collected.

CHAPTER 4. RESULTS

The results of this research were divided into the following sections: Subject Demographics, DET Performance Measurement, Image Quality, and finally Zoo Analysis.

4.1 Subject Demographics

Subject ethnicity was classified in two categories, Hispanic and Non-Hispanic. The subjects who participated in the data collection were predominantly Non-Hispanic, as seen in Figure 4.1. Among all 60 subjects only six were of Hispanic descent, and no racially Asian or Black subjects were of Hispanic descent.

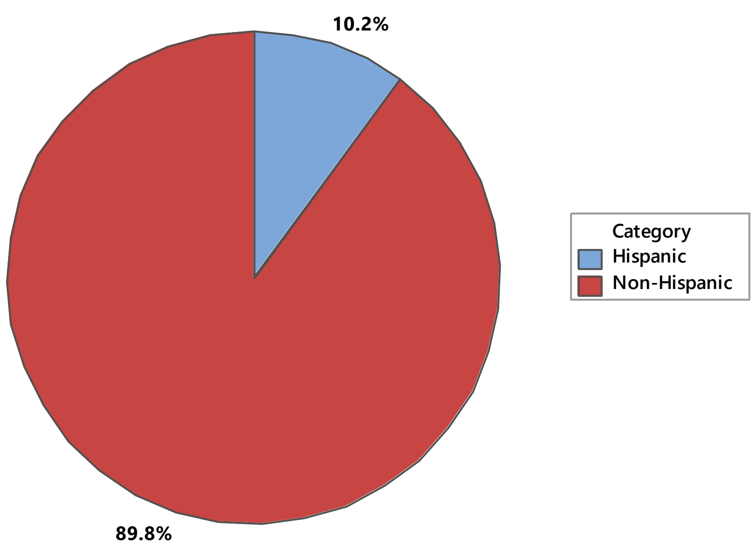

Figure 4.1: Pie Chart of Subject Ethnicity.

Subject racial characteristics were captured in six different categories. No American Indians or Alaskan Natives participated in this study, and no subjects that participated declined to report their race. The subjects that participated in this data collection were predominantly White, who also made up more than the other three racial categories combined.

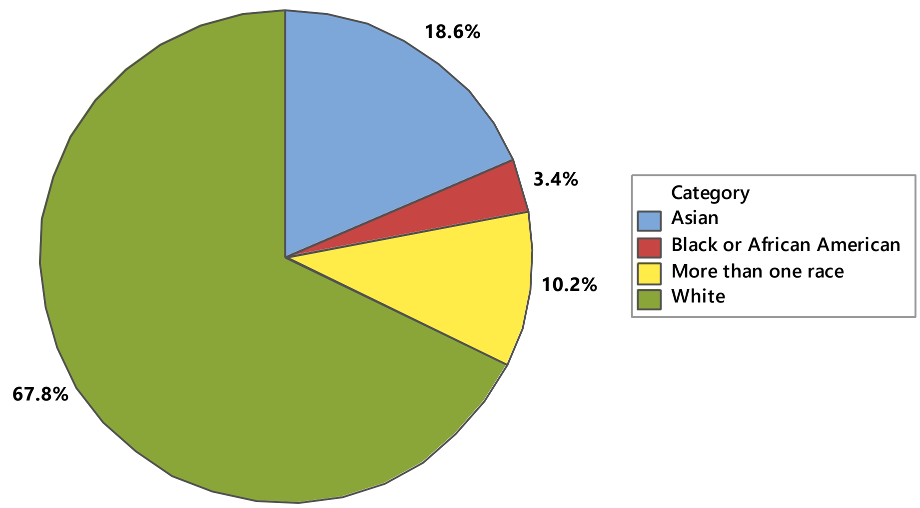

Figure 4.2: Pie Chart of Subject Race.

Subjects also had their biological sex recorded. There were three categories for sex, male and female, and also an option for not reported. The subjects that participated in this data collection were mostly female, but only by a slight majority, as shown in Figure 4.3. No subjects that participated declined to report their sex.

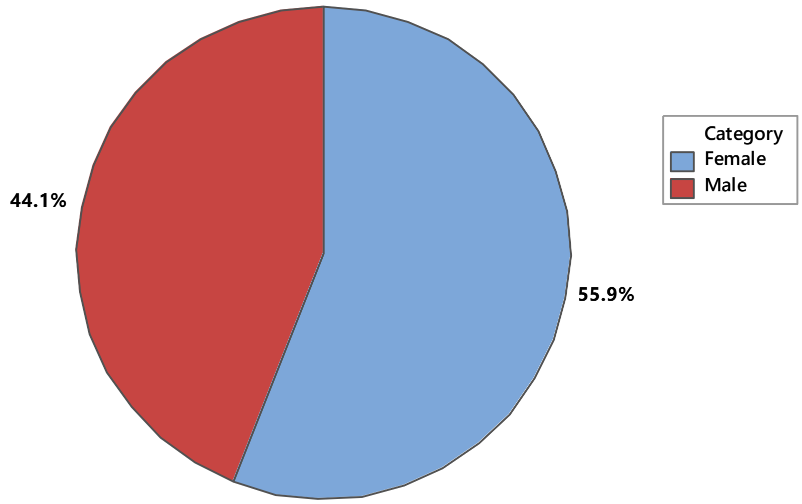

Figure 4.3: Pie Chart of Subject Sex.

Subjects that participated in this data collection were mostly in their early twenties. As with any human subject data collection, the histogram of age is skewed to the left, as shown in Figure 4.4. This was due to the stipulation that only subjects eighteen or older can legally consent for human subject research.

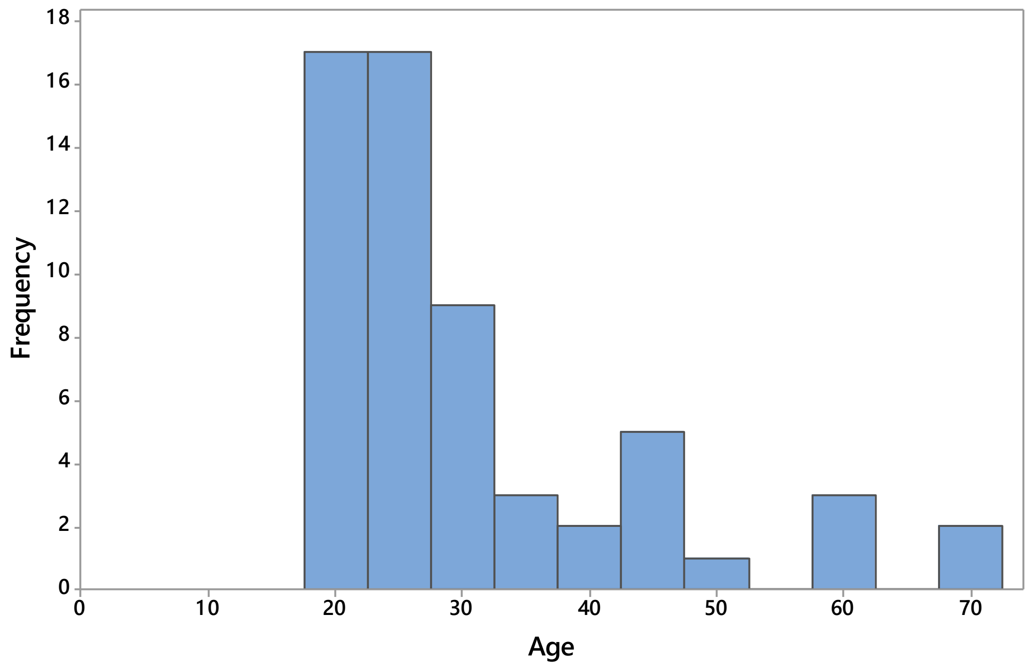

Figure 4.4: Histogram of Subject Age

Half of the subjects who participated in this study had preexisting scars. The split between atrophic and hypertrophic scars is even, each accounting for half of the scars reported as shown in Figure 4.5.

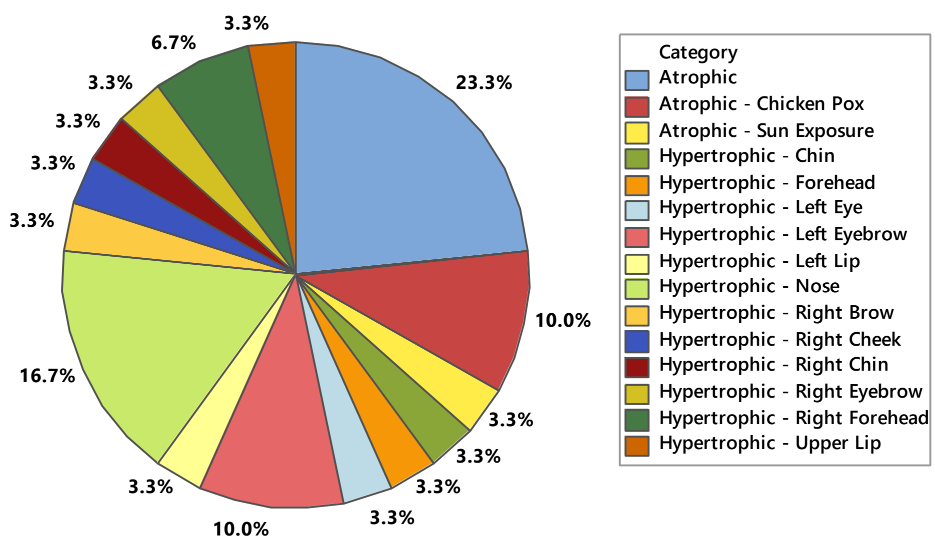

Figure 4.5: Pie Chart of Subject Scarring

For data transformation, the reported scarring is recorded with location details. It was interesting to note that atrophic scarring affects the face as a whole rather than specific areas.

4.2 DET Performance Measurement

Throughout the performance results, the data did not show any indications of poor performance. Table 4.1shows the EERs for both non-scar subjects and subjects with preexisting scars through the various data capture settings for this study. The data showed evidence that both unscarred and scarred individuals can achieve good performance in a face recognition system.

Table 4.1: Performance Summary

Scarring	Environment	EER	FRR		
			FAR=1	FAR=0.1	FAR=0.01
No	Studio	0.00%	0.00%	0.00%	0.00%
Yes	Studio	0.00%	0.00%	0.00%	0.00%
No	Powder	0.00%	0.00%	0.00%	0.00%
No	Booth	0.00%	0.00%	0.00%	0.00%
Yes	Booth	0.00%	0.00%	0.00%	0.00%
Preexisting	Studio	0.00%	0.00%	0.00%	0.00%
Preexisting	Powder	0.00%	0.00%	0.00%	0.00%
Preexisting	Booth	0.00%	0.00%	0.00%	0.00%
Non-Scar Enroll to Scar Match	Studio	0.00%	0.00%	0.00%	0.00%
Non-Scar Enroll to Scar Match	Booth	0.00%	0.00%	0.00%	0.00%

The performance of the same baseline but with the setting powder pretreatment can be seen under the rows designed with powder as the environment. This pretreatment was given to all subjects, non-scarred and scared, and was present for the duration of the data collection. There was no change in performance with the addition of the pretreatment.

Simulated scarring using theatrical methods and liquid latex showed equally good performance results. EERs were at 0.00% for both studio and booth environments. EER percentages are considered good the closer it is to zero (Dunstone & Yager, 2008; Schuckers, 2012). Table 4.1 shows good performance in before and after simulated scaring in studio, and equally good performance when the same subjects were captured using the booth environment.

The last section of Table 4.1 shows the performance of verifying a scarred image to an original non-scarred enrollment. This is operationally interesting due to the decade-long validity of passport enrollments. Within ten years, it is possible for individuals to develop scars, be it hypertrophic repair of trauma or atrophic developments from sun or disease recovery. These performance results show that the face recognition matching is still effective with changes from scarring.

4.3 Hypothesis Statements

Table 4.2: Statistical Hypothesis

Description	Statement	Subsectioı
Studio non scarred and scarred	$H_0: \mu_{no-scar} = \mu_{scar}$	4.4.1
Booth non scarred and scarred	$H_0: \mu_{no-scar} = \mu_{scar}$	4.4.2
Baseline and Powder	$H_0: \mu_{baseline} = \mu_{powder}$	4.4.3
Studio VeriLook Confidence	$H_0: \mu_{no-scar} = \mu_{scar}$	4.5.1
Booth VeriLook Confidence	$H_0: \mu_{no-scar} = \mu_{scar}$	4.5.2
Studio VeriLook Gender Accuracy	$H_0: \chi_{no-scar} = \chi_{scar}$	4.5.3
Booth VeriLook Gender Accuracy	$H_0: \chi_{no-scar} = \chi_{scar}$	4.5.4

In Table 4.2, the statistical comparisons are listed with the hypothesis model used. The subsection and cross references are also shown. Statistical analysis was used for both image quality and VeriLook estimation confidence and accuracy. The Student's t-test was used for comparing means across the function of scarring. The Chi-squared test was used to evaluate distribution association between gender estimation accuracy and the function of scarring.

4.4 Student's t-test of Image Quality

This section contains evaluations for the pre- and post-scarring t-test for both the studio and booth environments, with further details in subsections 4.4.1, 4.4.2, and 4.4.3. Table 4.3 summarizes the statistical analysis of all image quality metrics. Several metrics did not yield meaningful statistical conclusions because all images generated the same values. These were mostly dimensional and digital sizing metrics, as seen in Figure 4.6 where the two subjects feature equal dimensions. Ergo some metrics were not evaluated in depth.

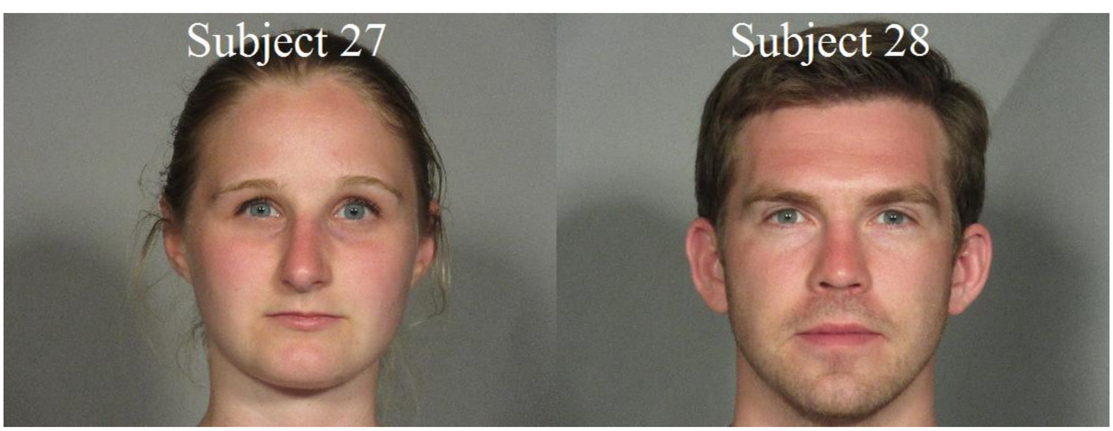

Figure 4.6: Image dimension consistency

Table 4.3: Image Quality Statistical Summary

Metric	Studio - Mean Value Baseline	Scar	P-Value	Booth - Mean Value Baseline	Scar	P-Value
EYE SEPARATION	787.70	799.90	0.33	181.23	176.90	0.39
EYE AXIS ANGLE	-0.15	0.39	0.55	1.00	0.41	0.15
EYE AXIS LOCATION RATIO	0.52	0.52	0.52	0.52	0.51	0.75
CENTERLINE LOCATION RATIO	0.52	0.52	0.01	0.50	0.50	0.52
IMAGE HEIGHT	3456.00	3456.00	*	1080.00	1080.00	*
IMAGE WIDTH	4608.00	4608.00	*	1920.00	1920.00	*
HEIGHT TO WIDTH RATIO	0.75	0.75	*	0.56	0.56	*
HEAD HEIGHT TO IMAGE HEIGHT RATIO	0.68	0.69	0.45	0.53	0.51	0.24
IMAGE WIDTH TO HEAD WIDTH RATIO	2.72	2.68	0.46	5.05	5.18	0.41
EYE CONTRAST	4.98	4.98	*	4.43	4.52	0.25
BRIGHTNESS SCORE	4.99	4.99	1.00	4.33	4.43	0.33
FACIAL DYNAMIC RANGE	7.64	7.63	0.89	7.66	7.68	0.62
PERCENT FACIAL BRIGHTNESS	57.28	57.30	0.94	43.21	43.74	0.66
PERCENT FACIAL SATURATION	0.00	0.00	*	0.00	0.00	*
PERCENT BACKGROUND GRAY	43.52	44.42	0.51	51.21	50.45	0.24
PERCENT BACKGROUND UNIFORMITY	97.12	96.82	0.08	71.51	81.50	0.05
BACKGROUND TYPE	1.03	1.14	0.01	1.93	1.94	0.76
DEGREE OF CLUTTER	0.10	0.31	0.04	2.47	2.13	0.22
DEGREE OF BLUR	0.17	0.07	0.16	0.02	0.01	0.56
SMILE	0.03	0.03	1.00	0.01	0.01	*
GLASSES	0.00	0.00	*	0.00	0.02	*
SMILE LIKELIHOOD	0.03	0.03	1.00	0.01	0.01	*
GLASSES LIKELIHOOD	0.00	0.00	*	0.00	0.03	*
POSE ANGLE	0.57	0.63	0.71	1.47	1.60	0.78
DEGREE OF POSE	0.00	0.00	*	0.04	0.07	0.52
IMAGE FORMAT	4.00	4.00	*	4.00	4.00	*
FILE SIZE	3806463.34	3794393.14	0.52	293704.10	296032.26	0.65
JPEG QUALITY LEVEL	-1.00	-1.00	*	-1.00	-1.00	*
J2K COMPRESSION RATIO	-1.00	-1.00	*	-1.00	-1.00	*
J2K ROI BACKGROUND COMPRESSION RATIO	-1.00	-1.00	*	-1.00	-1.00	*
J2K ROI FOREGROUND COMPRESSION RATIO	-1.00	-1.00	*	-1.00	-1.00	*
DESIRED BACKGROUND RGB RED	143.51	141.70	0.59	123.80	125.80	0.28
DESIRED BACKGROUND RGB GREEN	144.90	142.40	0.46	125.14	127.07	0.31
DESIRED BACKGROUND RGB BLUE	140.70	138.60	0.57	122.31	124.60	0.20
DESIRED BACKGROUND HSL HUE	93.70	90.70	0.69	111.59	112.88	0.94
DESIRED BACKGROUND HSL LIGHTNESS	56.01	55.14	0.53	48.44	49.27	0.24
DESIRED BACKGROUND HSL SATURATION	2.26	2.07	0.15	2.16	1.93	0.22
DESIRED BACKGROUND HSV HUE	93.70	90.70	0.69	111.59	112.88	0.94
DESIRED BACKGROUND HSV SATURATION	3.53	3.34	0.50	4.05	3.54	0.16
DESIRED BACKGROUND HSV VALUE	56.96	56.01	0.48	49.44	50.16	0.31
DEGREE OF LEFT EYE OBSTRUCTION	0.00	0.08	*	0.00	0.00	*
DEGREE OF RIGHT EYE OBSTRUCTION	0.00	0.00	*	0.00	0.00	*
DEGREE TO WHICH EYES ARE CLOSED	0.00	0.00	*	0.00	0.01	*
DEGREE OF ILLUMINATION ASYMMETRY	1.59	1.73	0.45	4.44	4.40	0.54

4.4.1 Studio non-scarred and scarred

This section evaluated the hypothesis of H_0: $\mu_{no-scar} = \mu_{scar}$ for the studio environment. Three metrics were found to have significant difference with the function of scarring. Centerline location ratio location of the centerline as a fraction of the image width measured from the left side of the image. Background type indicates simple or cluttered, with a 0 or 1 scoring system. Degree of clutter measures how much clutter occurs, with a scoring scale of 1 to 5. There was a significant difference in the centerline location ratio for pre- (M=0.52, SD=0.01) and post-scarring (M=0.52, SD=0.01); t(176)=2.53, p=0.01.

Figure 4.7: Centerline location ratio between pre- and post-scarring

As seen in Figure 4.7 and the mathematical means and standard deviations from the t-test, the centerline location ratio is very similar within the function of scarring. The central tendency for the centerline location value falls well beyond two decimal places, and requires impractical accuracy and precision. This reflected that the centerline location as a metric for image quality is viable, but can generate mathematical errors that may not reveal any practical difference between two images.

There was a significant difference in the background type for pre- (M=0.97.12, SD=0.69) and post-scarring (M=96.82, SD=1.47); t(126)=1.75, p=0.01. There was also a significant difference in the degree of clutter for pre- (M=0.10, SD=0.54) and post-scarring (M=0.31, SD=0.816); t(154)=-2.04, p=0.04

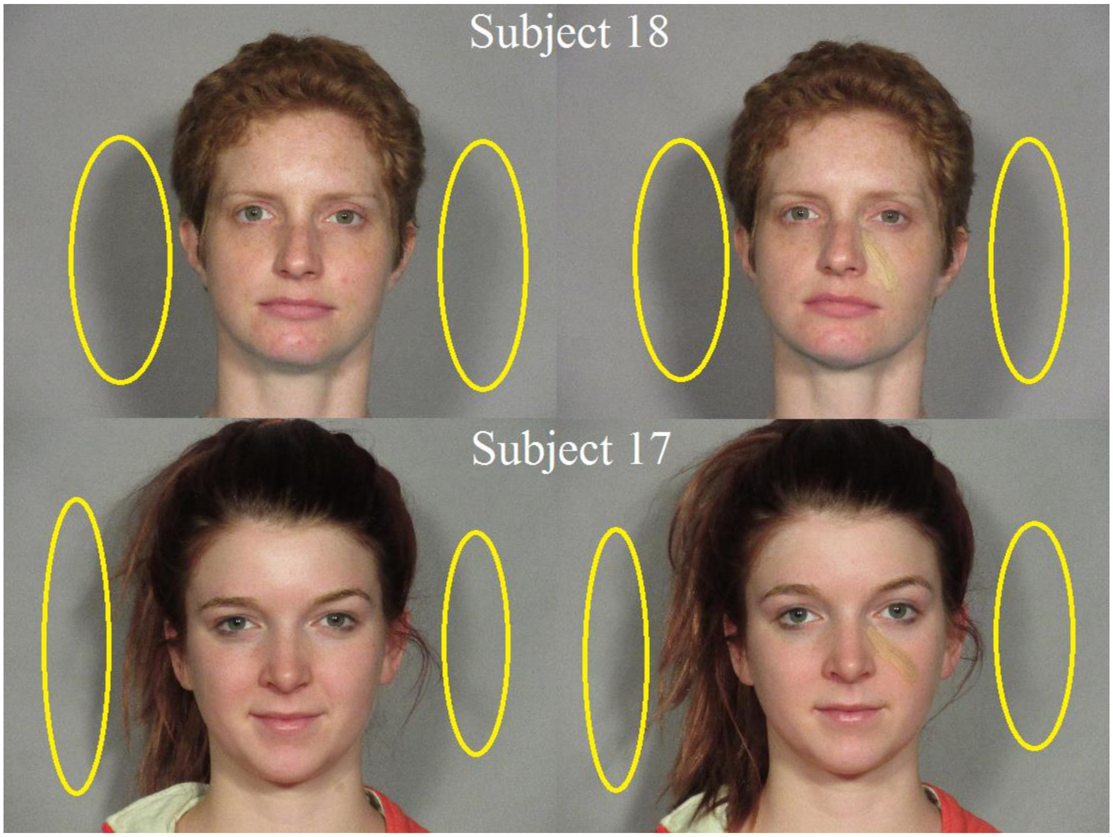

Figure 4.8: Background measurements between pre- and post-scarring

The results of the t-tests for background type and clutter are highlighted with Figure 4.8. There is visible difference between the pre- and post-scarring images, but more so between the two subjects. There is evidence that the degree of background changes are an artefact of the intra-subject variability. It can be seen with subject 18 that there is almost no change in shadowing in the background, but the natural hair movements from subject 17 creates more variability.

4.4.2 Booth non-scarred and scarred

This sections evaluated the hypothesis of H_0: $\mu_{no-scar} = \mu_{scar}$ within the booth environment. Only one metric resulted in significant difference with the function of scarring. Percent background uniformity reflects the variation of color throughout the background of the image as a percentage. For the booth environment, a significant difference appeared in the percent background uniformity for pre- (M=71.51, SD=38.5) and post-scarring (M=81.50, SD=29.1); t(165)=-1.97, p=0.05.

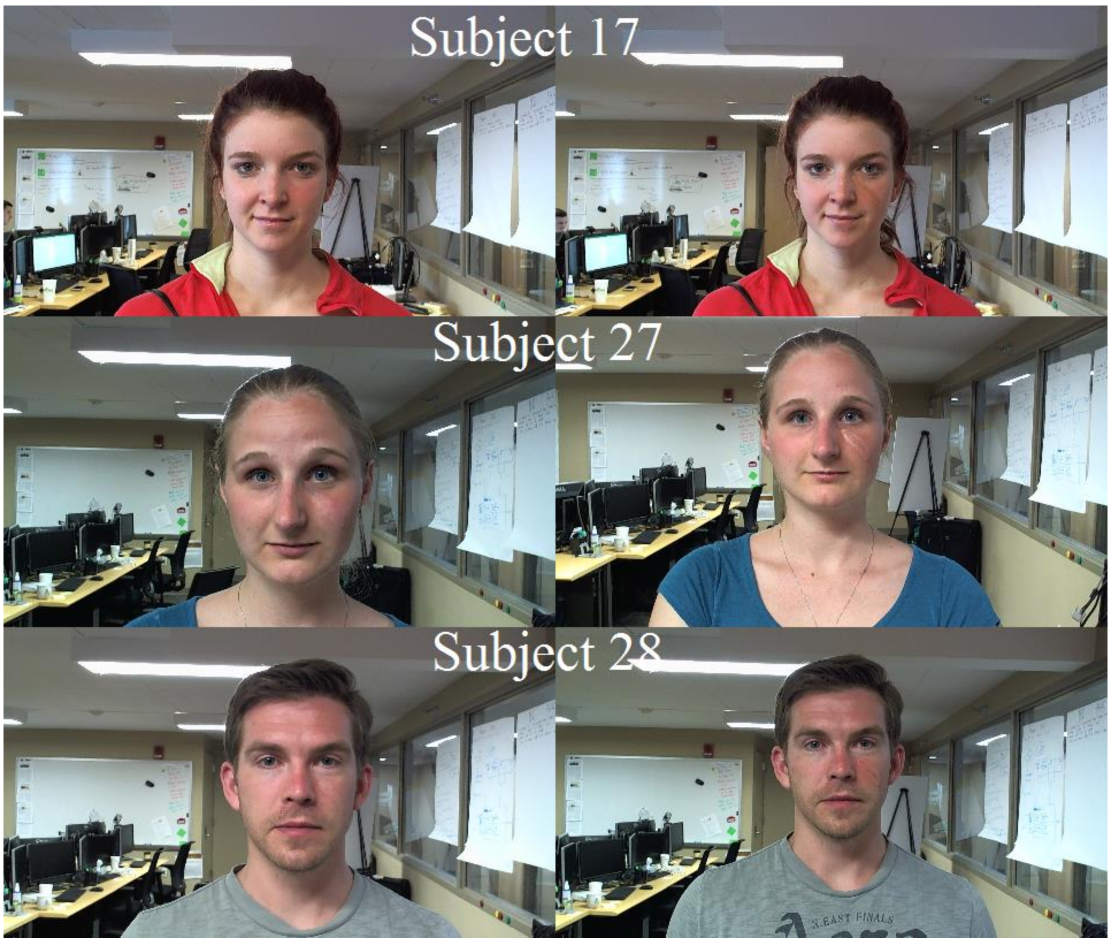

Figure 4.9: Background uniformity between pre- and post-scarring

The results of the t-test does show significant difference of background uniformity with the function of scarring, Figure 4.9 affirms the convention that variability is from intra-subject tendencies when engaged in an uncontrolled environment (Jain, Klare, & Park, 2011; Li & Jain, 2005). With only a unimodal reference point for users to engage, the Logitech Webcam, there is little reference for users to guide their interface with the system. Subsequently, the capture operations may diminish in consistency of capture angle and distance. Though the distance and angle tolerance provided by ISO standards are adequate, 35° above line of sight with 1.2-2.5 meters distance from user, this is set for a controlled studio environment. With the uncontrolled nature of the operation environments such as the booth the tolerance allowed by the ISO standard created more variation in the booth than the studio, ergo another set of standards for the booth would be appropriate.

4.4.3 Baseline and Powder

This section evaluated the hypothesis of $H_0: \mu_{baseline} = \mu_{powder}$, to examine the function of the pretreatment powder.The same statistical methods used in for the function of scarring was also used for the function of setting powder. The pretreatment effects were measured to ensue metric values were consistent for basis of data collection uniformity. In Table 4.4 show the t-test results for the pretreatment; all results were done within the studio environment.

Table 4.4: Image Quality Statistical Summary for Pretreatment

Metric	Non-Scarred - Mean Value			Preexisting Scarred - Mean Value		
	Baseline	Powder	P-Value	Baseline	Powder	P-Value
EYE SEPARATION	787.70	799.80	0.32	806.60	808.20	0.90
EYE AXIS ANGLE	-0.15	-0.04	0.79	-0.56	-0.24	4.37
EYE AXIS LOCATION RATIO	0.52	0.52	0.92	0.52	0.52	0.54
CENTERLINE LOCATION RATIO	0.52	0.52	0.97	0.52	0.53	0.61
IMAGE HEIGHT	3456.00	3456.00	*	3456.00	3456.00	*
IMAGE WIDTH	4608.00	4608.00	*	4608.00	4608.00	*
HEIGHT TO WIDTH RATIO	0.75	0.75	*	0.75	0.75	*
HEAD HEIGHT TO IMAGE HEIGHT RATIO	0.68	0.68	0.67	0.68	0.68	0.98
IMAGE WIDTH TO HEAD WIDTH RATIO	2.72	2.68	0.41	2.66	2.65	0.95
EYE CONTRAST	4.98	4.98	*	4.93	4.91	0.58
BRIGHTNESS SCORE	4.99	4.99	1.00	4.98	4.98	1.00
FACIAL DYNAMIC RANGE	7.64	7.61	0.15	7.61	7.60	0.50
PERCENT FACIAL BRIGHTNESS	57.28	56.94	0.25	54.76	54.74	0.97
PERCENT FACIAL SATURATION	0.00	0.00	*	0.00	0.00	0.57
PERCENT BACKGROUND GRAY	43.52	44.44	0.50	41.10	40.80	0.82
PERCENT BACKGROUND UNIFORMITY	97.12	96.97	0.30	96.94	97.15	0.29
BACKGROUND TYPE	1.03	1.07	0.31	1.09	1.06	0.39
DEGREE OF CLUTTER	0.10	0.17	0.47	0.24	0.13	0.28
DEGREE OF BLUR	0.17	0.11	0.46	0.20	0.21	0.89
SMILE	0.03	0.03	1.00	0.00	0.00	*
GLASSES	0.00	0.00	*	0.00	0.00	*
SMILE LIKELIHOOD	0.03	0.03	1.00	0.00	0.00	*
GLASSES LIKELIHOOD	0.00	0.00	*	0.00	0.00	*
POSE ANGLE	0.57	0.67	0.53	0.75	0.49	0.14
DEGREE OF POSE	0.00	0.00	*	0.00	0.00	*
IMAGE FORMAT	4.00	4.00	*	4.00	4.00	*
FILE SIZE	3806463.34	3813485.00	0.69	3834841.00	3832956.00	0.92
JPEG QUALITY LEVEL	-1.00	-1.00	*	-1.00	-1.00	*
J2K COMPRESSION RATIO	-1.00	-1.00	*	-1.00	-1.00	*
J2K ROI BACKGROUND COMPRESSION RATIO	-1.00	-1.00	*	-1.00	-1.00	*
J2K ROI FOREGROUND COMPRESSION RATIO	-1.00	-1.00	*	-1.00	-1.00	*
DESIRED BACKGROUND RGB RED	143.51	141.40	0.53	149.60	150.50	0.82
DESIRED BACKGROUND RGB GREEN	144.90	142.50	0.48	150.90	151.80	0.81
DESIRED BACKGROUND RGB BLUE	140.70	138.30	0.51	148.30	147.50	0.87
DESIRED BACKGROUND HSL HUE	93.70	92.90	0.92	112.50	110.80	0.86
DESIRED BACKGROUND HSL LIGHTNESS	56.01	55.07	0.50	58.55	58.80	0.83
DESIRED BACKGROUND HSL SATURATION	2.26	2.30	0.80	2.50	2.47	0.85
DESIRED BACKGROUND HSV HUE	93.70	92.90	0.92	112.50	110.80	0.86
DESIRED BACKGROUND HSV SATURATION	3.53	3.66	0.66	3.55	3.52	0.94
DESIRED BACKGROUND HSV VALUE	56.96	56.03	0.50	59.40	59.80	0.83
DEGREE OF LEFT EYE OBSTRUCTION	0.00	0.00	*	0.00	0.00	*
DEGREE OF RIGHT EYE OBSTRUCTION	0.00	0.00	*	0.00	0.00	*
DEGREE TO WHICH EYES ARE CLOSED	0.00	0.00	*	0.00	0.00	*
DEGREE OF ILLUMINATION ASYMMETRY	1.59	1.52	0.74	1.68	1.23	0.01

The pretreatment only showed significant difference in one metric for preexisting scarred subjects, the degree of illumination asymmetry, see Table 4.4. The degree of illumination asymmetry represents the extent to which the illumination of the image is not symmetrical with a score from 0 to 5. A significant difference appeared in the degree of illumination asymmetry for the preexisting scarred baseline (M=1.68, SD=1.21) and the pretreatment (M=1.23, SD=1.08); t(175)=-2.60, p=0.01.

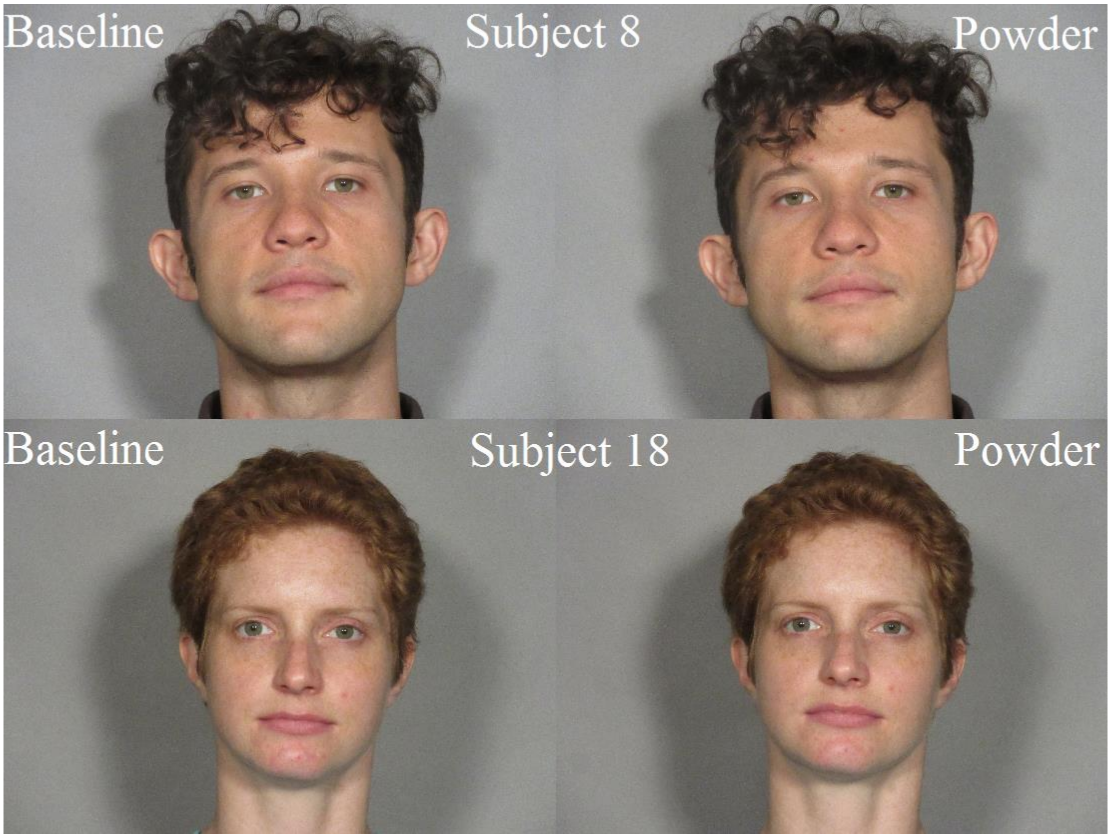

Figure 4.10: Asymmetry of illumination between baseline and pretreatment powder

This t-test report of asymmetric illumination reveals practical impacts that did not appear in other metrics, such as brightness score and percent facial brightness. It can be seen in Figure 4.10 that there is visible changes between the baseline and the pretreatment powder. Baseline faces have more specular reflectance, noticeably in highlight areas such as the nose inflection points of the nasal labial folds, the chin, and the forehead. After the pretreatment, the powder diminishes this specular reflectance, and the overall face is mattified with uniform illumination, concurring with the value means gathered. This discovery has direct impact on the adaptability of image capture, in any environment, as cosmetic powder has common use.

4.5 VeriLook 8.0 Estimation Results

The confidence scores from VeriLook 8.0 were analyzed with MiniTab 17. A two-sample t-test was conducted to compare confidence scores in pre- and post-scarring, and a Pearson's chi-squared goodness of fit test was done to evaluate correct and incorrect estimations of gender. Table 4.5 summarizes the t-test results for confidence scores.

Table 4.5: VeriLook t-test Summery

	Studio - Mean of Confidence Score			Booth - Mean of Confidence Score		
Estimation	Before Scars	After Scars	P-Value	Before Scars	After Scars	P-Value
Gender	62.10	63.80	0.82	62.70	60.74	0.69
Expression	53.80	58.00	0.09	58.60	57.50	0.63
Blink	99.26	98.78	0.50	95.40	96.30	0.62
Mouth Open	71.50	84.20	0.03	70.50	72.20	0.70
Glasses	43.00	63.30	0.01	48.90	53.40	0.60
Dark Glasses	64.60	60.70	0.03	72.50	71.30	0.57
Quality	78.89	78.76	0.85	73.99	73.96	0.97
Age Error	3.98	4.53	0.27	4.82	5.23	0.45

4.5.1 Studio VeriLook Confidence

This section evaluated the hypothesis of $H_0: \mu_{no-scar} = \mu_{scar}$ for VeriLook confidence within the studio. The data shows evidence that scarring in studio environment has a significant impact on estimation confidence for whether or not the mouth is open, glasses and dark glasses presence. Nevertheless, we see that the booth environment generates lower confidence in estimation, so it not to say that the studio performs worse. There is evidence that accents that the booth environment performs poorly in general, ergo significant difference is not present.

Mouth open, glasses, and dark glasses fall within the feature points located on the face for extraction and matching. The data shows evidence that scarring has a significant impact on the local feature points where the scar makes contact with. There was a significant difference in the confidence scores for whether or not the mouth was open for pre- (M=71.50, SD=31.90) and post-scarring (M=84.20, SD=43.6); t(163)=-2.22, p=0.03. There was a significant difference in the confidence scores for glasses present on the face for pre- (M=43.00, SD=37.30) and post-scarring (M=63.30, SD=66.6); t(139)=-2.52, p=0.01. There was also a significant difference in the confidence scores for dark glasses present on the face for pre- (M=64.60, SD=12.5) and post-scarring (M=60.7, SD=12.2); t(177)=2.15, p=0.03.

4.5.2 Booth VeriLook Confidence

This section evaluated the hypothesis of H_0: $\mu_{no-scar} = \mu_{scar}$ for confidence within the booth environment. In Table 4.5 it is shown that only the studio environment presents statistically significant difference in select estimations with a function of scarring. Though there are not statistically significant differences reported in the t-tests for the booth environment there are lower mean values for confidence. The studio environment showed higher blink estimation confidence values for non-scarred (M=98.79, SD=4.95) and scarred (M=99.26, SD=4.27) compared to the booth non-scarred (M=96.3, SD=11.40) and scarred (M=95.40, SD=12.70). Whether the mouth is open or not, the studio showed higher confidence values for non-scarred (M=84.20, SD=43.60) and scarred (71.50, SD=31.90) than the booth non-scarred (M=12.20, SD=27.00) and scarred (M=70.5, SD=32.60). Overall VeriLook quality assessment taken into consideration, studio images were rated higher with non-scarred (M=78.76, SD=4.83) and scarred (M=78.89, SD=4.67) compared to the booth non-scarred (M=73.96, SD=6.22) and scarred (M=73.99, SD=5.34). It is evident while the booth presented no significant changes over the function of scarring, the confidence means were lower with the exception of dark glasses and expression, which showed that the confidence of VeriLook's system was lower overall in the booth compared to the studio.

4.5.3 Studio VeriLook Gender Accuracy

This section evaluated the hypothesis of H_0: $\chi_{no-scar} = \chi_{scar}$ for association from distribution in the studio. A Pearson's chi-squared test was done to evaluate the frequency distributions of the correct and incorrect gender estimations under pre- and post-scarring. Cognate to the t-tests performed, the chi-squared was also done for the studio and booth exclusively. There was no significant relationship between pre and post-scarring and the accuracy of gender estimation for the studio, $\chi^2(1, n = 90) = 0.00, p = 1.00$. The data shows a lack of evidence that there was an association between correct gender estimation and the function of scarring within the studio environment.

4.5.4 Booth VeriLook Gender Accuracy

This section evaluated the hypothesis of H_0: $\chi_{no-scar} = \chi_{scar}$ for association from distribution in the booth. The booth shared similar non-association results as the studio, $\chi^2(1, n = 90) = 2.79, p = 0.09$. The data shows a lack of evidence that there is an association between correct gender estimation and the function of scarring within the operational booth environment.

4.6 Zoo Analysis

The zoo analysis provided a textured look at the performance data by plotting genuine and impostor scores within a plot. This allowed genuine and impostor distribution variations to manifest into visual movements along the zoo plot. Interquartile ranges for each genuine and impostor distribution was established for each zoo plot, which determined animal classifications based on their scoring characteristics. In Table 4.6, the zoo plots used for analysis are as listed.

Table 4.6: Zoo Plot Summary

Description	Plot	Subsection
Studio Non-Scarred	Baseline (1)	4.6.1
Studio Non-Scarred with Powder	Baseline (2)	4.6.1
Studio Non-Scarred with Prosthetic Scar	Baseline (3)	4.6.1
Booth Non-Scarred	Baseline (4)	4.6.1
Booth Non-Scarred with Prosthetic Scar	Baseline (5)	4.6.1
Studio Scarred	Preexisting (1)	4.6.2
Studio Scarred with Powder	Preexisting (2)	4.6.2
Booth Scarred	Preexisting (3)	4.6.2
Studio Pre-Scar Enroll to Post-Scar Verify	Interoperability (1)	4.6.4
Booth Pre-Scar Enroll to Post-Scar Verify	Interoperability (2)	4.6.4

4.6.1 Non-Scarred Subjects

Zoo analysis of the non-scarred subjects revealed classification movement of more than one-third of subjects. These movements were highlighted in Table 4.7. Among the eleven subjects that presented movement, only two showed movements among all settings, be it without or without scars in the studio or the booth.

Table 4.7: Zoo Movements of Non-Scarred Subjects

		Studio		Booth	
Subject ID	Powder	Before Scars	After Scars	Before Scars	After Scar
1	Doves	Normal	Doves	Normal	Normal
2	Normal	Doves	Normal	Normal	Doves
3	Normal	Normal	Normal	Normal	Normal
4	Normal	Phantoms	Normal	Normal	Phantoms
5	Normal	Normal	Phantoms	Normal	Normal
6	Normal	Normal	Normal	Normal	Normal
7	Normal	Normal	Normal	Normal	Normal
8	Normal	Normal	Normal	Normal	Normal
9	Normal	Normal	Normal	Normal	Normal
10	Normal	Normal	Normal	Normal	Normal
11	Normal	Normal	Doves	Normal	Normal
12	Normal	Normal	Normal	Normal	Worms
13	Worms	Worms	Worms	Worms	Worms
14	Normal	Normal	Normal	Normal	Normal
15	Normal	Normal	Normal	Normal	Normal
16	Normal	Worms	Normal	Normal	Normal
17	Normal	Normal	Normal	Normal	Normal
18	Normal	Normal	Normal	Normal	Normal
19	Normal	Normal	Normal	Chameleons	Chameleons
20	Worms	Worms	Worms	Worms	Normal
21	Doves	Phantoms	Normal	Normal	Normal
22	Normal	Normal	Normal	Normal	Normal
23	Phantoms	Normal	Normal	Normal	Normal
24	Normal	Normal	Normal	Normal	Normal
25	Normal	Normal	Normal	Normal	Normal
26	Normal	Normal	Normal	Normal	Normal
27	Phantoms	Phantoms	Phantoms	Normal	Normal
28	Normal	Normal	Normal	Normal	Normal
29	Normal	Normal	Normal	Normal	Normal
30	Normal	Normal	Normal	Phantoms	Normal

Table 4.7 showed the zoo animal classification for each of the non-scarred subjects. Subjects would sometimes move between animal classifications with the introduction of factors and covariates, which in this case is environmental setting and scarring.

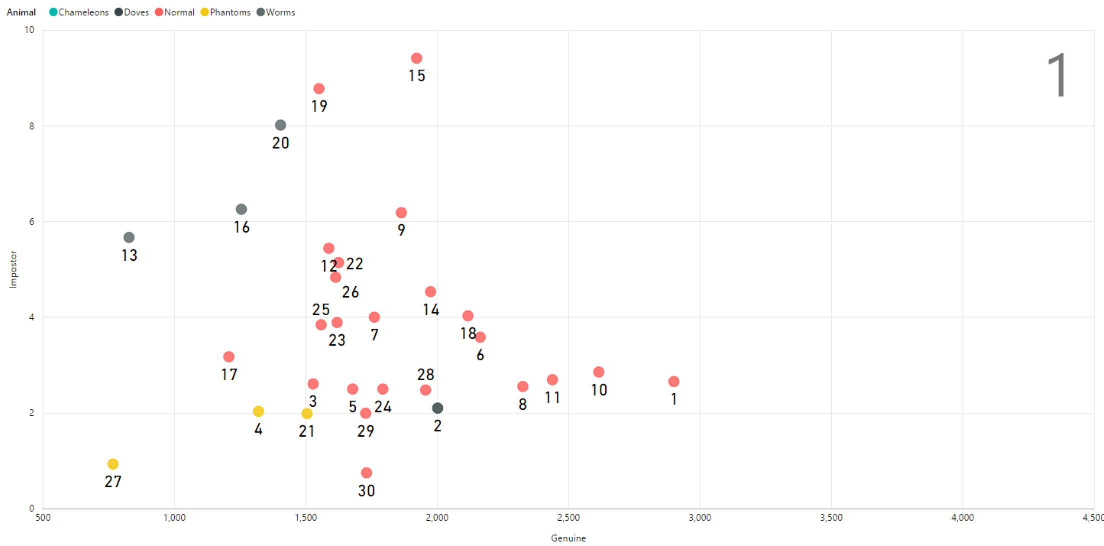

Figure 4.11: Zoo Plot of Studio Non-Scarred, Baseline (1)

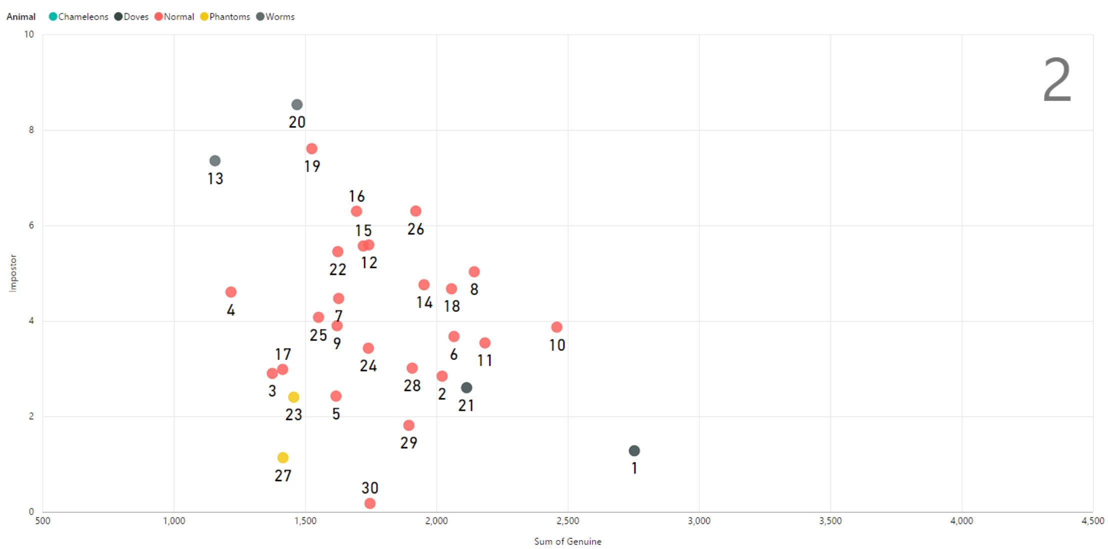

Figure 4.12: Zoo Plot of Studio Non-Scarred with Powder, Baseline (2)

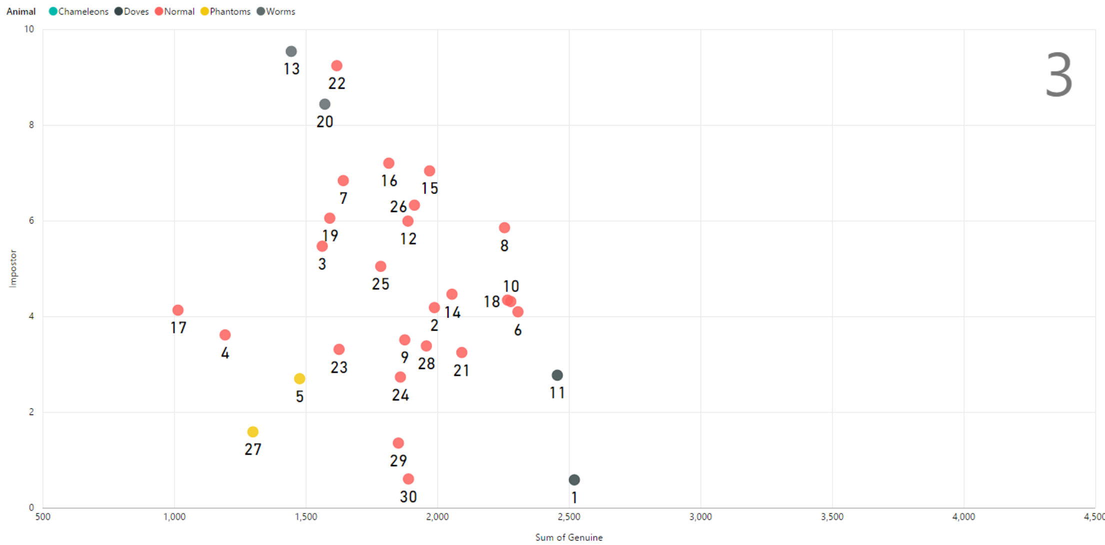

Figure 4.13: Zoo Plot of Studio Non-Scarred with Prosthetic Scar, Baseline (3)

Figure 4.11 is the zoo plot for the baseline face images. These are faces with no pretreatment and no preexisting scars. These face would later have prosthetic scars applied for a scar to no-scar comparison

Figure 4.12 is the zoo plot of the same subjects of Figure 4.11, but with the setting powder pretreatment in preparation for the application of liquid latex. The pretreatment does show evidence of subject movement, but the range of genuine and impostor scores remain similar. In Figure 4.16 the stability score results show that there is some movement of pre- and post-scarring. More interestingly there was also some instances where the pretreatment resulted in higher instability than the function of scarring.

Figure 4.13 displays the same subjects from Figure 4.11, but with prosthetic scars applied. Before, the baseline showed more centralized position in the lower left, indicating both low genuine and impostor score. When scars are applied, the subjects moved higher within the zoo plot, showing that impostor score moved when scarring was introduced.

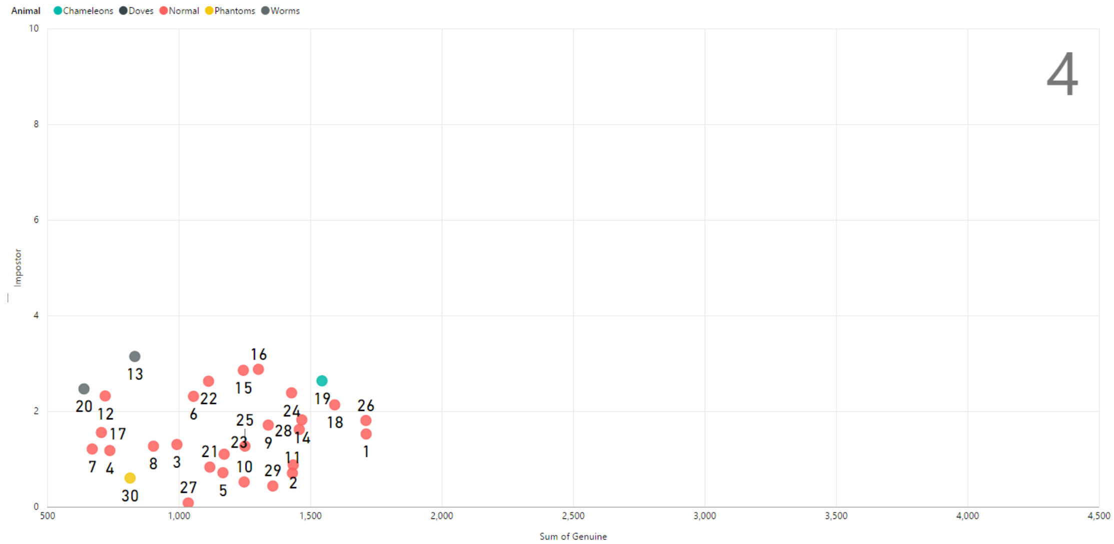

Figure 4.14: Zoo Plot of Booth Non-Scarred, Baseline (4).

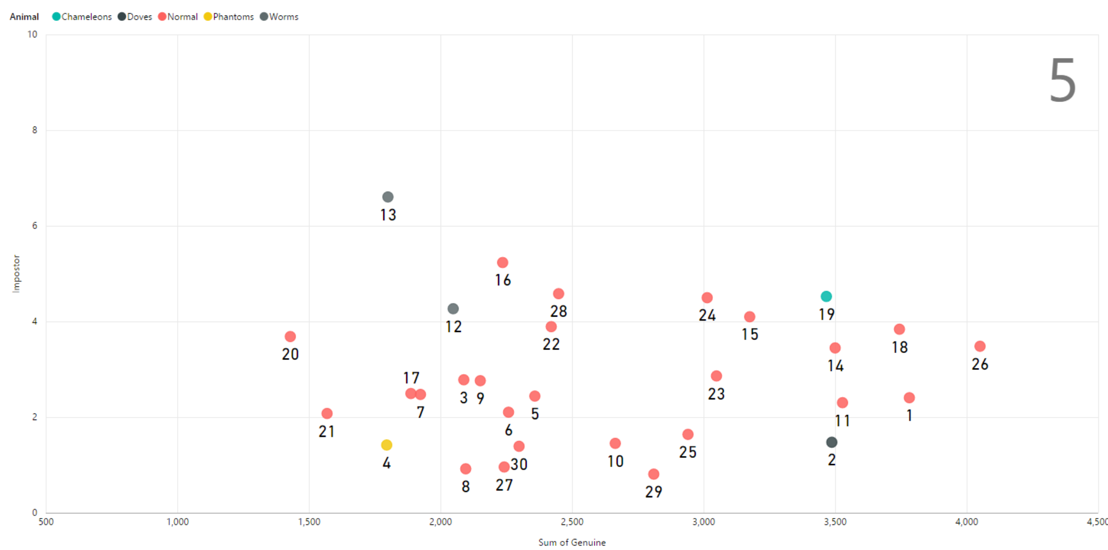

Figure 4.15: Zoo Plot of Booth Non-Scarred with Prosthetic Scar, Baseline (5)

The booth environment showed a decline in both genuine and impostor scores, and all subjects were closely clustered in the lower left corner of the zoo plot. Though the movement can be considered extreme in regards to the results in Figure 4.11 and Figure

4.13, the movement of Figure 4.14 does align with the results of Gross et al.'s (2005) previous work.

The zoo plots showed evidence that studio environments present less variance in genuine and impostor score distributions. Even though Table 4.7 only shows five subject movements in a booth environment, which is less than what was seen in the studio. As observed in Figure 4.14 and Figure 4.15, the entire sample shifted and the maximum genuine and impostor score increased, as well as the greater distance between subjects. In Figure 4.11 and Figure 4.13, it was noticed that the studio sample set central tendency shifted to a higher genuine and impostor score, but not as drastic as the sample booth set.

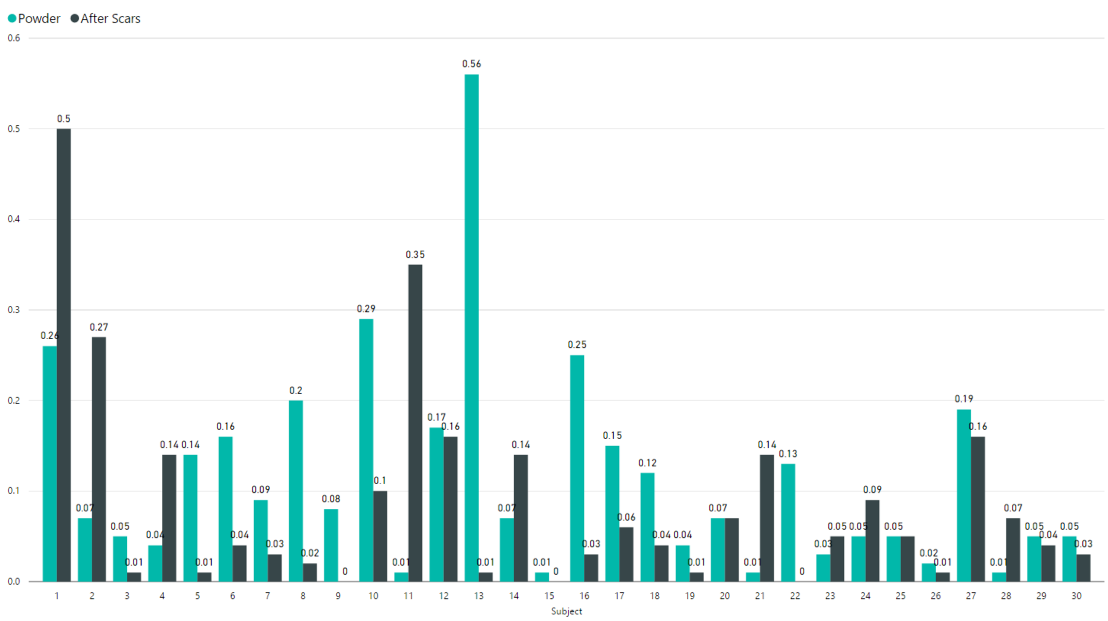

Figure 4.16: Stability scores for Pretreatment Powder and Scarring in the Studio.

The stability score of the subjects tested for scarring showed movement for the function of scarring as well as the pretreatment. Eighteen subjects, more than half of the sample, showed higher instances of instability in the pretreatment than the application of scarring. One subject, subject 22, showed no instability for scarring with a stability score of 0, but showed zoo distribution movement with the pretreatment with a stability score of 0.13. This can be seen in Figure 4.16.

4.6.2 Preexisting Scarred Subjects

Data on preexisting scars subjects was also plotted into zoo menageries to compare genuine and impostor scores distributions. These were completely different subjects, so a one on one comparison between factors were not done. Instead, a comparison between the same factors but with different subject samples was made.

Table 4.8: Zoo Movements of Scarred Subjects.

Subject ID	Powder	Studio	Booth
31	Normal	Normal	Normal
32	Normal	Worms	Normal
33	Normal	Normal	Phantoms
34	Normal	Normal	Normal
35	Normal	Normal	Normal
36	Worms	Worms	Worms
37	Normal	Doves	Normal
38	Normal	Normal	Normal
39	Phantoms	Normal	Worms
40	Normal	Doves	Doves
41	Worms	Worms	Normal
42	Doves	Normal	Normal
43	Normal	Normal	Normal
44	Normal	Normal	Normal
45	Doves	Doves	Normal
46	Normal	Normal	Normal
47	Normal	Normal	Normal
48	Normal	Normal	Normal
49	Normal	Normal	Normal
50	Normal	Normal	Normal
51	Worms	Normal	Normal
52	Normal	Normal	Normal
53	Normal	Normal	Worms
54	Normal	Normal	Normal
55	Chameleons	Chameleons	Normal
56	Chameleons	Normal	Normal
57	Normal	Doves	Normal
58	Normal	Normal	Normal
59	Normal	Phantoms	Phantoms
60	Normal	Normal	Normal

Table 4.8 shows a greater amount of subject movement from subjects who have developed scarring. Thirteen of those who came into the data collection with their scars moved animal classifications, opposed to the eleven on non-scarred subjects who simulated scars.

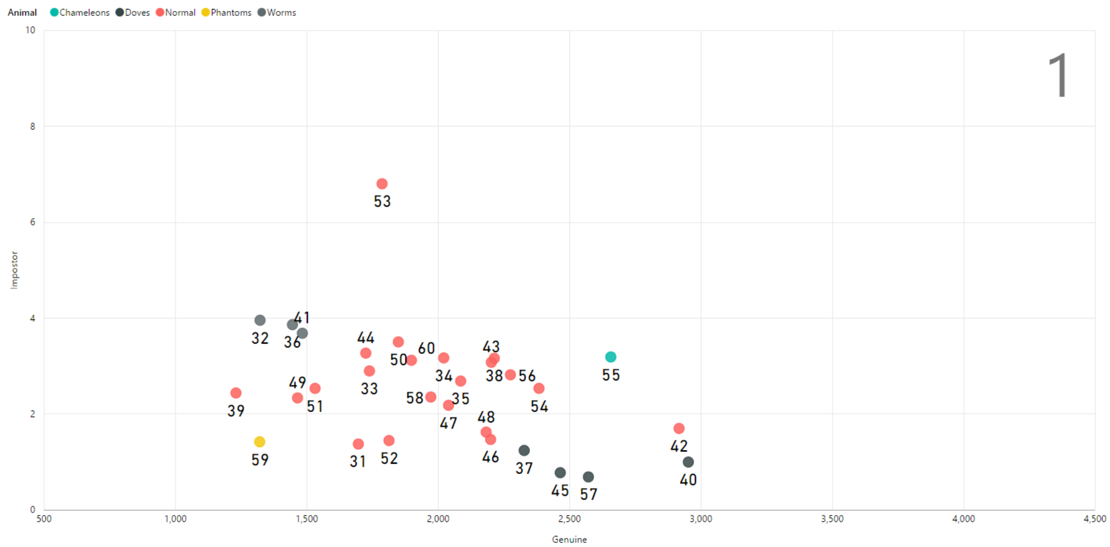

Figure 4.17: Zoo Plot of Studio Scarred, Preexisting (1).

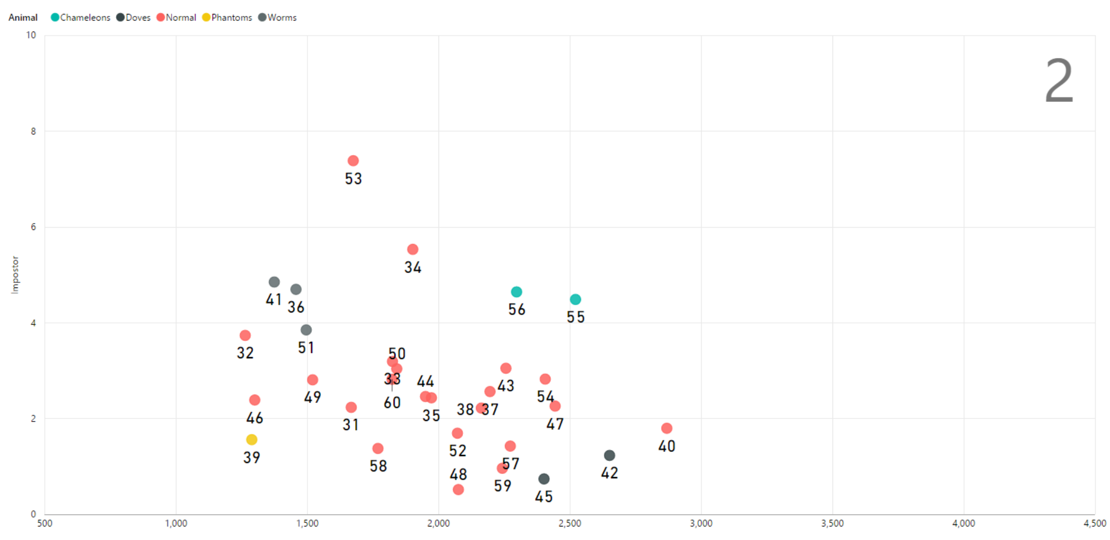

Figure 4.18: Zoo Plot of Studio Scarred with Powder, Preexisting (2)

Figure 4.17 shows the zoo plot for those with preexisting scars in a studio environment. The factor of scarring was omitted for this subject sample set, as they have preexisting scars, and they cannot be concealed. Within this zoo plot there was similar distributions to the non-scarred baseline in Figure 4.11. Despite the low left concentration similarity, the preexisting scars group showed higher genuine score distribution.

Figure 4.18 is the zoo plot for subjects with preexisting scars, but with the setting powder pretreatment. The pretreatment did not change much of the distribution from Figure 4.17; the genuine score distribution remained largely unchanged while there was a little more variation in impostor score distribution.

The setting powder pretreatment did show some subject movement for subjects with scars, but like the previous non-scarred sample set the range of genuine and impostor scores do not show drastic change. The pretreatment does not affect the genuine and impostor distribution within the two samples, compared to the magnitude of change from a face without scars to a face with scars.

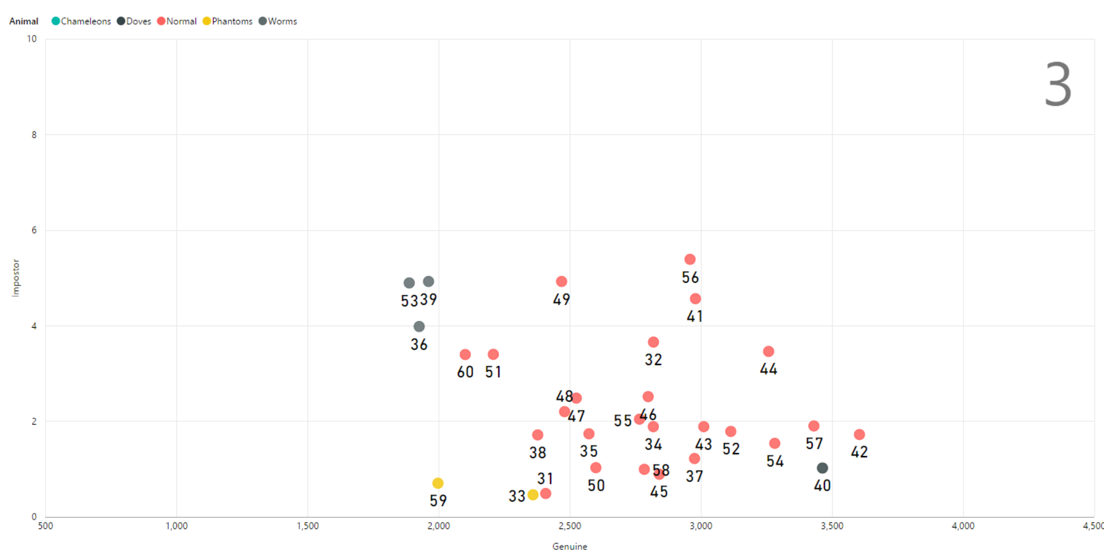

Figure 4.19: Zoo Plot of Booth Scarred, Preexisting (3)

Those with scars displayed more variance than their non-scarred counterparts. This was evident in comparisons between non-scarred before and after zoo plots, as seen in Figure 4.11 to Figure 4.13 and to Figure 4.14. Even comparing the two different subject sample sets, Figure 4.11 to Figure 4.17 and Figure 4.14 to Figure 4.19, it is apparent that scarring can affect sample set stability.

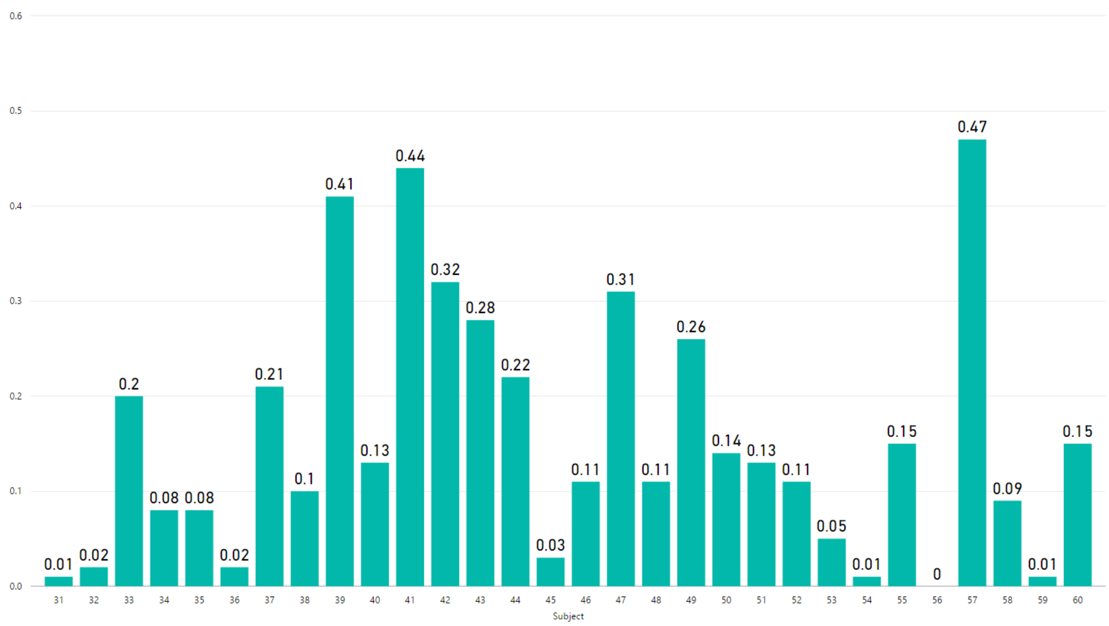

Figure 4.20: Stability scores for Pretreatment of preexisting scarred subjects in the Studio.

The stability scores for the preexisting scars also show that the pretreatment had an effect on subject movement, as seen in Figure 4.20 compared back to Figure 4.16. There was only one preexisting scarred subject, subject 56, which showed no instances of instability.

4.6.3 Stability and Confounding Variables

Due to the general nature of genuine and impostor scoring for the zoo menagerie, it is difficult to analyze instability that is precisely connected to certain variables. As seen in Table 4.3 and Figure 4.8, there is visible illumination halo cast on the studio background, which directly impacts the background image quality.

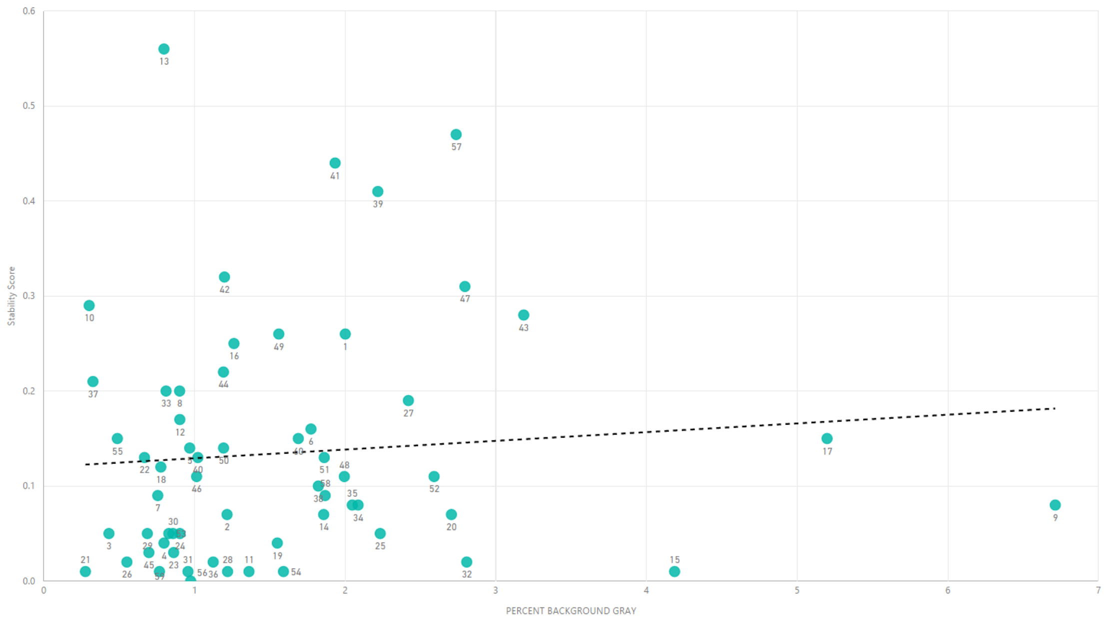

Figure 4.21: Stability Score over standard deviation of Percent Background Gray

The stability score in relation to the standard deviation of background gray percentage is shown in Figure 4.21. At first glance, the trend line does not show a strong regression, but the general patter and dispersion of the data reveals an elemental connection between stability and background. The subjects with lower instances of instability also feature lower standard deviations of percent background gray. This relationship was also evident in Figure 4.22, when analyzing the stability score with background uniformity.

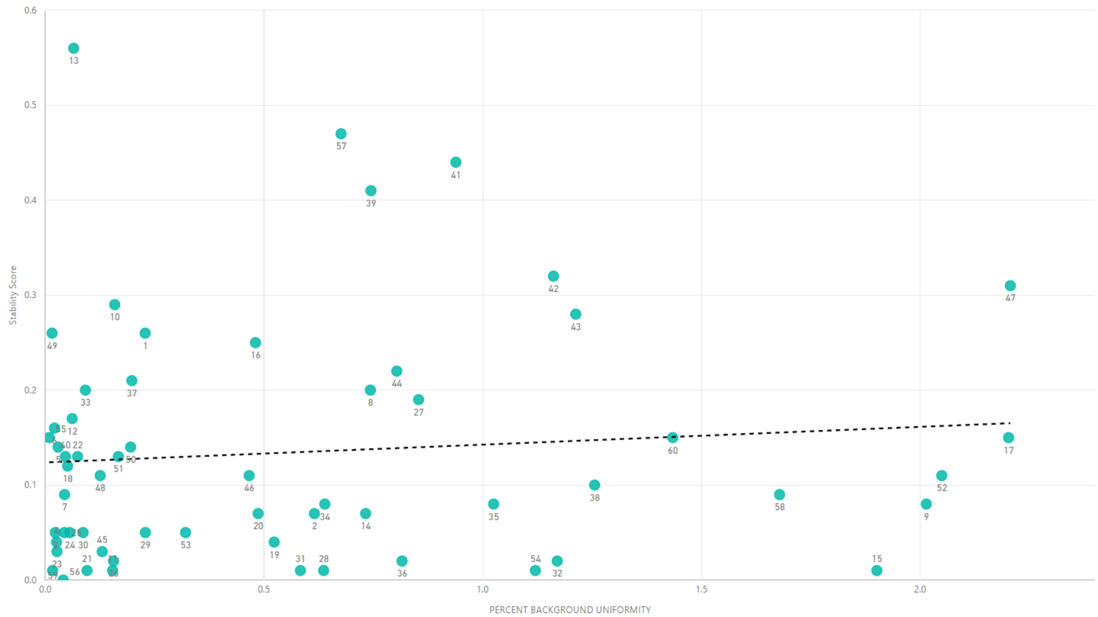

Figure 4.22: Stability Score over standard deviation of Percent Background Uniformity

It is important to highlight that what is observed is a practical difference within image quality and stability. Statistically there was a lack of evidence that the standard deviation of percent background gray [F (1, 58) = 0.42, p= 0.52] and uniformity [F (1, 58) = 0.51, p= 0.48] have an effect on the stability of a subject, at a conventional p<0.05 level. Yet Figure 4.21 and Figure 4.22 show different results that affirm the practical implications of background haloing seen within the raw data.

4.6.4 Matching Scarred to a Non-Scarred Enrollment

Testing for interoperability was also done to see how well scarred images matched to non-scarred templates that could have come from a previous enrollment. Table 4.9 shows the zoo movements, comparing the original non-scarred baseline to the match with scar results.

Table 4.9: Zoo Movements of Matching Scarred to Non-Scarred Enrollment

	Studio		Booth	
Subject ID	Before Scars	Match with Scar	Before Scars	Match with Scar
1	Normal	Doves	Normal	Normal
2	Doves	Normal	Normal	Doves
3	Normal	Normal	Normal	Normal
4	Phantoms	Normal	Normal	Normal
5	Normal	Normal	Normal	Normal
6	Normal	Normal	Normal	Normal
7	Normal	Normal	Normal	Normal
8	Normal	Normal	Normal	Normal
9	Normal	Normal	Normal	Normal
10	Normal	Normal	Normal	Doves
11	Normal	Normal	Normal	Normal
12	Normal	Normal	Normal	Normal
13	Worms	Worms	Worms	Normal
14	Normal	Normal	Normal	Normal
15	Normal	Normal	Normal	Normal
16	Worms	Worms	Normal	Normal
17	Normal	Normal	Normal	Normal
18	Normal	Normal	Normal	Normal
19	Normal	Normal	Chameleons	Chameleons
20	Worms	Normal	Worms	Worms
21	Phantoms	Normal	Normal	Normal
22	Normal	Worms	Normal	Normal
23	Normal	Normal	Normal	Normal
24	Normal	Phantoms	Normal	Normal
25	Normal	Normal	Normal	Normal
26	Normal	Normal	Normal	Normal
27	Phantoms	Phantoms	Normal	Phantoms
28	Normal	Normal	Normal	Normal
29	Normal	Normal	Normal	Normal
30	Normal	Normal	Phantoms	Normal

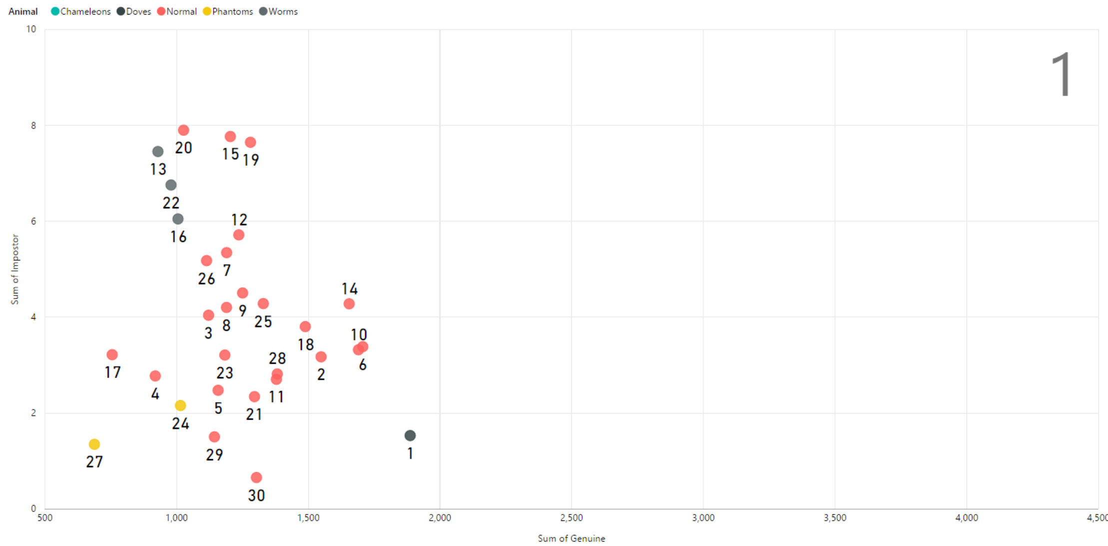

Figure 4.23: Zoo Plot of Studio Pre-Scar Enroll to Post-Scar Verify, Interoperability (1)

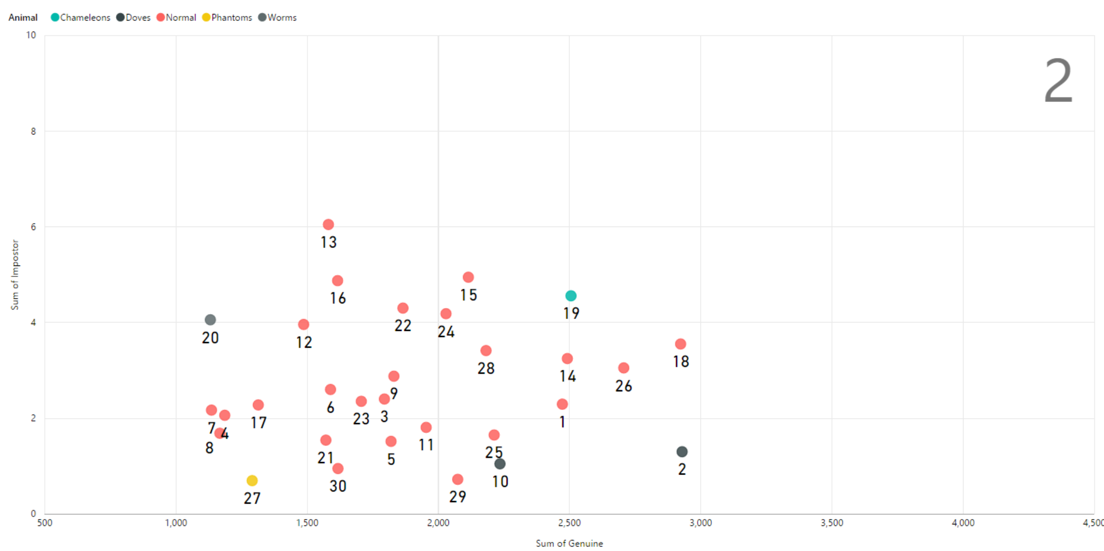

Figure 4.24: Zoo Plot of Booth Pre-Scar Enroll to Post-Scar Verify, Interoperability (2)

Figure 4.23 show the zoo menagerie of verifying a scarred image to an original non-scarred enrollment. Figure 4.24 is the same verification match but of the booth environment. Both show an increase variance compared to the exhaustive match scores of regular single non-scar or scar sample sets. Though there are animal shifts between the zoo plots, it is not beyond the regular variance of the previous zoo analysis.

4.7 Results Summary

This chapter provided the results gathered from the data collection of this study. Starting with conventional demographics data that was recorded from each subject to describe the overall characteristics of subjects who participated. The performance was analyzed using the DET curves, a biometric industry standard for performance measurement, as well as a 2-sample t-test and a Pearson's chi-squared test for association. Image quality was also reported from all face images collected from the subjects. Finally, stability analysis was done to show subject movement and the respective distributions of genuine and impostor scores.

CHAPTER 5. CONCLUSIONS AND FUTURE WORK

The final chapter of this research is divided into two section. This first section is the conclusion, which provides the verdict for performance and zoo stability for the subjects of this research, and also the overall findings of image quality. The last section is with respect to future research in this field, contributing directions for exploration and furnishing research ideas relation to what was and was not done in this research.

5.1 Conclusions

Suffice it to say; scarring does not seem to be a major contributor to performance or image quality deterioration. However, it should be noted that the zoo results show increase variance in genuine and impostor scores. The matching and image quality assessment software within the current face recognition standard are robust enough to make accurate identification and verification judgments, but are too sensitive in some aspect and not enough in others. Review of the ISO standard should be done to ensure that control of the control and constraints for face image quality are not only feasible, but practical as well.

5.1.1 Performance

All DET curves showed EER of 0.00%, desirable performance for any biometric system. Even comparing matching results from before and after scarring using the liquid latex methodology showed EER of 0.00% from both samples, showing evidence that if an individual develops a scar, performance can remain at optimal levels.

5.1.2 Image Quality

The image quality deterioration aligned with previous conclusions from Gross et al. (2005), Barsi & Jacobs (2006), and Adini, Moses, & Ullman, 1997. The controlled studio environment of the studio provided better image quality than that of the operational environment of the booth. Among all the image quality variance, there was a lack of evidence for scarring as a contributor to image quality deterioration. Assuredly, face image quality does not seem affected by the emergence of scarring.

5.1.2.1 Validation of Testing Methodologies

Several of the image quality metrics showed complete uniformity, where all image reported the same values, mostly in respect to dimensions and format. J2K digital formatting showed equal results among all images, all images were captured as. jpgs, and digital saturation of pixels within the face region were all equal. This validated the testing methodology of this study, and provided metadata that showed conformance to the testing protocol across all subjects and visits. Even the t-test of centerline location ratio in the studio that showed significant difference reported arithmetic mean so close, as well as standard deviations of 0.01 for both pre- and post-scarring, revealed that the capture of the face was well within the limits pertaining to ISO standards.

Physical constraints applied by the test administrator also had evidence that the data was collected properly to ISO standards. Metrics that showed either very close values or values that were equal included degree of pose, pose angle, facial dynamic range, brightness score, and eye contrast. Pose metrics such as degree of pose and pose angle showed that the test administrator took precautions to ensure the head was properly positioned within the centerline of the image dimension. Facial dynamic range showed near equal results across all images, and validated that the head size within the image was not just adequate for ISO standards, but also mathematically and practically similar. Eye metrics such as eye contrast, eye separation, and eye axis angle and location ratio showed that the feature points of the eyes were properly centered during data collection. The eyes play an important role in biometric feature extracting algorithms, and the ISO standards for the eyes ensure clarity and location for matching purposes.

The digital color background metrics measured in Red Blue Green (RGB), Hue Saturation Value (HSV), and Hue Lightness Value (HLV), showed no significant changes across the function of scarring. Additionally, upon evaluation of the standard deviations for background clutter and degree of clutter, there is much overlap between the standard deviation from central tendency. This showed that arithmetically it can be said with confidence that there is significance within the function of scarring, but there is little practicality within actual application or data capture.

The image quality data as a whole showed evidence that face image data collected from a standardized studio setting will produce raw similar, if not exactly equal, raw values. However, the image quality assessment algorithm sensitivity can still mathematically show significant difference in central tendency, rendering results difficult to interpret for practical biometrics. The case for this study was the centerline location ratio, as both pre- and post-scar samples showed arithmetic means of 0.52 and standard deviations of 0.1. The t-test still rendered a significant result, because the results recorded were in such detailed decimals that any minute change, from scarring or otherwise, would ripple through. At such focus to detailed decimal results, any non-overlap the distribution of value would be highlighted above appropriation. This leads to practical implications for the ISO standards currently in place.

5.1.2.2 Practical Impact on Image Quality

While the data does show that the function of scarring does not impact image quality generally, several aspects of the data collection showed visible changes to the data captured. These changes, though not pertaining to scarring, effect image quality as a whole and would explain the significant results in the t-tests.

Figure 5.1: Visible effects of the pretreatment powder.

The pretreatment only significantly affects one image quality metric for the preexisting scar subject sample, and no metric was found significant difference for the non-scarred subject sample. With only the degree of illumination asymmetry effected for preexisting scars, it is concluded that the data collection was done within ISO standards.

There are no determinations for illumination asymmetry set forth by the ISO, but even with the incompliances with select metrics in select images, there were no other metric values that showed statistically significant difference.

Statistically, the brightness metrics are unaffected by the pretreatment powder. Brightness score, indicates how the darken dynamic range is centered in the facial region with a scoring of 1 to 5, showed no significant difference in our results between baseline (M=4.99, SD=0.11) and powder (M=4.99, SD=0.11); $t(178)=0.00$, $p=1.00$. Similarly percent facial brightness, the average luminance of the facial region as a percent, also showed no significant difference baseline (M=57.28, SD=2.03) and powder (M=56.94, SD=1.86); $t(176)=-1.15$, $p=0.252$. Although, from Figure 5.1 we can see lesser luminance and specular reflectance from the forehead and underneath the eyes. Scar pitting from the subject's atrophic scars were also more defined within his baseline image compared to his pretreatment image.

Figure 5.2: Comparison of visible effects from pretreatment.

Figure 5.2 shows the brightness reduction effect, but from subjects without preexisting scars, reaffirming our conclusion from Figure 5.1. There was evidence that the pretreatment mattifies the skin, even if not statistically significant the effect is present. The significance of this conclusion is the implications for border security systems. The Dantcheva, Chen, and Ross (2012) study on cosmetics showed that there was an effect in performance for face recognition within the function of makeup. Although this study is focused on the function of scarring, base makeup was used for simulation. Base makeup such as setting powder or color foundation is widely used, due to its affordability and longevity.

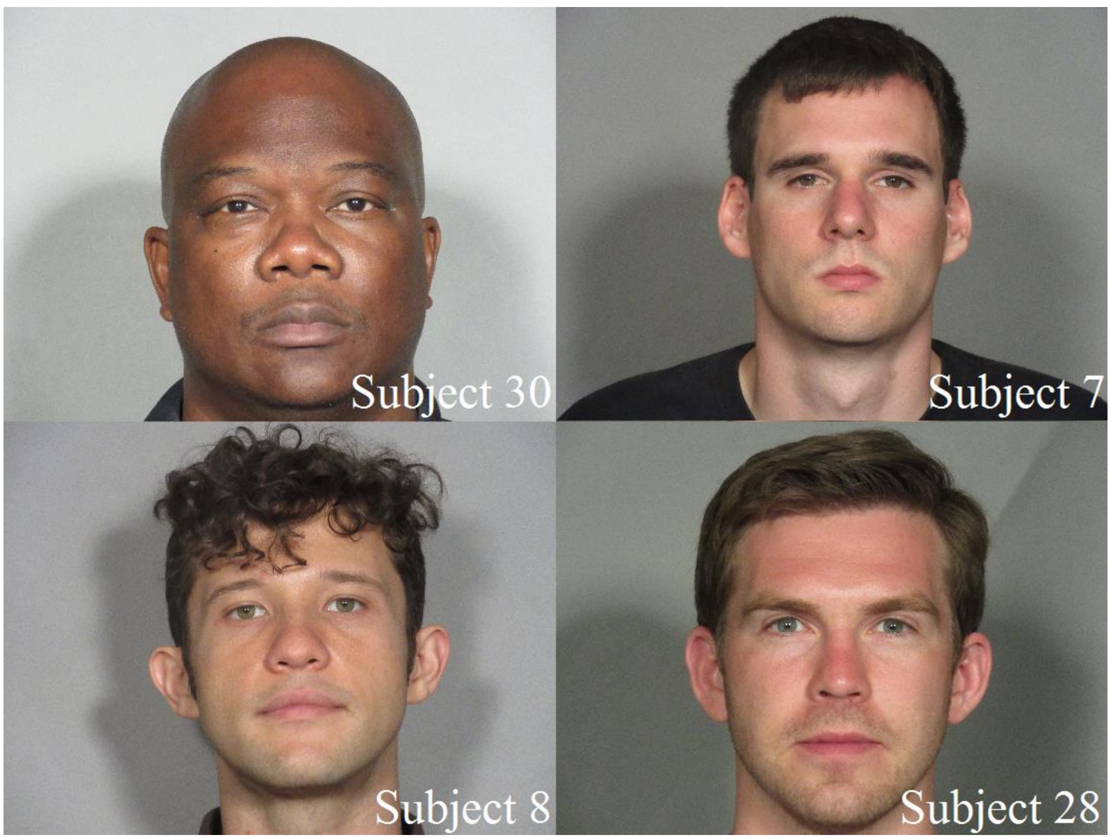

Figure 5.3: Skin pigmentation on background effects.

Skin pigmentation showed effects on background image quality, as seen with the four subjects in Figure 5.3. Though not enough subjects for each race or skin pigmentation was collected during this study, it was observed that darker pigmented face was accompanied by lighter gray backgrounds. This is the result of the autofocus capabilities of modern digital and webcams. The camera speed and exposure standards set forth by ISO is inclusive to all skin pigmentations, and will acquire a face of sufficient quality for biometric authentication. Autofocus functions on cameras are well within these limits. Without real time feedback, it is difficult for data collectors to know if the autofocus is over exposing to compensate for darker skin pigmentations, or vice-versa. This was evident in the biometric performance analysis performed for this study, where images with visible variation in background still matched without incident.

The background variance did not show significant change in value prima facie. Subject 30 had a percent background gray from 19.77% to 21.15% and a percent background uniformity from 96.63% to 96.75%. Subject 7 had a percent background gray from 49.96% to 50.77% and a percent background uniformity of 96.91% to 96.94%. These results for the dark skinned subjects 30 and 8 were compliant, but the lighter skinned subject 7 and 28 were considered too gray. This showed practical changes that revealed a flaw within the ISO standard. If image quality is to keep background as part of the quality metrics, there needs to be an adaptive solution towards skin pigmentations and background gray.

Figure 5.4: Capture time and background reflectance.

The time of capture also presented effects that were not anticipated for this study. In the operational booth simulation, it can be seen that exterior sun lighting had an effect on background glare. The effect extended to camera sensitivity and the changes have been seen on the foreground as well in the shadowing of the face. For percent facial brightness 49%, 50%, and 44% for subject 17, 18, and 27 respectively. These values for facial brightness were all compliant by ISO standards. For background HSL lightness 50.95, 47.95, and 45.54 for subjects 17, 18, and 27 respectively. Though there are not determinations for background HSL for the ISO standard, it is evident that there is an effect from the time of capture. This would prove important for airports where exterior sunlight cannot be controlled.

5.1.3 Zoo Analysis

The zoo menageries do not reveal system performance, but it does show subject behavior within the biometric system. Evaluating the zoo plots show that despite the good performance of the face recognition system, subject movement and their respective genuine and impostor score distributions reveal instabilities within the face recognition system. Though fluctuations within the genuine and impostor score are common, it can pose problems for the face recognition system; scarring does not seem to exacerbate this instability phenomenon. This conclusion comes with good confidence as the data exhibit behavior similar to the work Dunstone & Yager, (2007) and O'Connor et al. (2015) where instability can be observed with the introduction of a factor. The effect factor of this study was scarring and environment, and it is observed that both the studio and the booth show different levels of genuine and impostor distributions. The distribution changes caused by scarring was not as salient as the environment. The data does show changes, but not from the factor of interest for this study.

5.1.3.1 Distribution Changes from Pretreatment

As noted from the image quality results, the pretreatment did have a practical effect, and while no manifestations were in the performance results it can be seen in the zoo analysis. Figure 5.5 shows the eighteen subjects that had higher instability with the powder pretreatment than the scarring.

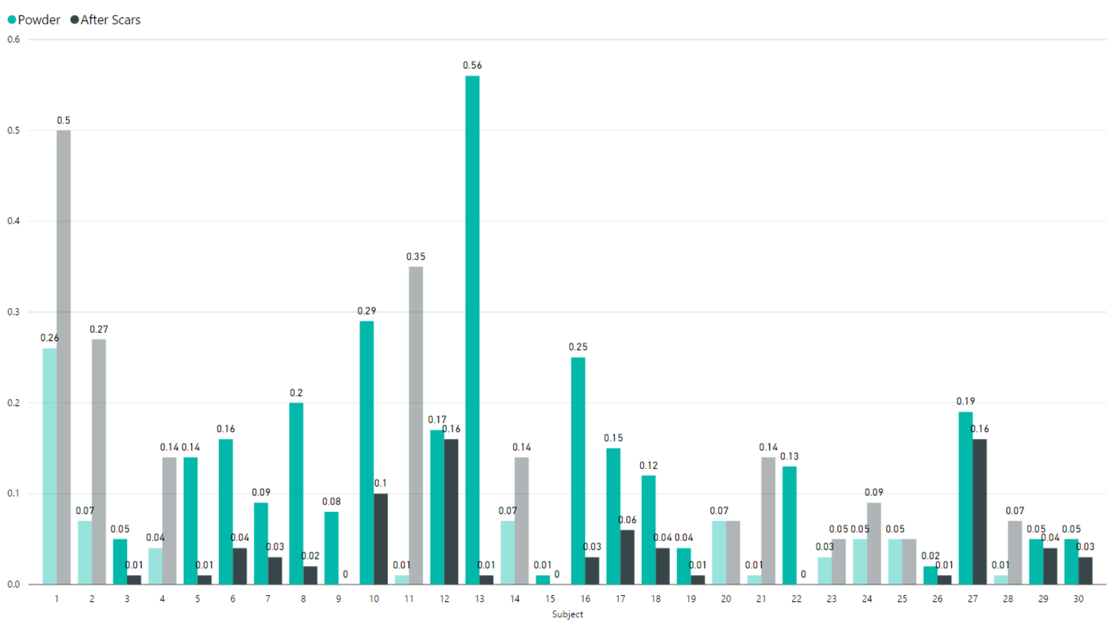

Figure 5.5: Higher instability results for pretreatment than scarring.

Evidence that unintendedly emerged showed that powder pretreatment has can have a greater effect on genuine and impostor score distribution than the function of scarring. A baseline face can change in stability with the application of cosmetic setting powder; this change can be greater than a powdered face with the application of a prosthetic scar that was designed, constructed, and applied for color and texture change.

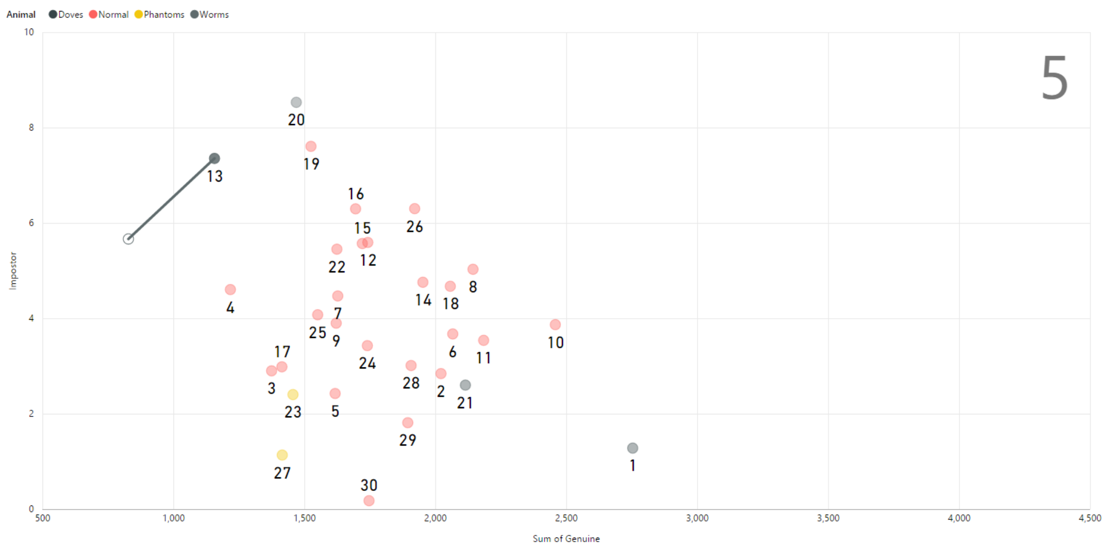

Figure 5.6: Highest instability recorded for baseline to powder, subject 13.

Figure 5.6 shows an example of a large magnitude zoo movement, subject 13 with a stability score of 0.56. Though previous conclusions of performance show that all faces were able to match without dispute, the practical implications are still problematic. While Figure 5.2 shows visible evidence of the effects setting powder on the face, Figure 5.5 and Figure 5.6, show mathematical evidence. This showed a duplex effect, but presents a difficult challenge for machine learning and machine vision. While the human visual system can observe the changes seen in Figure 5.2, there is also dependency that the machine can calculate and discern the differences in Figure 5.5.

5.2 Recommendations

The conclusions of the study bring about several recommendations for the current model of face recognition systems used for border control applications. Firstly, it is resolved that scarring does not affect the performance of face recognition systems. This implies that attack presentations using scars, either manufactured or purposeful mutilation, would not cloak an attacker from the face recognition system. Border control agents should focus on factors that would cause acquisition or capture failures. This could be illumination, background clutter, or expressions.

The texture and color changes from scarring may have no effect, but the study inadvertently uncovered practical effects from setting powder and skin pigmentation. The wide use of setting powder in cosmetic makeup and the variation in user skin pigmentation in border control operations can be a source of instability in image quality and matching score distribution.

Scarring has shown a penchant for creating more variation among match scores, and border agents should keep personalized records to dexterously identify and verify travelers. Subject movement and variation can be integrated into biometrics for system adaptation and contextual machine learning, and scarring could provide a factor for increasing the accuracy in the match score equation.

5.3 Future Work

With the closure of this research, another channel for research opens. Various other techniques and procedures can be used in replication of this study to test, not only its validity but its applicability. Race and skin pigmentation made another appearance in the paradigm of biometrics, due to the practical effects seen within the ISO standard background measurements of this study. New ideas on testing for makeup effects was also presented with the revelation of setting powder pretreatment effects. Also to be presented is another metric that could potentially reveal tendencies in machine vision.

5.3.1 Race, Skin Pigmentation, Background, and Exposure

It was seen in this study that the darker skin pigmentation triggered greater camera image sensory exposure, which incidentally changed background dynamics within images. This poses a problem for automated biometric systems implemented within border control, as the variation in user race and skin pigmentation would be higher than a homogenous environment, and the automated image capture hardware will compensate for clarity in the foreground. The high level of foreign traffic engaging biometric border systems presents race and skin pigmentation as a salient issue for ISO passport compliancy.

Switching to a manual image sensory adjustment system would not be cost effective, and would hinder throughput in the biometric border system. Ergo race and skin pigmentation should be integrated as a function to the image capture system. At first, a conventional general linear model with Cramér's V could be done on the association between skin pigmentation and background measurements, as well as an ANOVA analyzing race and background measurements. The statistical models resulting from these studies could help augment the current ISO standards to find the optimal background settings in regards to the face. This study showed that even non-compliant background measurements yielded 0.00% error in matching performance. The rigidity of the ISO standards, while providing good guideline for data collectors, is shown to be too rigid. New results from skin pigment and race studies could provide a foundation for a more adaptive ISO standard that result in optimal background levels based on user skin and race characteristics.

5.3.2 Other Theatrics

Different theatrical techniques could be used to simulate more conditions and environments. This could expand this research on scarring to other use case environments, other than conventional overhead strip lighting found in border security and airports. The wide use and commercially diverse selection of solid state powder cosmetic makeup should also be explored, as the study showed effects from the setting powder pretreatment.

5.3.2.1 Pose and Illumination

This study was limited to the established ISO full frontal lighting scheme, but we also tested uncontrolled overhead strip lighting as a wild operational scenario. Collecting data on various lighting levels and directions, and performing an exhaustive match, would imaginably yield meaningful performance reports. The direction and intensity of lighting could be explored to find the best operational setting.

Different light bulbs and emitters could also be explored. It is common practice theater, film, and photography to use incandescent bulbs that emit soft yellow light. This punctilio was chosen through decades of trial and error, and it was realized that it was much easier to feature or distinguish objects in a scene. The current ISO does not impose standards on light bulbs and emitters themselves.

Lightbulbs and emitters would be a very marketable research as face biometric users tend to be large-scale implementers, such the DHS, and Law Enforcement, who are looking to control cost as much as possible. Overhead strip lighting that is commonly found in DHS use case operations, such airports, and borders, would not be able to utilize incandescent light bulbs. This would suggest that the infrastructure would need to be overhauled, and that would indicate another cost. For large scale users like the DHS or DoD, this cost could be immense as they have many facilities and areas of operation. If research is done to find a light emitting source that could perform similarly to soft yellow incandescent bulbs while utilizing the existing infrastructure of large scale biometric users, this could lead to a cost-effective solution for specular reflectance and shadow.

5.3.2.2 Simulating Various Scars

This study only evaluated performance under a single scarring condition, if scars were applied or not. Since liquid latex can be fitted into various molds, this research could be expanded to other scar dimensions. Though the complication with medical science is that scar dimensions are hard to define, biometric standards entities could make their own. If a research potentially reveals scarring dimensions that affect performance more than others, then it would provide a foundation for the biometrics developers to launch new standards and recommendations.

Another method worth exploring is using Kryolan Tuplast scar polymer. Instead of liquid latex poured into a mold, Kryolan Tuplast and be drawn on a layer by layer. This method could be used to add more elevation and mass to simulated scars, providing another dimension for performance analysis.

5.3.2.3 Global Changes in Face Characteristics

While this study investigated the effects of scarring using a simple linear scar and naturally developed scars, it did not cover massive face disfigurement. It is not outlandish to image individuals developing global changes to facial anatomy. Third-degree burns, destruction of bone, and paralysis can cause changes within the principle components used by face recognition systems. Though such damage is rare and intuitively noteworthy, it could be studied to further analyze the capability of face recognition systems. Face recognition research covered in this study’s literature review follows the conventional analysis of generic faces for the purpose of wide application and universality. Notwithstanding, deviant faces could be encountered by border control operations.

5.3.2.4 High Definition Makeup Techniques

Besides the conventional makeup used in this study for superficial color blending, high definition makeup used commonly in film and photography can also be used to simulate scarring. This study assumed scarrings creates changes in skin texture and color as a result of mammalian tissue repair process. However, with advancements in medical science, it is possible to have very discrete scarring. The potential for smaller scars, ones so obscure that they are almost unnoticeable, is greater with contemporary medical science. A biometric face recognition experiment employing high definition makeup techniques could be used to simulate not just scarring, but also aging and cosmetic surgery.

5.3.2.5 Powder Cosmetic Makeup

Solid state powder is one of the oldest varieties of cosmetic makeup (Corson & Glavan, 2001; Debreceni, 2013; Sartor & Pivovarnick, 2001). With widespread use, it is actively encountered by face recognition systems (Dantcheva, Chen, & Ross, 2012). The mattifying effects of solid state powder has shown practical effects in illumination within this study. Future studies could expand from to embrace different types of solid state powder. The setting powder used for this study's pretreatment was a translucent base powder, but many commercially available solid state powders come in a variety of colors and perform various functions. In addition to base setting powder there are face primers, foundations, concealers, highlights, and contour shadowing. Though there are unimaginable permutations and combinations for all these solid state powders, a general linear model should be done first to scale effects of the different types of solid state powder within biometrics. Afterwards, the conventional permutations and combinations of solid state makeup, commonly taught to aspiring makeup artists, can be analyzed through a multi-level ANOVA would give a general and conservative effect analysis for the operational biometric setting. This could potentially expand to market and brand product analysis, and give context and measurability to the effects of brand-named proprietary makeup.

5.3.3 Other Matching Algorithms

The matching algorithm for this study was NeuroTechnology's VeriLook 8.0, validated by the National Institute of Standards and Technology (NIST). Further research can be conducted to see if other algorithms behave similarly when scars are introduced. NEC's NeoScan® face recognition solution would be an exemplary research and easily applied to the border control use case due to NEC' deployment for John F. Kennedy International Airport (Foster, 2016). Other algorithms that could be used for performance research would be Cognitec's FaceVACS series of face recognition solutions, FaceFirst products and solutions, and Griaule's GBS programs.

5.3.4 Estimation Tools

NeuroTechnology's VeriLook 8.0 also feature estimation tools that will make demographic estimates on processed images. These estimations include age, sex, and emotional state. This estimation feature could be used as another set of metrics to measure assumptions and tendencies of machine vision. Biometric systems could exhibit a bias towards certain demographics in respects to performance and match scores. The advantage of using VeriLook estimation is that it is a single image process, and does not require multiple images or probe and gallery method matching to output results. It is an algorithmic analysis of the image as is, and it reveals how the machine perceives the image in and of itself. Researching this facet of machine visions could help render a more defined conclusion of bias in machine vision. These findings could be employed not just in biometrics, but in robotics and digital signal processing as well.

5.4 Summary of Research

This chapter provides the conclusions and recommendations made with data collected for this research. It also lays the foundation and launching point for future research, not just within face recognition, but for biometrics and machine visual processes as a science.

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APPENDICES

Appendix A: Liquid Latex Demonstration

Video Link: https://youtu.be/xKlw3VtJr3E

Appendix B: Application of Prosthetic Scars

Video Link: https://youtu.be/0B7iX6zcOKA

Appendix C: Model Release Forms

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POLYTECHNIC

I, Roxanne Schroeder (please print), grant permission to Purdue University and its agents and employees the irrevocable and unrestricted right to reproduce the photographs and/or video images taken of me, or members of my family, for the purpose of publication, promotion, illustration, advertising, or trade, in any manner or in any medium. I hereby release Purdue University and its legal representatives for all claims and liability relating to said images. Furthermore, I grant permission to use my statements that were given during an interview or guest lecture with or without my name, for the purpose of advertising and publicity without restriction. I waive my right to any compensation.

I acknowledge that I am (X) over the age of 18
( ) the legal guardian of the following

If legal guardian of model(s), please list name(s) here:

Signature ______________________ Date: 4-29-16

Address 543 Ridgemont Drive Corydon IN 4711

E-mail Schroe28@gmail.com

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I, Olivia Hardebeck (please print), grant permission to Purdue University and its agents and employees the irrevocable and unrestricted right to reproduce the photographs and/or video images taken of me, or members of my family, for the purpose of publication, promotion, illustration, advertising, or trade, in any manner or in any medium. I hereby release Purdue University and its legal representatives for all claims and liability relating to said images. Furthermore, I grant permission to use my statements that were given during an interview or guest lecture with or without my name, for the purpose of advertising and publicity without restriction. I waive my right to any compensation.

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( ) the legal guardian of the following

If legal guardian of model(s), please list name(s) here:

Signature ______________________ Date: 5/22/16

Address ______________________

E-mail ______________________

____

____

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I, WEN YEN ESTHER . FOO (please print), grant permission to Purdue University and its agents and employees the irrevocable and unrestricted right to reproduce the photographs and/or video images taken of me, or members of my family, for the purpose of publication, promotion, illustration, advertising, or trade, in any manner or in any medium. I hereby release Purdue University and its legal representatives for all claims and liability relating to said images. Furthermore, I grant permission to use my statements that were given during an interview or guest lecture with or without my name, for the purpose of advertising and publicity without restriction. I waive my right to any compensation.

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( ) the legal guardian of the following

If legal guardian of model(s), please list name(s) here:

Signature ________________ Date: 4/20/2016

Address 171 E. STATE ST. APT #362, ITHACA, NY 14850

E-mail estherfoo@outlook.com.

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I, Bradford Thorne (please print), grant permission to Purdue University and its agents and employees the irrevocable and unrestricted right to reproduce the photographs and/or video images taken of me, or members of my family, for the purpose of publication, promotion, illustration, advertising, or trade, in any manner or in any medium. I hereby release Purdue University and its legal representatives for all claims and liability relating to said images. Furthermore, I grant permission to use my statements that were given during an interview or guest lecture with or without my name, for the purpose of advertising and publicity without restriction. I waive my right to any compensation.

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( ) the legal guardian of the following

If legal guardian of model(s), please list name(s) here:

Signature [signature] Date: 4/30/2016

Address 224 S. Grant St. West Lafayette IN 47906

E-mail thorneb@purdue.edu

PURDUE
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I, BRIDGET KILBRIDE (please print), grant permission to Purdue University and its agents and employees the irrevocable and unrestricted right to reproduce the photographs and/or video images taken of me, or members of my family, for the purpose of publication, promotion, illustration, advertising, or trade, in any manner or in any medium. I hereby release Purdue University and its legal representatives for all claims and liability relating to said images. Furthermore, I grant permission to use my statements that were given during an interview or guest lecture with or without my name, for the purpose of advertising and publicity without restriction. I waive my right to any compensation.

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( ) the legal guardian of the following

If legal guardian of model(s), please list name(s) here:

Signature Bridget Kilbride Date: 04/29/16

Address 720 NORTHWESTERN AVE. APT. 508C WEST LAFAYETTE, IN 47906

E-mail b.kilbride17@gmail.com

I, Marcela Foster (please print), grant permission to Purdue University and its agents and employees the irrevocable and unrestricted right to reproduce the photographs and/or video images taken of me, or members of my family, for the purpose of publication, promotion, illustration, advertising, or trade, in any manner or in any medium. I hereby release Purdue University and its legal representatives for all claims and liability relating to said images. Furthermore, I grant permission to use my statements that were given during an interview or guest lecture with or without my name, for the purpose of advertising and publicity without restriction. I waive my right to any compensation.

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( ) the legal guardian of the following

If legal guardian of model(s), please list name(s) here:

Signature Marcela Foster Date: 4/29/16

Address 310 third street Hillenbrend Hall West Lafayette IN

E-mail foster85@purdue.edu

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I, Sylvia Lefebvre (please print), grant permission to Purdue University and its agents and employees the irrevocable and unrestricted right to reproduce the photographs and/or video images taken of me, or members of my family, for the purpose of publication, promotion, illustration, advertising, or trade, in any manner or in any medium. I hereby release Purdue University and its legal representatives for all claims and liability relating to said images. Furthermore, I grant permission to use my statements that were given during an interview or guest lecture with or without my name, for the purpose of advertising and publicity without restriction. I waive my right to any compensation.

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( ) the legal guardian of the following

If legal guardian of model(s), please list name(s) here:

Signature [signature] Date: 4/20/16

Address 2531 N 250 W

E-mail slefebvr@purdue.edu

PURDUE
POLYTECHNIC

I, Marissa S. Piosso (please print), grant permission to Purdue University and its agents and employees the irrevocable and unrestricted right to reproduce the photographs and/or video images taken of me, or members of my family, for the purpose of publication, promotion, illustration, advertising, or trade, in any manner or in any medium. I hereby release Purdue University and its legal representatives for all claims and liability relating to said images. Furthermore, I grant permission to use my statements that were given during an interview or guest lecture with or without my name, for the purpose of advertising and publicity without restriction. I waive my right to any compensation.

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( ) the legal guardian of the following

If legal guardian of model(s), please list name(s) here:

Signature [signature] Date: 23.5.16

Address 60 Carver St. Wellesley MA 02482

E-mail piosso.1 @asu.edu

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I, Jennifer White (please print), grant permission to Purdue University and its agents and employees the irrevocable and unrestricted right to reproduce the photographs and/or video images taken of me, or members of my family, for the purpose of publication, promotion, illustration, advertising, or trade, in any manner or in any medium. I hereby release Purdue University and its legal representatives for all claims and liability relating to said images. Furthermore, I grant permission to use my statements that were given during an interview or guest lecture with or without my name, for the purpose of advertising and publicity without restriction. I waive my right to any compensation.

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( ) the legal guardian of the following

If legal guardian of model(s), please list name(s) here:

Signature Jennifer White Date: 7/5/16

Address Purdue University / YONG 323

E-mail jkwhite@purdue.edu

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I, TORREY HUTCHISON (please print), grant permission to Purdue University and its agents and employees the irrevocable and unrestricted right to reproduce the photographs and/or video images taken of me, or members of my family, for the purpose of publication, promotion, illustration, advertising, or trade, in any manner or in any medium. I hereby release Purdue University and its legal representatives for all claims and liability relating to said images. Furthermore, I grant permission to use my statements that were given during an interview or guest lecture with or without my name, for the purpose of advertising and publicity without restriction. I waive my right to any compensation.

I acknowledge that I am (X) over the age of 18
( ) the legal guardian of the following

If legal guardian of model(s), please list name(s) here:

Signature [signature] Date: 20160705

Address 2243 U.S. Highway 52 W. Apt 2215 West Lafayette IN 47906

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I, Jaclyn Cole (please print), grant permission to Purdue University and its agents and employees the irrevocable and unrestricted right to reproduce the photographs and/or video images taken of me, or members of my family, for the purpose of publication, promotion, illustration, advertising, or trade, in any manner or in any medium. I hereby release Purdue University and its legal representatives for all claims and liability relating to said images. Furthermore, I grant permission to use my statements that were given during an interview or guest lecture with or without my name, for the purpose of advertising and publicity without restriction. I waive my right to any compensation.

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If legal guardian of model(s), please list name(s) here:

Signature [signature] Date: 7/4/16

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( ) the legal guardian of the following

If legal guardian of model(s), please list name(s) here:

Signature Boris Yeli Date: 4/1/16

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I acknowledge that I am (X) over the age of 18
( ) the legal guardian of the following

If legal guardian of model(s), please list name(s) here:

Signature Debh E Kull Date: 4 July 2016

Address 2205 Robinhood Lane, W. Lafayette IN 47906

E-mail debkull@gmail.com

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I, Kristopher L. Ezra (please print), grant permission to Purdue University and its agents and employees the irrevocable and unrestricted right to reproduce the photographs and/or video images taken of me, or members of my family, for the purpose of publication, promotion, illustration, advertising, or trade, in any manner or in any medium. I hereby release Purdue University and its legal representatives for all claims and liability relating to said images. Furthermore, I grant permission to use my statements that were given during an interview or guest lecture with or without my name, for the purpose of advertising and publicity without restriction. I waive my right to any compensation.

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( ) the legal guardian of the following

If legal guardian of model(s), please list name(s) here:

Signature [signature] Date: 7/6/16

Address ____________________

E-mail ____________________

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Appendix D: Image Quality Metrics

- Eye Axis Angle: slope of the eye-axis measured in degrees clockwise from the horizontal.

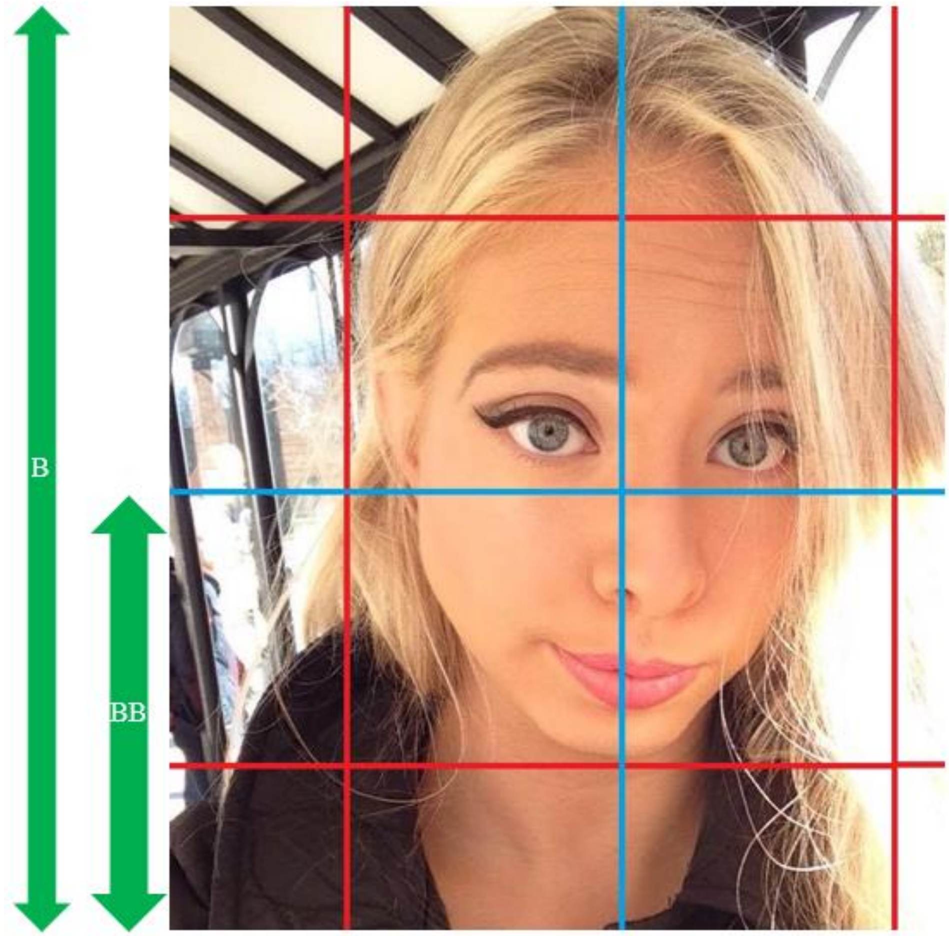

Figure D.1.1: Eye Axis Location Ratio.

- Eye Axis Location Ratio: location of the eye axis as a fraction of the image height up from the bottom (BB:B in the ISO standard), as shown in Figure D.1.1.

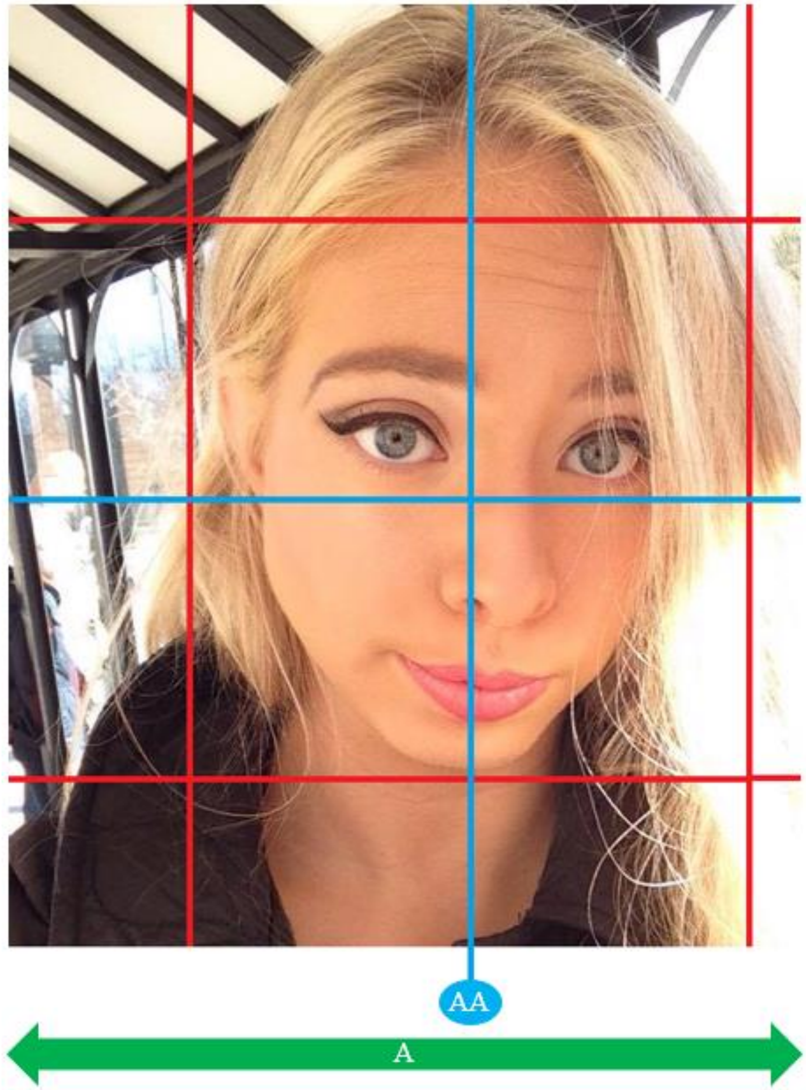

Figure D.1.2: Centerline Location Ratio.

- Centerline Location Ratio: location of the centerline as a fraction of the image width measured from the left side of the image (AA:A in the ISO standard), as shown in Figure D.1.2.

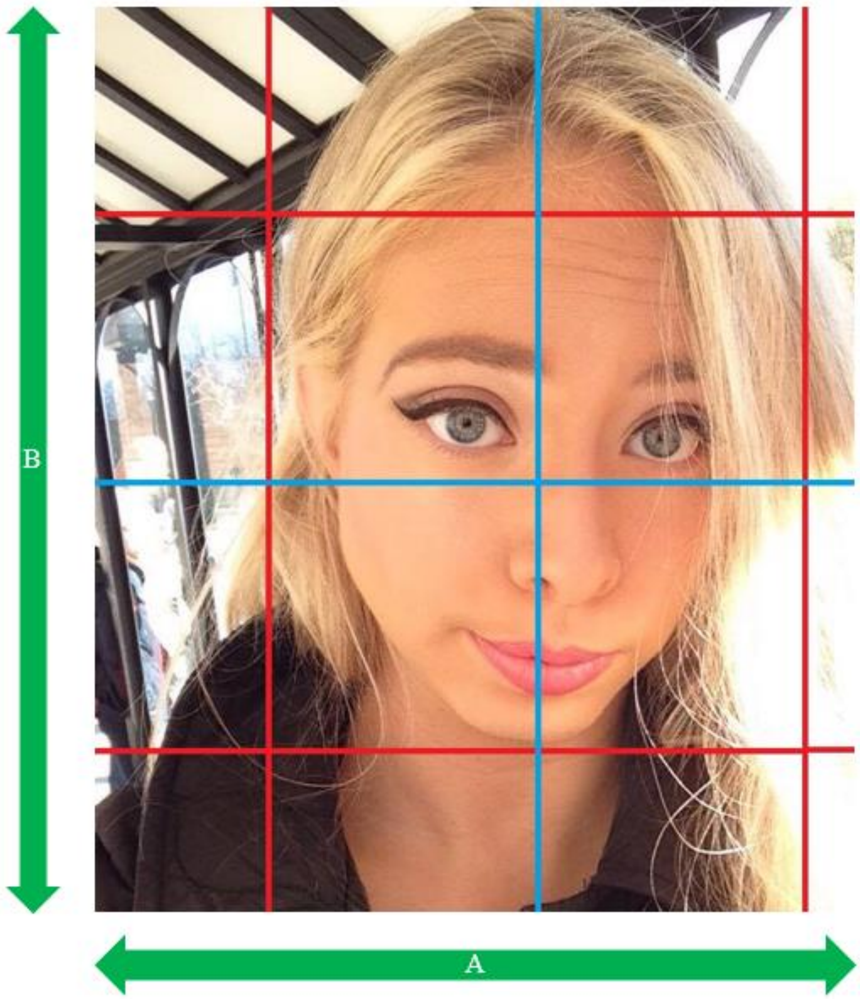

Figure D.1.3: Height to Width Ratio.

- Height to Width Ratio: ratio of image height to image width (B:A in the ISO standard), as shown in Figure D.1.3.

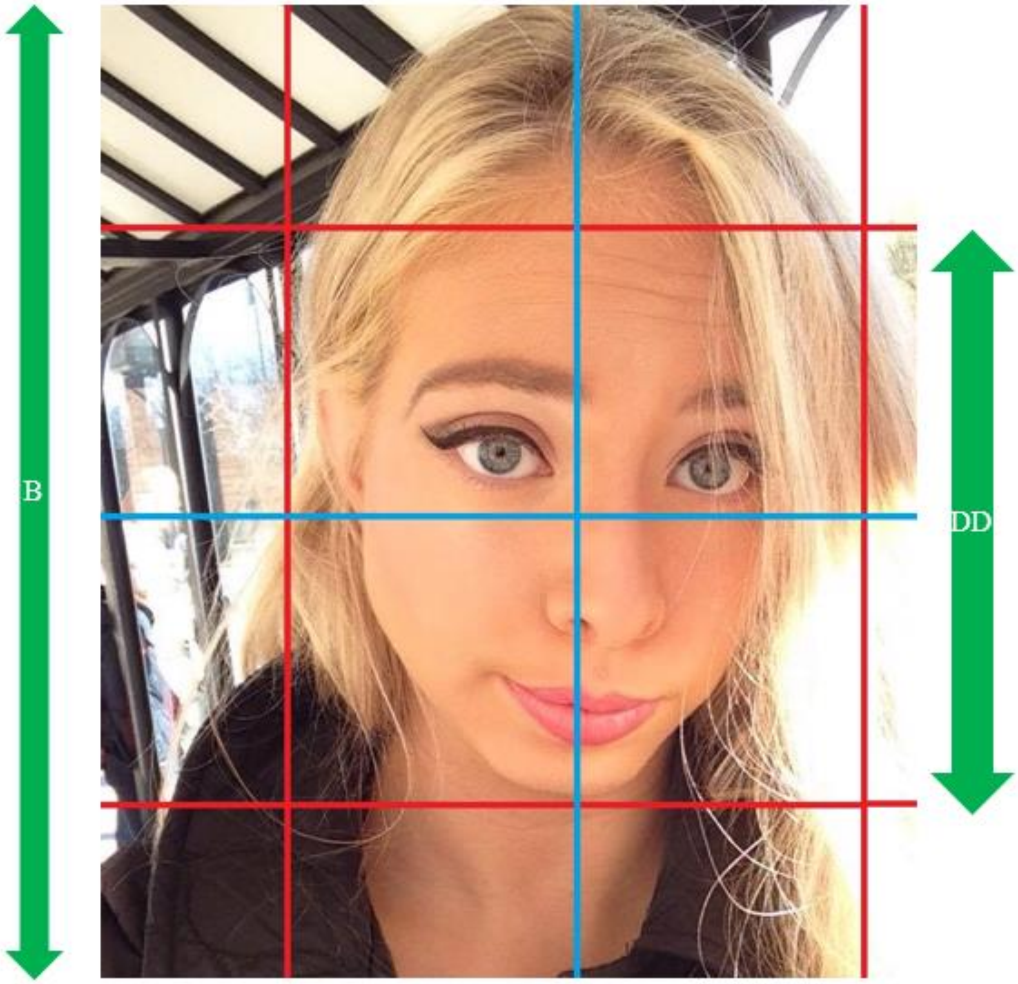

Figure D.1.4: Head Height to Image Height Ratio.

- Head Height to Image Height Ratio: ratio of the head height to image height (DD:B in the ISO standard), as shown in Figure D.1.4.

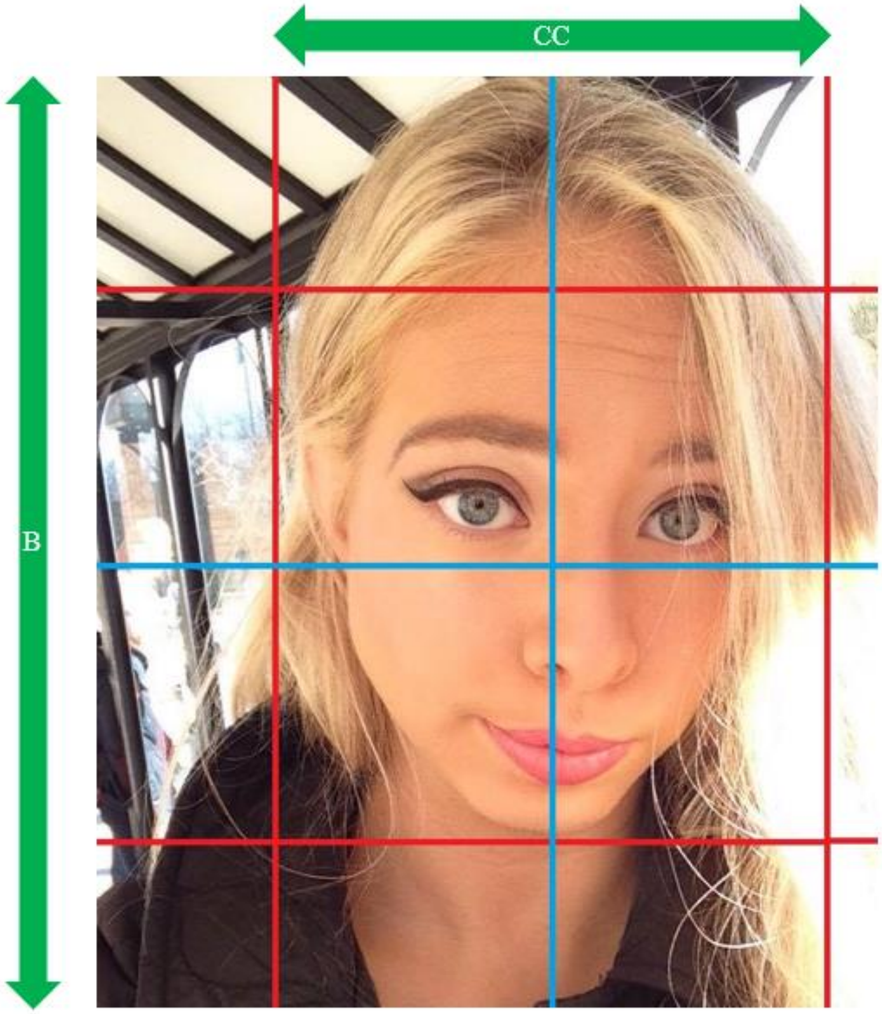

Figure D.1.5: Image Width to Head Width Ratio.

- Image Width to Head Width Ratio: ratio of image width to head width (A:CC in the ISO standard), as shown in Figure D.1.5.
- Eye Contrast: indicates how well the dynamic range is spread in the eye regions of the image. The contrast value will range of 1 to 5. A score of 3 or higher is adequate (the higher the better). A score of 2 or less is inadequate.

- Brightness Score: indicates how the dynamic range is centered in the facial region of the image. Scoring ranges from 1 to 5. Value should be greater than or equal to 3, values below 3 indicate that the facial region may be too dark. A special value of 0 applies to facial images that have too much saturated black.
- Facial Dynamic Range: indicates the number of bits in the dynamic range of the facial region of the input image. A minimum of 7 is required.
- Percent Facial Brightness: average luminance of the facial region as a percent. Valid values are in the range 25-75%.
- Percent Facial Saturation: percent fraction of pixels saturated in the facial region.
- Percent Background Gray: reflects the level of gray in the background as a percentage. Optimal is 18%.
- Percent Background Uniformity: reflects the variation of color throughout the background of the image as a percentage. Optimal is 100%.
- Background Type: indicates the type of background the image has. At 0 indicates a simple background.
- Degree of Clutter: indicates how much background clutter occurs in the image. Scores are in the range 0 to 5. With 0 indicating no background clutter and 5 indicating a high degree of background clutter.
- Degree of Blur: indicates how much focus and/or motion blur is present in the image. Scores are in the range 0 to 5. With 0 indicating no blur and 5 indicating a high degree of image blur.
- Smile: if smiles are present or not using the aw_fac_get_image_value function. 0 indicates no smiles were detected.

- Smile Likelihood: indicates the allowed likelihood of a smile. 0 indicates a smile is very unlikely. 1-5 indicate an increasing likelihood of a smile.
- Degree of Pose: extent to which a face deviates from the frontal position. Scores are in the range 0 to 5, with 0 indicating frontal pose and 5 indicating a very extreme pose.
- Format: the digital format of the image, such as .jpg or .png.
- File size: number of bytes for JPEG 2000 compressed file.
- JPEG quality level: used for assessing JPEG file quality for compression operations.
- J2K Compression Ratio: the ratio for JPEG 2000 compression.
- J2K ROI Background Compression Ratio: compression ratio in the background region (outside of the ROI) for ROI based JPEG 2000 compression.
- J2K ROI Foreground Compression Ratio: compression ratio within region of interest for ROI based JPEG 2000 compression.
- Desired Background RGB Red: red-channel-value desired for background, values range from 0 to 255.
- Desired Background RGB Green: green-channel-value desired for background, values range from 0 to 255.
- Desired Background RGB Blue: blue-channel-value desired for background, values range from 0 to 255.
- Desired Background HSL Hue: desired background color in reference to the spectrum in the HSL color space, values are in angular degrees, 0 to 360.

- Desired Background HSL Lightness: brightness of the background in the HSL color space, values range from 0 to 100.
- Desired Background HSL Saturation: desired intensity of hue for the background in the HSL color space, values range from 0 to 100.
- Desired Background HSV Hue: desired background color in reference to the spectrum in the HSV color space, values are in angular degrees, 0 to 360.
- Desired Background HSV Saturation: desired intensity of hue for the background in the HSV color space, values range from 0 to 100.
- Desired Background HSV Value: brightness of the background in the HSV color space, values range from 0 to 100.
- Degree of Left Eye Obstruction: indicates to what degree there is an obstruction of the left eye. Scores are in the range 0 to 5, with 0 indicating no obstruction and 5 indicating significant obstruction.
- Degree of Right Eye Obstruction: indicates to what degree there is an obstruction of the right eye. Scores are in the range 0 to 5, with 0 indicating no obstruction and 5 indicating significant obstruction.
- Degree to which Eyes can be Considered Closed: indicates to what degree the eyes are closed. Scores are in the range 0 to 5, with 0 indicating very unlikely either eye is closed and 5 indicating very likely that one or both eyes are closed.
- Degree of Illumination Asymmetry: indicates the extent to which the illumination of the image is not symmetrical. Scores are in the range 0 to 5.

Appendix E: Application to Use Human Subjects

Revised 3/8 Ref. # ___

APPLICATION TO USE HUMAN RESEARCH SUBJECTS
Purdue University
Institutional Review Board

1. Project Title: Face Image Capture with Special Effects Makeup Scarring

2.Full Review ☐ Expedited Review ☒

3.Anticipated Funding Source: International Center for Biometric Research

4. Principal Investigator *[See Policy on Eligibility to serve as a Principal Investigator for Research Involving Human Subjects]*:

Stephen Elliott	TLI, 4-2311, elliott@purdue.edu

5.Co-investigators and key personnel *[See Education Policy for Conducting Human Subjects Research]*:

Kevin Chan	TLI, 4-2311, kjchan@purdue.edu

6.Consultants *[See Education Policy for Conducting Human Subjects Research]*:

Kevin O'Connor	TLI, 4-2311, koconnor@purdue.edu

7.The principal investigator agrees to carry out the proposed project as stated in the application and to promptly report to the Institutional Review Board any proposed changes and/or unanticipated problems involving risks to subjects or others participating in the approved project in accordance with the HRPP Guideline 307 Researcher Responsibilities, Purdue Research Foundation-Purdue University Statement of Principles and the Confidentiality Statement. The principal investigator has received a copy of the Federal-Wide Assurance (FWA) and has access to copies of 45 CFR 46 and the Belmont Report. The principal investigator agrees to inform the Institutional Review Board and complete all necessary reports should the principal investigator terminate University association.

Principal Investigator Signature Date

8. The Department Head (or authorized agent) has read and approved the application. S/he affirms that the use of human subjects in this project is relevant to answer the research question being asked and has scientific or scholarly merit. Additionally s/he agrees to maintain research records in accordance with the IRB's research records retention requirement should the principal investigator terminate association with the University.

Department Head *(printed)* Department Name

Department Head Signature Date

APPLICATION TO USE HUMAN RESEARCH SUBJECTS

9. This project will be conducted at the following location(s): (please indicate city & state)
   - ☒ Purdue West Lafayette Campus
   - ☐ Purdue Regional Campus (Specify): ______
   - ☐ Other (Specify): ______

10. If this project will involve potentially vulnerable subject populations, please check all that apply.
   - ☐ Minors under age 18
   - ☐ Pregnant Women
   - ☐ Fetus/fetal tissue
   - ☐ Prisoners Or Incarcerated Individuals
   - ☐ University Students (PSYC Dept. subject pool ___)
   - ☐ Elderly Persons
   - ☐ Economically/Educationally Disadvantaged Persons
   - ☐ Mentally/Emotionally/Developmentally Disabled Persons
   - ☐ Minority Groups and/or Non-English Speakers
   - ☐ Intervention(s) that include medical or psychological treatment

11. Indicate the anticipated maximum number of subjects to be enrolled in this protocol as justified by the hypothesis and study procedures: 60

12. This project involves the use of an **Investigational New Drug** (IND) or an **Approved Drug For An Unapproved Use**.
   ☐ YES ☒ NO
   Drug name, IND number and company: ______

13. This project involves the use of an **Investigational Medical Device** or an **Approved Medical Device For An Unapproved Use**.
   ☐ YES ☒ NO
   Device name, IDE number and company: ______

14. The project involves the use of **Radiation or Radioisotopes**:
   ☐ YES ☒ NO

15. Does this project call for: (check-mark all that apply to this study)
   - ☒ Use of Voice, Video, Digital, or Image Recordings?
   - ☒ Subject Compensation? Please indicate the maximum payment amount to subjects. $10 for one visit

     Purdue's Human Subjects Payment Policy Participant Payment Disclosure Form
   - ☐ VO2 Max Exercise?
   - ☐ More Than Minimal Risk?
   - ☐ Waiver of Informed Consent?
   - ☐ Extra Costs To Subjects?
   - ☐ The Use of Blood? Total Amount of Blood _____ Over Time Period (days) _____
   - ☐ The Use of rDNA or Biohazardous materials?
   - ☐ The Use of Human Tissue or Cell Lines?

☐ The Use of Other Fluids that Could Mask the Presence of Blood (Including Urine and Feces)?
☐ The Use of Protected Health Information (Obtained from Healthcare Practitioners or Institutions)?
☐ The Use of academic records?

16. Does investigator or key personnel have a potential financial or other conflict of interest in this study?
☐ YES ☒ NO

APPLICATION NARRATIVE

A. PROPOSED RESEARCH RATIONALE

The aim of this study is to determine whether or not scarring affects face recognition performance and image quality. Scarring will be replicated using theatre arts application of liquid latex.

B. SPECIFIC PROCEDURES TO BE FOLLOWED

The testing area will have a digital camera collecting data for the experiment, data collection will only start after a subject has signed a consent form. Digital photographs will be the only data media captured from subjects.

Subjects will only have to visit the lab once in order to complete the study, as all experiment factors can be captured in one visit.

The subjects will be asked to sit in an International Standards Organization/International Electrotechnical Commission standard photo studio for data capture, as seen in Figure 1. Three (3) pictures will be taken of them as they are. Another three (3) will be taken of them with a theatre special effects make-up scar. The following video link shows the process for applying the latex scar:

https://youtu.be/0B7iX6zcOKA

This scar is constructed of liquid latex casted in a silicone mold. The following link shows a video demonstration on constructing prosthetic liquid latex scars:

https://youtu.be/xKlw3VtJr3E

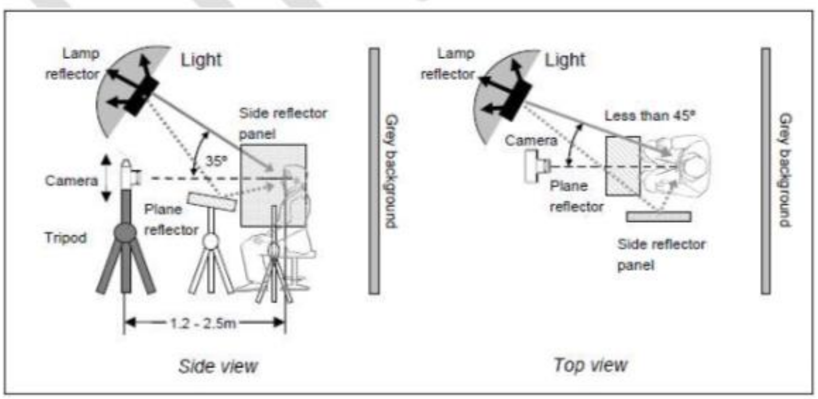

Figure 1. ISO/IEC JTC SC 37 compliant face image capturing arrangement.

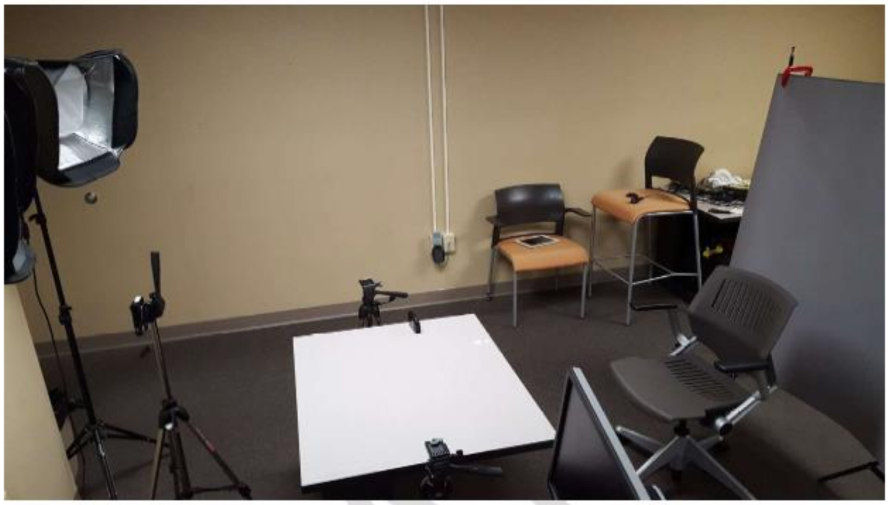

Figure 2. Current face image capturing setup at the ICBR.

Detailed Test Plan

Consent

1. Subject enters and is greeted by the test administrator
2. The test administrator gives a brief description of the data collection process and provides the subject with the consent form.
3. The subject reads and fills out the consent form and returns it to the test administrator.
    a. Any questions from the subject will be answered by the test administrator.
    b. Test administrator will ask questions to elicit understanding.
    c. Lastly, test administrator asks is most directly manner is subject is willingly volunteering their participation for the study.
4. The subject will be asked if they have noticeable facial scarring.
    a. Subject with self-declared noticeable facial scarring will only participate in Baseline and Operational Baseline data collections.
5. The test administrator saves the consent form and saves the subject data to the database.
6. After consenting the subject will be asked to take a seat within the ISO/IEC standard photo studio, as shown above in 2.
7. The test administrator will then go through the data collection procedure so the subject is made aware of the data collected.

Baseline Photos

1. Subject sits in the ISO/IEC standard photo studio.

2. Test administrator adjusts the camera to align camera centerline with subject face.
3. Test administrator checks to ensure camera is between 1.2 to 2.5 meters away from subject.
4. Subject will be asked to temporarily remove glasses (if any are worn).
5. Subject will be asked to temporarily refrain from smiling and making expressions.
6. Test administrator takes three (3) photographs
7. Test administrator gives the subject some face setting powder, and the subject applies the powder at his/her discretion.
8. Test administrator takes three (3) more photographs
9. Test administrator stops data collection.
10. Test administrator saves data to online storage.

Operational Baseline Photos

1. Subject stands in front of the mock border control booth.
2. Test administrator adjusts the webcam to align camera centerline with subject face.
3. Subject will be asked to temporarily remove glasses (if any are worn).
4. Subject will be asked to temporarily refrain from smiling and making expressions.
5. Test administrator takes three (3) photographs
6. Test administrator stops data collection.
7. Test administrator saves data to online storage

Scar – Photos with Special Effects

1. Subject is asked about any latex related allergies.
   a. Latex allergen is an exclusion criterion, which prevents subject participation.
   b. If subject has no medical issues, they may participate in the data collection.
2. Test administrator affixes liquid latex scar onto the top of the left brow of the subject.
3. Test administrator adjusts the camera to align camera centerline with subject face.
4. Test administrator checks to ensure camera is between 1.2 to 2.5 meters away from subject.
5. Subject will be asked to temporarily remove glasses (if any are worn).
6. Subject will be asked to temporarily refrain from smiling and making expressions.
7. Test administrator takes three (3) photographs
8. Test administrator stops data collection
9. Test administrator saves data to online storage

Operational Scar – Photos with Special Effects in an Operational Setting

1. With the liquid latex scar already affixed, the subject moves to the mock border control booth.
2. Test administrator adjusts the webcam to align camera centerline with subject face.
3. Subject will be asked to temporarily remove glasses (if any are worn).
4. Subject will be asked to temporarily refrain from smiling and making expressions.
5. Test administrator takes three (3) photographs
6. Test administrator stops data collection
7. Test administrator saves data to online storage

End of Visit

1. Once all photos have been taken, the subject will be paid for their time and the visit will end.
2. The test admin will navigate to the data in online storage and back it up in the database.

3. Once the data is synced, the test admin will rename each session folder to reflect the factor of the photo, baseline or scar, as well as the subject ID and visit number

During the study, the researchers (test administrators) will log any questions the subjects may ask as well as the investigators' responses to the questions.

C. SUBJECTS TO BE INCLUDED

While the study is all-inclusive for participants over the age of 18, the study seeks a broad range of ages, genders, ethnic backgrounds, and occupations. We intend to collect a maximum of 60 people, 30 regular subjects and 30 subjects with noticeable facial scarring; this is dependent on subjects who may drop out. Subjects with noticeable facial scarring is a self-disclosed classification. There are only one exclusion criteria for the study, which is latex allergic individuals.

Subjects will be asked to complete demographic information, such as:

- Sex
- Ethnicity
- Date of Birth
- Latex Allergy (Yes or No categorization)
    - Latex allergy will not be asked of subject with facial scarring
    - Subjects with facial scarring will not need prosthetic latex scars applied for this study

For subject management purposes, the subject's full name will be recorded but will not be stored with the study data.

D. RECRUITMENT OF SUBJECTS AND OBTAINING INFORMED CONSENT

Human subjects are required because the study is aimed at collecting photographic face data to examine possible effects on face recognition systems.

Subjects will be recruited in a number of possible ways, through the use of listservs, email, flyers, newspaper advertisements, and/or Facebook. These listservs exist in University email groups, for example various department's faculty/staff listserv. Other organizations on campus also have listservs that may be utilized for this study. We may recruit from various classes and student group meetings. If we do so, we will do so only after classes or meetings have ended (at the regularly-scheduled time or earlier) and the instructor and any other individuals associated with the conduct of the class/meeting (e.g., TA's, etc.) have left the room. The classes will be decided based on availability.

Potential subjects will come to the lab where they will receive a copy of the consent form to review at their convenience and research personnel will discuss the purpose and procedures of the study and answer any questions. If the signed consent form is returned to the study's research personnel, that subject will begin the study procedures at a mutually agreeable time.

Subjects should not have any visual or hearing impairments.

E. PROCEDURES FOR PAYMENT OF SUBJECTS

There will be a compensation of $10 for one visit. Subjects will be paid upon completion of the data collection at their visit.

F. CONFIDENTIALITY

A study ID will be given to each subject. This ID will be associated with all the study data collected as indicated in table under the specific procedures section of this application. Subjects' names will not be associated with any of the data collected in this study. A code key containing subjects' names and their study ID will be kept only for the purposes of tracking subjects' visits to the lab for data collection and their payment. The code key will be stored separately from the study data in the PI's office and destroyed after completion of the study.

The digital camera's SD memory card will have data manually transferred to the International Center for Biometrics Research (ICBR) storage. However, no other parties will not have access to the code key, subject names, or contact information. All study data will be secured in the PI's office, which is accessible only by key and biometric access control or magnetic card access, and on secure server accessible only by authorized researchers from Purdue's ICBR. Access to study data will be limited to the Purdue researchers. The study data will be kept indefinitely by both the PI for research and analysis purposes and product improvement only.

In addition, the ICBR may share the Research Data with third parties to help fulfill the Purposes. For example, the ICBR may ask faculty from a university, or other companies for help in analyzing this information. In this case, these third parties will have access to the Research Data.

For the purposes of distributing compensation, subjects' names, social security numbers, and contact information may be provided to the business office of Purdue University.

The study's research records may be reviewed by the Purdue University's Institutional Review Board and other federal officials as appropriate and by departments at Purdue University responsible for regulatory and research oversight.

G. POTENTIAL RISKS TO SUBJECTS

The study is determined to present no greater than minimal risk to subjects and is no more than they would encounter in everyday life. There is a potential risk of breach of confidentiality due to the collection of face image data. Data transferred and held within the system is encrypted

Latex allergens would have manifested in some way, shape, or form; for all adults. It is impossible to not come into contact with latex by consenting age. On the highly unlikely chance that a subject did not know they were latex allergic, the manifestations will vary from a simple red rash to small red hives. There is no life threatening risk as the latex application is on the epidermis, and not consumed or injected into the body.

Subjects will be asked to report all problems to the Purdue researchers.

H. BENEFITS TO BE GAINED BY THE INDIVIDUAL AND/OR SOCIETY

There are no direct benefits for the participant at this time. However, the benefits from the face image data from participants for future applications in security and access control could be immeasurable in the future.

I. INVESTIGATOR'S EVALUATION OF THE RISK-BENEFIT RATIO

There are no anticipated direct benefits to subjects and the risk is no greater than minimal risk which results in a favorable risk-benefit ratio.

L. SUPPORTING DOCUMENTS ***(to be attached to the Application Narrative)***

TO:

FROM:

SUBJECT: Recruitment of subjects for a study on face recognition and scarring

We are currently looking for people over the age of 18 to participate in a study that collects face image data to examine possible changes in face recognition systems. We will use special effects makeup to apply fake scars made with liquid latex. We are also trying to recruit those who have facial scarring to participate as well.

Why would you be interested in participating in this study?

The focus of this work is to understand the effects of scarring on a face recognition system. This study will contribute to our current identification and authentication paradigms; such as passports, driver's licenses, and automated face recognition.

What do I need to do to participate?

The study is very easy. During your visits, you will sit in an ISO/IEC standard photo studio and have your picture taken. Then will have some special effects makeup applied to simulate scarring. Another round of pictures will be taken, and the study concludes. Those who already have facial scarring only need to come in for taking pictures.

Study Duration and Compensation:

You will be paid a sum of $10 for one visit, only if you participate in the data collection. The visit should take no more than half an hour.

Study Location:

Young Room B030A

Participant Registration:

To register for an appointment, please visit our website at: www.icbrpurdue.org

Contact Information:

If you would like more information about this study, please contact us by email (provided below).

Kevin Chan: kjchan@purdue.edu

Appendix F: Research Participant Consent Form

RESEARCH PARTICIPANT CONSENT FORM
Face Image Capture with Special Effects Makeup Scarring
Dr. Stephen Elliott
Technology, Leadership, and Innovation
Purdue University

What is the purpose of this study?
The aim of this study is to determine whether or not scarring affects face recognition performance and image quality. Scarring will be replicated using theatre arts application of liquid latex.

Scarring is a normal function of mammalian tissue repair, optimized to heal wounds quickly under less sanitary conditions. Scarring and facial marks have been used within biometrics as a soft form of feature detection, which presents evidence that scarring may have an effect on performance and image quality. Face scarring can change the texture and color of the skin, both of which can affect face recognition algorithms as they are common factors analyzed in machine vision.

In this research, we are interested in the effects of scarring on face recognition performance and image quality. There are challenges with scarring as it manifests differently between individuals, and it presents texture and color changes to the face. Two different settings, controlled studio and a mock booth to simulate actual operations, will be used for the data capture.

Please note that if you are latex allergic, you cannot participate in this study.

What will I do if I choose to be in this study?
Only 1 Visit
After a signature has been collected from the consent form, the following steps will be taken in order to complete this data collection:

1. During the visit, you will be assigned a study ID number. This allows us to keep track of all your biometric data without using information about them that directly identifies you, such as your name. You will be asked to complete demographic information about yourself, such as gender, ethnicity, date of birth, any face scarring developed prior to visit, first name, middle name, and last name.

2. Up to 15 samples of face biometric data will be captured:
    a. Face photograph taken for subsequent face recognition analysis using a camera
    b. Baseline Procedure
        i. 3 Images of your face under normal everyday conditions
        ii. 3 Images of your face with setting powder
            1. The amount of powder application is at your own discretion

   iii. 3 Images of your face with a prosthetic scar using the mock booth set up

c. Liquid Latex Makeup Procedure
   i. The test administrator will apply a latex scar.
      1. These are commonly used special effects makeup used in film and theatre
      2. The prosthetic scars will be applied onto your left check
   ii. 3 Images of your face with a prosthetic liquid latex scar to measure against our first 3 baseline images
   iii. 3 Images of your face without the prosthetic scar using the mock booth set up

Subjects will be paid $10 for their one and only visit.

<u>Visit for Individuals with Facial Scarring</u>

The same process will be followed from those who have developed facial scarring within their lifetime. The only difference is that a total of 9 samples of face images will be captured, as there will not be a need to simulate face scarring using prosthetics.

Facial scarring will be a self-declaration. If you know you have developed a facial scar. Inform the test administrator.

Facial scarred subjects will be paid the same $10 for the visit.

<u>How long will I be in the study?</u>
The study consists of one in-person visits. Each visit will take about 20 minutes to complete.

<u>What are the possible risks or discomforts?</u>
The study is determined to be minimal risk, and is no more than they would encounter in everyday life. The data from each camera will be collected without any information that will directly identify you except for images from the application. All data from the application will be securely stored (*e.g.,* encrypted) within the International Center for Biometric Research. Although the data will be coded by using a study ID, there is a risk of a breach of confidentiality that could result in you being identified. The data will be kept indefinitely.

Latex allergens would have manifested in some way, shape, or form; for all adults. It is impossible to not come into contact with latex by consenting age. On the highly unlikely chance that you did not know you were latex allergic, the manifestations will vary from a simple red rash to small red hives. There is no life threatening risk as the latex application is on the epidermis, and not consumed or injected into the body.

<u>Are there any potential benefits?</u>
There are no anticipated direct benefits. However, the benefits from the evaluation and feedback from participants' interactions with new technologies for future applications in security and access control could be immeasurable in the future

<u>Will information about me and my participation be kept confidential?</u>
Only authorized researchers from Purdue's International Center for Biometric Research (ICBR) will have access to your de-identified data. As noted above, your data will be coded by using a unique study ID. Your name will not be associated with the de-identified data. Consent forms will be stored in a locked file cabinet in the lab only at Purdue.

Subjects' names will not be associated with any of the data collected in this study. A code key containing subjects' names and their study ID will be kept only for the purposes of tracking subjects' visits to the lab. The code key will be stored separately in the PI's office and destroyed after completion of the study.

The digital camera's SD memory card will have data manually transferred to the International Center for Biometrics Research (ICBR) storage. However, no other parties will not have access to the code key, subject names, or contact information. All study data will be secured in the PI's office, which is accessible only by key and biometric access control or magnetic card access, and on secure server accessible only by authorized researchers from Purdue's ICBR. Access to study data will be limited to the Purdue researchers. The study data will be kept indefinitely by both the PI for research and analysis purposes and product improvement only. In addition, the ICBR may share the Research Data with third parties to help fulfill the Purposes. For example, the ICBR may ask faculty from a university, or other companies for help in analyzing this information. In this case, these third parties will have access to the Research Data.

For the purposes of distributing compensation, subjects' names, social security numbers, and contact information may be provided to the business office of Purdue University.

The study's research records may be reviewed by the Purdue University's Institutional Review Board and other federal officials as appropriate and by departments at Purdue University responsible for regulatory and research oversight.

What are my rights if I take part in this study?

You do not have to participate in this research study. Participation is entirely voluntary. Refusal to participate will involve no penalty or loss of benefits to which you may be entitled. If you agree to have to participate, you can discontinue participation at any time without penalty or loss of benefits to which you may otherwise be entitled by contacting the principal investigator whose contact information is listed below. If you choose to discontinue your participation with the study at any point during data collection, compensation will not be provided for a visit that is not completed to the best of their ability. Compensation for a visit is only given to those individuals who complete the visit to the best of their ability. If you discontinue their study participation, the information already collected will be retained and used in the study.

Who can I contact if I have questions about the study?

If you have any questions about this research project or need to report an injury, you can contact the principal investigator, Stephen Elliott, by phone at 765-494-2311 or by email elliott@purdue.edu.

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu) or write to:

Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.,
West Lafayette, IN 47907-2114

Documentation of Informed Consent

Purdue IRB Protocol #: 1603017484 - Expires on: 30-MAY-2017

I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. We I am prepared to participate in the research study described above. I will be offered a copy of this consent form after I sign it.

__________________________________ ____________________
Participant's Signature Date

__________________________________ ____________________
Researcher's Signature Date

Appendix G: Research Advertisement and Recruitment Material

VITA

VITA

KEVIN J. CHAN
15 Ashbrook, Irvine, CA 92604 (permanent address)
(765) 430-1900 • kjchan@icbrpurdue.org

EDUCATION

Purdue University, West Lafayette, Indiana, USA

Master of Science — Aug 2014 to Aug 2016

Bachelor of Arts — Aug 2007 to Dec 2012

Berkshire School, Sheffield, MA

High School Diploma — Jun 2007

PERTINENT QUALIFICATIONS

Fluent in English, working knowledge of Chinese (both Mandarin and Cantonese).
Dual citizenship, US and Hong Kong.

PROFESSIONAL EXPERIENCE

Int'l Center for Biometric Research (ICBR), Purdue University — Aug 2014 to Present

Teaching Assistant and Center Research Staff

- Self-developed thesis on the effects of scarring on face recognition.
- Lecturing assistant for biometrics course, instructor for biometrics practical labs of 50 students.
- Co-author and editor contributions for scientific publications and proposals.
- Test administrator for human subject testing and biometric data collection.
- Collaborative writing for proposals to Institutional Review Board.
- Data collection and cleaning, Statistical Analysis, testing and performance reporting.
- Participated Projects
    - GlobalGood: Proposal author and data collection.
    - Wavefront Biometric: Data collection, test administrator, report author.
    - DHS/FPS Access Control: Proposal author, data collection, and test administrator.
    - Google ATAP: Data collection, test administrator, report author.
    - Authentify Phases 1 and 2: Data collection and test administrator.
    - NSTIC: Data collection and test administrator.
    - Paycasso: Data collection and report author.

Oshkosh Trucking Corp May 2014 to Aug 2014

Team Coordinator Intern

- FMTV Truck Floor and Trailer Tongue Weld Supervisor.
- Truck Remanufacture Co-Supervisor.
- Assisted in production line renovation projects for Truck Remanufacture Line and FMTV Floor Line
- Practitioners experience with high variance analysis, proficient in both control charting and Six-Sigma.

United States Marine Corps May 2008 to Dec 2013

Reservist – Corporal (E-4)

- Section Chief, Site Chief, and Platoon Sergeant managing and leading 40 Marines.
- Previous Clearance Level: SECRET.
- EKMS Custodian (Electric Key Maintenance & Security), planning and transport of high value assets.
- MIMS Clerk (Marine Integrated Maintenance System), collaborative projects with all job functions.
- 0612 Field Wireman, Telecommunications Programmer and Communications Maintenance.
- Point of Contact: Sgt. Koelling (317)370-3534.
- Participated Operations
    - Operation Javelin Thrust.
        - 2011, Site Switchboard Operator, Hawthorne Army Munitions Depot.
        - 2012, EKMS and Section Non Commission Officer, 29 Palms MCAGCC Camp Wilson.
    - Headquarters & Services Battalion Exercise 2013, 4th MLG.
        - Pre-iteration maintenance and inspecting operator, Communications Company.
        - Pre-iteration section Non Commission Officer, Wire Mux Data Section.

CITATIONS & PUBLICATIONS

- Chan, K. J., & Elliott, S. J. (2015). Mugshot Compliance for Face Image Quality. In H. R. Arabnia, L. Deligiannidis, & Q.-N. Tran (Ed.), *Computational Science and Computational Intelligence (CSCI), 2015 International Conference on* (pp. 428-432). Las Vegas: IEEE. doi:10.1109/CSCI.2015.20
- Moore, Z., Robertson, J., Connor, K. O., Chan, K., Chudik, J., Hutchison, T., … Thompson, N. (2015). The Use of Critical and Associated Tracking Points for HBSI Evaluation. *IEEE Access (in press)* (pp. 1–12)
- Chan, K., Chudick, J., …Elliott, S.J. (2016) Subject Movement at Different Force Levels in a Fingerprint Recognition System. *Security and Management (SAM), 2016 International Conference on (in press)* (pp. 1-7)

- Moore, Z., Chudik, J., Chan, K.,… O'Connor, K. (2016). Fingerprint and Entropy: An Analysis Across Sensors. *Security Technology, 2016 IEEE International Carnahan Conference on (in press)* (pp. 1-7)
- Chan, K., Elliott, S.J. (2016) Privacy Perceptions in Biometric Operations. e-Learning, e-Business, Enterprise Information Systems, and e-Government (EEE), The 15th International Conference on (in press)(pp. 1-7)