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National Institute of Justice (NIJ)
Sensor, Surveillance, and Biometric Technologies (SSBT)
Center of Excellence (CoE)

Evaluation of Contact versus Contactless Fingerprint Data (Final Report v2)

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EXECUTIVE SUMMARY

The National Institute of Justice (NIJ) Sensor, Surveillance, and Biometric Technologies (SSBT) Center of Excellence (CoE) has undertaken an evaluation of fingerprint data gathered from traditional two dimensional (2D) contact-based fingerprint devices and techniques versus fingerprint data generated by next-generation three dimensional (3D) contactless fingerprint scanners. The evaluation investigates the comparative match performance of legacy/livescan fingerprint (LFP) data and contactless fingerprint (CFP) data, for the purposes of exploring interoperability, technology viability, and challenges to operational deployment of next-generation contactless fingerprint systems. The principal work was performed by Azimuth Inc., as a subcontractor to ManTech International Corporation, under the SSBT CoE program. The work was also performed in collaboration with the Department of Defense (DoD), Director of Defense Biometrics & Forensics and the Biometrics Identity Management Agency (BIMA).

The data analysis was conducted using a fingerprint dataset collected by West Virginia University (WVU). The dataset is available for use by third-party research organizations upon request. Fingerprint data was collected from 500 subjects on the following devices:

- Rolled-ink fingerprint cards – Digitized at 500 dots per inch (dpi) and 1000 dpi
- Legacy/Livescan Fingerprint (LFP) Devices:
    a. Cross Match Guardian R2 – Rolled fingers and slaps
    b. i3 DigID Mini – Rolled fingers and slaps
    c. L1 TouchPrint 5300 – Rolled fingers and slaps
    d. SEEK II – Rolled fingers and prints
- Contactless Fingerprint (CFP) Devices
    a. Touchless Biometric Systems (TBS) 3D Enroll Device – Individual fingers
    b. FlashScan 3D Single Finger Scanner – Individual fingers
    c. FlashScan 3D 4-Finger Slap D4 Scanner – Slaps

NOTE: The lack of available 3D matchers and varying collection methodologies and data formats used among 3D collection devices required the evaluation to focus on a format common to all devices: the 2D legacy fingerprint image. Due to the limitations of 3D images converted to 2D images, the quality or efficacy of the 3D contactless fingerprint devices in capturing topological fingerprint details was not investigated.

Twenty matching runs were performed on the data collected from devices and card-scans using the Neurotechnology MegaMatcher Suite fingerprint algorithm (version 4.2) software. The various matching efforts are organized into the following categories:

- Galleries were matched against themselves to establish ground truth performance
- LFP datasets were matched against LFP galleries
- CFP datasets were matched against LFP galleries
- CFP dataset were matched against CFP galleries
- Select LFP datasets were matched against a CFP gallery

NOTE: Raw 3D images generated from optical structured light (i.e. FlashScan Single and D4) and other methods are not directly compatible with existing fingerprint matching algorithms. As a result, all analysis discussed in this report does not utilize this 3D fingerprint data directly, rather the analysis is performed on images obtained from each 3D system's transformation of the scanned data into 2D grayscale images that are intended by their vendors to be matchable against existing fingerprint databases.

Matching results were analyzed and compared based on True Accept Rate (TAR) and National Institute of Standards and Technology (NIST) Fingerprint Image Quality (NFIQ) score. A summary of matching results is included here:

	Percent True Accept Rate (Based on Matched Pairs)	
MATCHING RUNS	**True Match**	**False Match**
Gallery Runs		
GR1- Cross Match R2 Set 1 vs. Set 1	100%	0%
GR2- Cross Match R2 Set 2 vs. Set 2	100%	0%
GR3- Card Scan 500 dpi vs. 500 dpi	100%	0%
GR4- FlashScan Single vs. Single	100%	0%
GR5- TBS (HT1) vs. TBS (HT1)	100%	0%
2D LFP Runs		
LFPR1- I3 vs. G1	92.66%	7.34%
LFPR2- L1 vs. G1	96.58%	3.42%
LFPR3- Card Scan 500 dpi vs. G1	91.34%	8.66%
LFPR4- Cross Match SEEK vs. G1	97.80%	2.20%
CFP Devices Runs		
CFP to LFP Runs		
CFPR1- FlashScan Single vs. G1	71.40%	28.60%
CFPR2- FlashScan D4 vs. G1	17.05%	82.95%
CFPR3- TBS (HT1) vs. G1	91.15%	8.85%
CFPR4- TBS (HT2) vs. G1	85.67%	14.33%
CFPR5- TBS (HT6) vs. G1	86.42%	13.58%
CFP to CFP Runs		
CFPR6- FlashScan D4 vs. G4	11.80%	88.20%
CFPR7- TBS (HT1) vs. G4	65.75%	34.25%
CFPR8- TBS (HT2) vs. G4	56.53%	43.47%
Additional GR5 Runs		
AR1- FlashScan Single vs. G5	65.64%	34.36%
AR2- Cross Match R2 Set 1 vs. G5	90.73%	9.27%
AR3- Cross Match SEEK vs. G5	91.20%	8.80%

In general, seven key observations/conclusions were identified as a result of this evaluation effort:

- This effort is the first quantitative demonstration by a third party that fingerprints collected under ideal conditions from LFP and CFP devices can be matched against each other in a statistically meaningful way.
  - Conclusion: The experimental methodology employed (data collection and analysis) can be used to determine a comparative match performance among LFP and CFP using 2D projections.

- Matching CFP legacy-equivalent images to LFP images provides less match performance than LFP images to LFP images.
  - Conclusion: More work is needed to improve the quality of captured images or the quality of 2D legacy-equivalent conversions. Additional research opportunities may exist in developing or modifying fingerprint matching algorithms that are less sensitive to skin elasticity.

- Matching CFP legacy-equivalent images between the various contactless devices provided very poor results as compared to currently available technologies.
  - Conclusion: Additional research may be necessary to provide better CFP to LFP conversion algorithm accuracy.

- The ink and paper collection provided lower similarity scores from the fingerprint matcher and had poorer NFIQ scores. We assume from this finding that ink and paper fingerprinting requires more skill and experience than collecting on live scan devices. Additionally, live scan fingerprint collection devices generally provide immediate quality feedback and the opportunity to recollect a poor fingerprint.
  - Conclusion: Rolled-ink tenprint cards may not be the "gold standard" ground-truth gallery for biometric testing or research

- The Cross Match SEEK II performed better than expected as a livescan collection device, as compared to the other legacy CFP systems. The reason for expectations of lower match performance was due to the smaller platen surface area.
  - Conclusion: SEEK may be suitable for field enrollments, and is more than adequate for field queries.

- The FlashScan D4 performed very poorly. The device had several failures during collection efforts and required vendor support. Also, due to the failures this device had the fewest number of collection subjects.
  - Conclusion: Data from prototypes can be significantly poorer than commercial systems using similar capture approaches, and therefore the purpose/objective of data collections should be taken into account when considering the inclusion of prototypes.

- The images collected by the TBS 3D Enroll are mirrored along the vertical axis, causing an inability to match against standard datasets. The Test Team corrected the images locally prior to testing. Images in the WVU dataset remain unchanged.
    - Conclusion: Devices developed for civilian access control applications, or for foreign markets, may not follow standard Appendix F requirements. Research, Development, Test, and Evaluation (RDT&E) must be aware of potential issues.

As one of the first research efforts to investigate the match performance and interoperability of contact and contactless fingerprint data, this work has made important first steps. However, there are many related areas or follow-on tasks that could be pursued. The dataset collection and foundational analysis should aid enterprise and research endeavors to improve biometric and identity management knowledge and capabilities.

1.0 SCOPE

Azimuth Incorporated, as a subcontractor of ManTech International Corporation, is supporting the NIJ SSBT CoE program in the test and evaluation (T&E) of prototype biometric technologies and devices. This document describes the Evaluation of Contact versus Contactless Fingerprint Data. The evaluation investigates the comparative match performance of legacy/livescan fingerprint (LFP) data and contactless fingerprint (CFP) data, for the purposes of exploring interoperability, technology viability, and challenges to operational deployment of next-generation 3D contactless fingerprint systems.

2.0 BACKGROUND

2.1 Classifications of Fingerprint Scanners

For purposes of this evaluation, the following definitions are used when describing fingerprint devices. Note that these are not formally approved or accepted by standard or professional organizations, but are in line with colloquial use of the terms in biometrics R&D and applications.

2D – A device or methodology that captures a flat projection of a fingerprint. No topographical surface or curvature information is captured.

3D – A device which captures topological surface and/or curvature information of the fingerprint

Contact – Any of a range of methods or devices that require subjects to press fingers onto a platen or surface to gather fingerprint images.

Contactless – A methodology of collecting fingerprint data that requires no direct contact between the fingerprint and a device. In this interpretation, "contactless" refers to the sensor and fingerprint area only; a system that requires no contact with the subject whatsoever would be considered a "touchless" system.

Nail-to-nail – A subject's fingerprint extending from one side of the finger (near the finger nail) all the way around to the other side (near the opposite side of the finger nail).

Rolled-ink Equivalent – See nail-to-nail

NOTE: The lack of available standards based 3D matchers and varying collection methodologies and data formats used among 3D collection devices required the evaluation to focus on a format common to all devices: the 2D legacy fingerprint image. Due to the limitation of working only with 3D images converted to 2D images, the quality or efficacy of the 3D contactless devices in capturing topological fingerprint details was not investigated.

NOTE: Because the terminology regarding fingerprint scanners is not standardized, vendors or researchers may utilize "3D", "touchless", "contactless", and "noncontact" interchangeably or in differing ways. Readers are advised to understand the technology and captured data of a device before making comparison or conclusions. For example, some use "3D" to indicate the capture of full 3D detail as a point-cloud that captures very fine ridge and shape detail across the surface of the finger (which is then projected algorithmically to a 2D rolled-equivalent representation), while others may use "3D" to mean capturing 2D photo images of a fingerprint from different angles and combining the images to produce a 2D rolled-equivalent image of a 3D object (i.e. finger). Both methods are identified as "3D", but the resulting scans provide vastly different types and amounts of data.

2.2 WVU Fingerprint Collection

The data analysis was conducted using a fingerprint dataset collected by WVU. For WVU Institutional Review Board and data request purposes, the collection, protocol, and dataset are formally titled "ManTech Innovations Fingerprint Study." The dataset is available for use by third-party research organizations by submitting an email request to wvubiometricdata@mail.wvu.edu The WVU provided *Data Types and Organization* document is provided as Appendix B. The full report detailing the WVU fingerprint collection is included in Appendix C for reference. Fingerprint data was collected from 500 unique subjects in a controlled, sterile environment during the time period of April – July 2012 on the following devices:

- Rolled-ink fingerprint cards – Digitized at 500 dpi and 1000 dpi
- Legacy Fingerprint Devices:
  a. Cross Match Guardian R2 – Rolled fingers and slaps
  b. i3 DigID Mini – Rolled fingers and slaps
  c. L1 TouchPrint 5300 – Rolled fingers and slaps
  d. SEEK II – Rolled fingers and prints
- Contactless Fingerprint Devices
  a. Touchless Biometric Systems (TBS) 3D Enroll Device – Individual fingers
  b. FlashScan 3D Single Finger Scanner – Individual fingers
  c. FlashScan 3D 4-Finger Slap D4 Scanner – Slaps
     i. *Due to technical issues, the D4 was not operational during the entire collection. As a result, data from only 184 subjects was collected on the FS3D D4.*

2.3 Fingerprint Scanners

Seven fingerprint scanners were included in this effort – 4 traditional contact-based devices and 3 contactless devices. The selection of the traditional devices was due to collaboration with the DoD, Director of Defense Biometrics & Forensics. These systems were offered up due to their availability and use in the field under various DoD biometric operations (e.g., enrollment, access control, identification verification, tactical operations). Resource and schedule limitations precluded the inclusion of additional devices. The contactless devices were selected based on availability. The development of the FlashScan prototypes had previously been funded by DoD BIMA and had not undergone performance T&E. BIMA had the FlashScan devices on-hand and provided them for use in this data collection. Additional contactless prototype fingerprint devices were pursued, but were unable to be included due to various limitations. While significant effort was made to identify commercially available contactless 3D fingerprint devices, only the TBS 3D Enroll was available for purchase prior to initiating this study.

Figure 1 – Cross Match Guardian R2

Guardian R2 (by Cross Match Technologies) – Compact desktop tenprint scanner for criminal and applicant livescan and enrollment applications. The device utilizes a contact optical capture with a transparent silicon pad with improved fingerprint collection. Federal Bureau of Investigation (FBI) Appendix F certified; 500 dpi capture resolution.
http://www.crossmatch.com/l-scan-guardian-r2.php

Figure 2 – i3 DigID Mini

DigID Mini (by i3) – Small desktop tenprint scanner for background checks. The device utilizes a contact optical capture. FBI Appendix F certified; 500 dpi capture resolution.
http://www.idintl.com/index.php/products-services/biometric-hardware/digid-mini

Figure 3 – L-1 TouchPrint 5300

TouchPrint 5300 (by L-1 Identity Solutions) – Medium-sized desktop tenprint scanner for law enforcement booking and enrollment. The device utilizes a contact optical capture. FBI Appendix F certified; 500-1000+ dpi capture resolution.
http://www.l1id.com/pages/745-5300-5600

Figure 4 – Cross Match SEEK II

SEEK II (by Cross Match) – Medium-large mobile handheld biometric device for queries and enrollment from the field. FBI SAP Level 45 certification; 500 dpi capture resolution.
http://www.crossmatch.com/seekII.php

Figure 5 – TBS 3D Enroll

3D Enroll (by TBS) – Commercially available compact desktop single-finger contactless scanner for civilian and criminal access control and enrollment applications. The device utilizes three fixed cameras with diffuse illumination to detect and capture an image of an inserted finger. Captured images are nail-to-nail in capture area, but do not include 3D topological ridge details. Not FBI-certified; Output includes three 2D converted grayscale rolled-equivalent images (HT1, HT2, HT6) for each individual finger generated using unspecified pre and post processing methods at 500 dpi resolution. The TBS vendor recommends HT1 or HT2 as probes against legacy databases.
http://www.tbs-biometrics.com/fileadmin/documents/products/productsheets_en/en_productsheet_3d-enroll.pdf

Figure 6 - FlashScan Single Finger Scanner

Single Finger Scanner (by FlashScan 3D) – Late stage prototype compact single-finger 3D contactless scanner. Though this is a fairly refined prototype, it is not a commercial offering. FlashScan has continued development on this line of scanners; the results in this report do not reflect any improvements made to the final product. The device utilizes a proprietary structured

light projection onto an inserted finger to detect and capture fingerprint details. The fingerprint scan provides finger shape and topological ridge detail across the surface of the finger. This captured data is projected as a 2D image which is equivalent to a legacy contact-based fingerprint. Not FBI-certified; Output includes a 2D converted grayscale contact-equivalent fingerprint image at 500 dpi resolution.
http://www.flashscan3d.com/

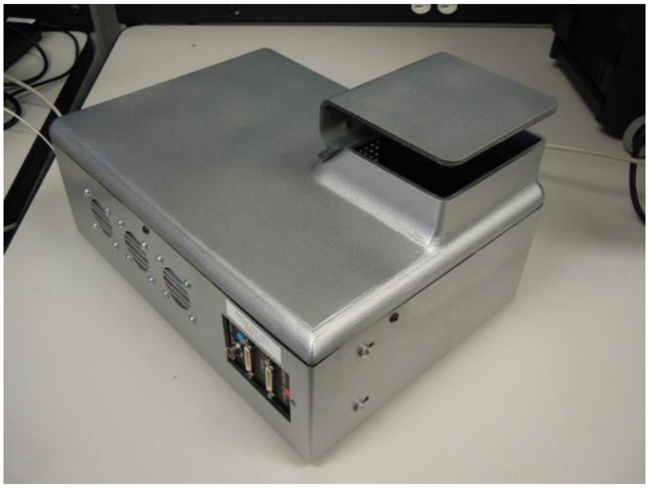


Figure 7 – FlashScan D-4 Scanner

D-4 Scanner (by FlashScan 3D) – Prototype medium-sized four-finger slap 3D contactless scanner. The device utilizes a proprietary structured light projection onto an inserted set of four fingers to detect and capture fingerprint details, followed by segmentation of individual fingerprints. Captured images are contact-equivalent in surface area and include detailed 3D topological ridge details. Not FBI-certified; Output includes a set of individual 2D converted grayscale rolled-equivalent fingerprint images (one for each of the four fingers) at 500 dpi resolution.
http://www.flashscan3d.com/

More information on the 3D contactless fingerprint scanners can be found in the report, *"Contactless Fingerprint Technologies Assessment,"* published by the SSBT CoE.

3.0 TEST ENVIRONMENT & APPROACH

3.1 System Test Environment.

The lab evaluation environment consists of the resources needed to evaluate the fingerprint images collected from the devices in the WVU dataset. The hardware environment for the evaluation consists of a Windows 7 (64 bit) operating system executing on a Dell Precision T7500 64-bit with a dual quad core processor. It has 12 GB of system RAM, a 256 GB solid state drive, and two 1 TB hard drives configured as a RAID 1 drive. Two such computers were utilized to run parallel matching runs. These computers hosted the Neurotechnology's MegaMatcher algorithms as well as the fingerprint datasets. The computers were also utilized to host the backend data reduction and analysis tools.

These computing resources host the Neurotechnology's MegaMatcher, which was used to enhance the images, extract the fingerprint features (create a template), and perform matching. This matcher was selected based on its low cost, product maturity, performance, and experience integrating it into many products. The performance of Neurotechnology algorithms is well known due to over 10 years of participation in National Institute of Standards and Technology (NIST) biometric algorithm performance challenges.[1]

3.2 Fingerprint Datasets for Evaluation

The fingerprint images used by this evaluation were collected from seven fingerprint collection devices as well as ink and paper, as detailed previously (see Section 2.1). Two sets of fingerprint data were captured from each device and are contained in the WVU collection dataset (see Appendix C). The data was captured on contactless and contact devices alike. Although the device collections contain multiple datasets, due to time and resource constraints only one set from each device was used in this evaluation. The contact-based devices and ink and paper datasets were evaluated against themselves (both gallery and probe images) to determine the set that had the highest TAR performance. The dataset with the best TAR and NFIQ distribution (combined with recommendations from WVU) was used as ground truth enrollment for the evaluation of all collected datasets. Both Cross Match R2 datasets (each dataset as both probe and gallery) were evaluated to determine which provides the better match scores. In the end, the better performer was the Cross Match R2 Set 1, based on matcher similarity scores and NFIQ distribution. This dataset was then used as the gallery for all the LFP and CFP dataset probes throughout the legacy matching evaluation. Additionally, the FlashScan3D Single Finger and TBS 3D Enroll galleries were used as enrollment galleries to explore CFP device interoperability in the CFP matching evaluation. The following list identifies how the evaluations and this document are organized.

[1] NIST, *Image Group Fingerprint Overview*, http://www.nist.gov/itl/iad/ig/fingerprint.cfm.

Gallery Runs

GR1 – Cross Match Guardian R2 Set 1 vs. Cross Match Guardian R2 Set 1
GR2 – Cross Match R2 Set 2 vs. Cross Match R2 Set 2
GR3 – Card Scan 500 dpi vs. Card Scan 500 dpi
GR4 – FlashScan Single vs. FlashScan Single
GR5 – TBS 3D Enroll (HT1) vs. TBS 3D Enroll (HT1)

LFP Device Runs

LFPR1 – i3 DigID Mini vs. Gallery 1
LFPR2 – L-1 TouchPrint 5300 vs. Gallery 1
LFPR3 – Card Scan 500 dpi vs. Gallery 1
LFPR4 – Cross Match SEEK II vs. Gallery 1

CFP Device Runs

CFP to LFP Runs

CFPR1 – FlashScan Single vs. Gallery 1
CFPR2 – FlashScan 4D vs. Gallery 1
CFPR3 – TBS 3D Enroll (HT1) vs. Gallery 1
CFPR4 – TBS 3D Enroll (HT2) vs. Gallery 1
CFPR5 – TBS 3D Enroll (HT6) vs. Gallery 1

CFP to CFP Runs

CFPR6 – FlashScan D4 vs. Gallery 4
CFPR7 – TBS 3D Enroll (HT1) vs. Gallery 4
CFPR8 – TBS 3D Enroll (HT2) vs. Gallery 4

Additional Runs with TBS (HT1) as Gallery

AR1 – FlashScan Single vs. Gallery 5
AR2 – Cross Match Guardian R2 Set 1 vs. Gallery 5
AR3 – Cross Match SEEK II vs. Gallery 5

The fingerprint images collected with contactless scanners do not suffer from distorted images due to varying degrees of pressure on a platen caused by skin elasticity or operator differences, nor do they suffer from the smearing caused by fingerprint movement on a platen or when collecting using ink and paper.

NOTE: Raw 3D images generated from optical structured light (i.e. FlashScan Single and D4) and other methods are not compatible with existing fingerprint matching algorithms. As a result, all analysis discussed in this report does not utilize this 3D fingerprint data directly, rather the analysis is performed on images obtained from the 3D system's transformation of the scanned data into 2D grayscale images that are intended to be matchable against existing fingerprint databases.

3.2.1 TBS 3D Enroll Mirrored Image Issue

A major problem with the TBS image collection was identified while matching runs were completing. During the matching runs that used the TBS device images, the match performance of the TBS images to the Cross Match R2 Set 1 and FlashScan Single galleries provided abysmal results (see table below). This problem would have never presented itself to TBS so long as they were matching images collected and stored as gallery to TBS device collected probe images (mirrored images matching to mirrored images). Also, this problem was not a result of poor or an incorrect collection effort by WVU. After some analysis, the CoE identified the issue to be that all TBS images were mirrored along the vertical axis. This caused some delay in schedule to first correct the TBS images and then to rerun the matching to both galleries. The matching results reflect the percent TAR for the original and the corrected mirrored TBS device images. Results are provided in the table below where Gallery 1 is the Cross Match R2 Set 1 and Gallery 4 is images from the FlashScan Single device.

		Percent True Accept Rate	
MATCHING RUNS		**Original TBS Images**	**Mirrored TBS Images**
CFPR3	TBS HT1 vs. Gallery 1	1.39%	91.15%
CFPR4	TBS HT2 vs. Gallery 1	0.89%	85.67%
CFPR5	TBS HT6 vs. Gallery 1	1.05%	86.42%
CFPR7	TBS HT1 vs. Gallery 4	0.46%	65.75%
CFPR8	TBS HT2 vs. Gallery 4	0.65%	56.53%

3.3 Evaluation Methodology

The evaluation team utilized the Neurotechnology MegaMatcher Standard SDK (Version 4.2) fingerprint matching algorithm. This matcher was selected based on its availability, low cost, product maturity, performance, and knowledge and experience of our staff integrating it into evaluation environments. The performance of the MegaMatcher algorithm is well known to the biometrics community due to its participation in NIST biometric algorithm performance challenges. However, the Neurotechnology MegaMatcher matching algorithm is not a 3D fingerprint matcher. Due to the lack of 3D fingerprint matching algorithms, all image data collected on contactless devices and used during matching was necessarily converted to a 2D (or legacy) representation. Each of the CFP devices performed the 2D conversion within its own software using methods specific to the capture technology. The use of a standard fingerprint matching software package was appropriate, as each of the devices performed its own conversions and was intended by its vendor to match against existing 2D databases that use similar algorithms.

The evaluations were conducted with known match result datasets. In all cases prior to conducting a matching run, the subject ID and finger positions for both probe and gallery correct matches were known. Prior to a matching run, the gallery was prepared for the run by creating a fingerprint template for each gallery image. Each probe fingerprint image was compared to all gallery entries and a set of similarity scores was recorded. The matching threshold was set to zero so that all comparisons would result in a similarity score. This process was repeated for all probes for an N:N matching run. Most N:N matching runs resulted in over twenty four and a half million comparisons or matches.

The similarity score is a metric for the probability that a matched pair of biometrics originated from the same person. Generally, a matcher threshold (specific similarity score value) is used to truncate all matches below the threshold to a null value to guarantee a non-match result. Because the matcher similarity score threshold was set to zero all matches returned a similarity score value that was needed and used in our analysis. According to MegaMatcher documentation, the matching threshold of its system is directly linked to the false accept rate (FAR), the probability that biometrics from different subjects are erroneously accepted as a true match. Neurotechnology provides an equation and resulting FAR-Threshold equivalence table in the SDK documentation.[2]

FAR	Matching Threshold Score
100%	0
10%	12
1%	24
0.1%	36
0.01%	48
0.001%	60
0.0001%	72
0.00001%	84
0.000001%	96

Following the matching runs, the analysis reported the total number of comparisons, the total number of mated pairs, number of unique subjects from the matched pairs, the number of rank 1 true matches, number of rank 1 false matches, the minimum and maximum similarity scores for genuine and imposter population, and a NFIQ score for each probe image. The similarity scores were compiled for genuine and imposter populations for each matching run. The matcher returned similarity score quantifies the correspondence between the probe and gallery comparison. The similarity scores generated are specific to this particular vendor's matching algorithm and cannot be directly compared to other vendors' matcher similarity scores. Following each matching run, the results were compiled and compared to other similar matching runs. Results and conclusions concerning the fingerprint device images were then compared to similar devices to determine performance.

[2] Neurotechnology, *MegaMatcher 4.2, VeriFinger 6.4, VeriLook 5.1, VeriEye 2.4, and VeriSpeak 1.0 SDK Developer's Guide* (2012).

4.0 EVALUATION RESULTS

The laboratory team evaluated the effectiveness of matching 2D LFP images collected by different devices to legacy datasets, matching CFP images to legacy 2D images, and matching CFP images to CFP images collected by other vendor devices. The CFP images used in this evaluation are 2D projections or rolled equivalents, 3D fingerprint images were not matched to any datasets.

4.1 Gallery Run Results

There were 5 galleries created to evaluate the images collected from the 7 fingerprint devices and ink and paper. These 5 galleries are the Cross Match R2 Set 1, Cross Match R2 Set 2, the 500 dpi Card Scan, the FlashScan Single Finger Scanner, and the TBS (HT1).

The 2D LFP collection that was selected as the ground truth was the Cross Match R2 Set 1. This image set was selected from the two datasets collected by the Cross Match R2 device because of higher match performance, as determined by the matcher similarity scores, and better NFIQ score distribution. This dataset was also recommended by WVU, based on their subjective evaluation of the quality of the images during the collection. The decision for gallery selection was based on an evaluation of match scores and NFIQ score distribution of both Set 1 and Set 2. Both datasets produced a TAR of 100% Rank 1 and neither of the datasets produced any false matches. The minimum and maximum score values were different enough to select set 1 as the gallery that would be used for the matching runs in this evaluation. Set 1 had a minimum match score value of 1724 and maximum was 6774. The minimum match score for set 2 was 812 and maximum value of 6534. The distribution of NIST NFIQ scores between the two datasets is very similar so this measure was not the discriminating factor in selecting set 1 as gallery (see Figure 49 - Gallery NFIQ Compare).

The CFP rolled equivalent image dataset selected to provide a gallery for contactless matching runs was the FlashScan Single collected image set. Although the FlashScan Single is not a commercial product it was the only CFP device that was considering FBI Criminal Justice Information Systems (CJIS) Appendix F certification. The TBS device is a commercial device sold for logical access. Following planned matching runs, there was schedule available to investigate matching of LFP devices to CFP rolled equivalents. Given the quality of the TBS (HT1) collected images, Gallery 5 was created and used for the additional runs.

4.1.1 GR1 – Cross Match Guardian R2 Set 1 vs. Cross Match R2 Set 1

The run consisted of probe images and gallery collected by the Cross Match Guardian R2 device. The Cross Match R2 collected 2 sets of fingerprint images from the same subjects. The purpose of the run was to determine the matching performance of set 1 and be able to compare it to the match performance of set 2. The Cross Match Guardian R2 Set 1 (GR1) consisted of the probe set with 4974 images from 498 unique subjects matched against the enrolled Galley 1. This combination resulted in 4974 matched pairs (total possible true matches) from 498 unique subjects. The Match Error of 0 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate was 100% and the false accept rate was 0%. There were 4974 True Matches where all occurred in rank 1. The similarity scores for the genuine population ranged from a low of 1724 to a high of 6774. There were no false matches so similarity scores were not generated for the imposter population. In addition, there are two graphics below that depict the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine population of rank 1 score values from the fingerprint matcher. The first graph provided (Figure 8) represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine population's graph (Figure 9) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	Description		Results	Percent	Score Min	Score Max
GR1						
Cross Match R1 Set 1 vs. Cross Match R1 Set 1	Gallery	Total Images	4974			
		Unique Subjects	498			
	Probe	Total Images	4974			
		Unique Subjects	498			
	Matches	Total Matched Pairs	4974			
		Matched Pair Subjects	498			
		True Match (Rank 1)	4974	100	1724	6774
		False Match (Rank 1)	0	0	n/a	n/a
		Error Match (Rank 1) (true mat not possible)	0			
		Total	24740676			

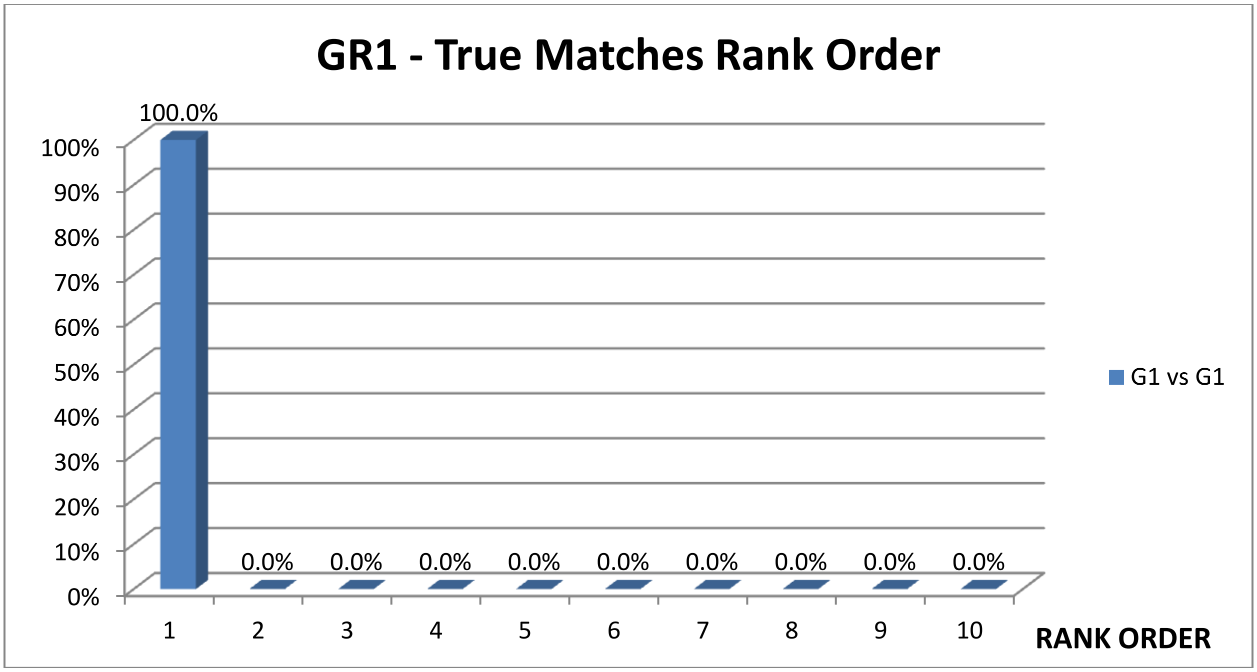


Figure 8 - GR1 True Matches Rank Order

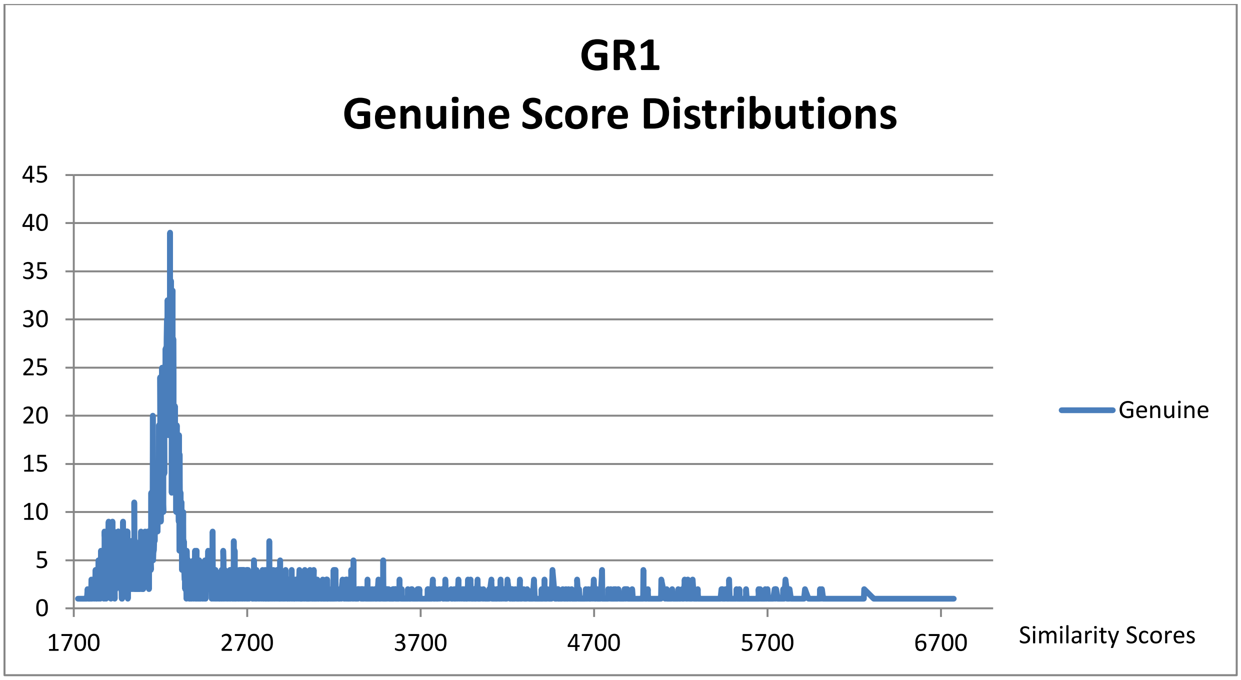


Figure 9 – GR1 Genuine Score Distributions

4.1.2 GR2 – Cross Match Guardian R2 Set 2 vs. Cross Match R2 Set 2

The run consisted of probe images and gallery collected by the Cross Match Guardian R2 device. The Cross Match R2 collected 2 sets of fingerprint images from the same subjects. The purpose of the run was to determine the matching performance of set 2 and be able to compare it to the match performance of set 1. The Cross Match Guardian R2 Set 2 (GR2) consisted of the probe set with 4963 images from 497 unique subjects matched against the enrolled Galley G2. This combination resulted in 4963 matched pairs (total possible true matches) from 497 unique subjects. The Match Error of 0 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate was 100% and the false accept rate was 0%. There were 4963 True Matches where all occurred in rank 1. The similarity scores for the genuine population ranged from a low of 812 to a high of 6534. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine population of rank 1 score values from the fingerprint matcher. The first graph (Figure 10) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine population's graph (Figure 11) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
GR2						
Cross Match R1 Set 2 vs. Cross Match R1 Set 2	Gallery	Total Images	4963			
		Unique Subjects	497			
	Probe	Total Images	4963			
		Unique Subjects	497			
	Matches	Total Matched Pairs	4963			
		Matched Pair Subjects	497			
		True Match (Rank 1)	4963	100	812	6534
		False Match (Rank 1)	0	0	n/a	n/a
		Error Match (Rank 1) (true mat not possible)	0			
		Total	24631369			

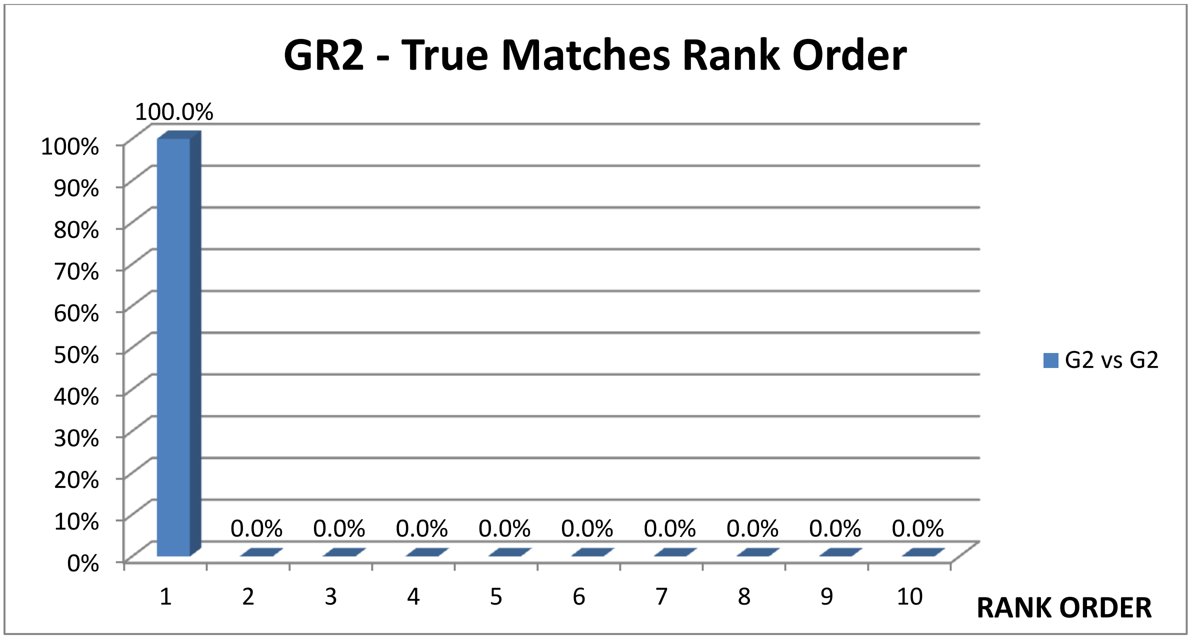


Figure 10 - GR2 True Matches Rank Order

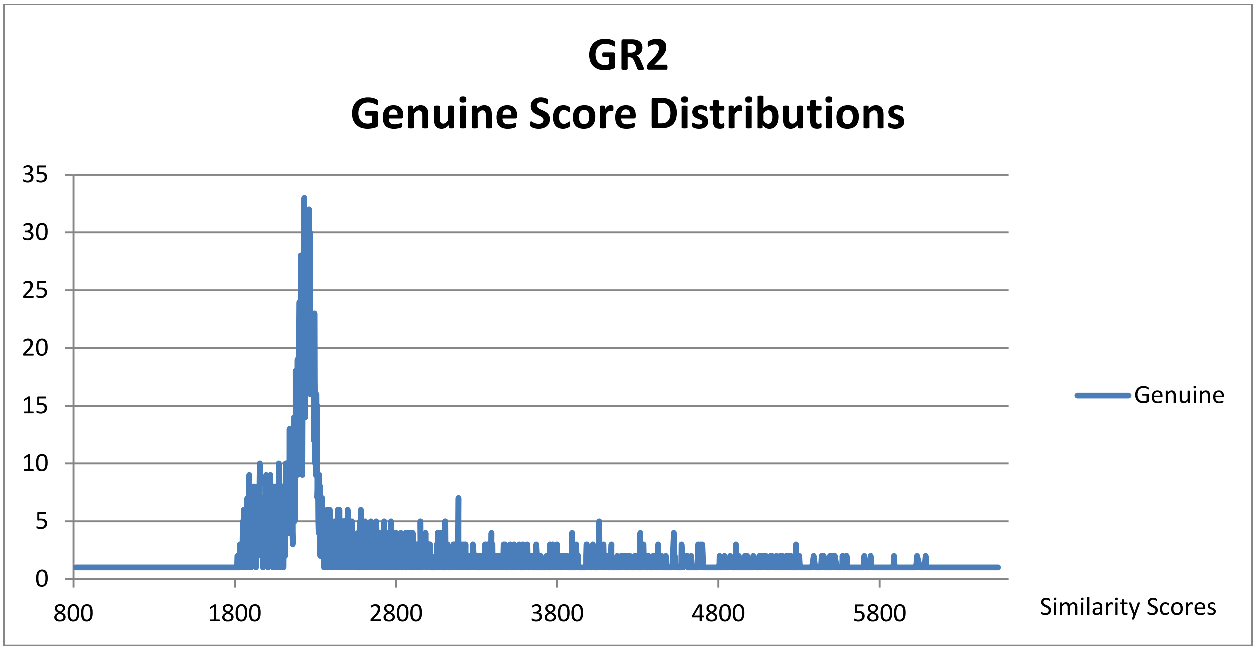


Figure 11 - GR2 Genuine Score Distributions

4.1.3 GR3 – Card Scan 500 dpi vs. Card Scan 500 dpi

The run consisted of probe images and gallery collected using ink and paper and then scanned at 500 dpi (using AWARE AccuScan software and FBI Appendix F certified Epson V700 scanner). The purpose of the run was to determine the matching performance of the ink and paper 500 dpi scanned images and compare it to itself. This run was also performed to confirm the qualitative observation that the Cross Match fingerprint data was of a higher quality than the rolled-ink prints, and therefore more suitable as a foundational 2D gallery. This match performance was useful in determining the strengths and weaknesses of the image collections. The Card Scan 500 dpi (GR3) consisted of the probe set with 4961 images from 497 unique subjects matched against the enrolled Galley 3. This combination resulted in 4961 matched pairs (total possible true matches) from 497 unique subjects. The Match Error of 0 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate was 100% and the false accept rate was 0%. There were 4961 True Matches where all occurred in rank 1 and 0 false matches. The similarity scores for the genuine population ranged from a low of 1046 to a high of 6660. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine population of rank 1 score values from the fingerprint matcher. The first graph (Figure 12) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine population's graph (Figure 13) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	Description		Results	Percent	Score Min	Score Max
GR3						
Card Scan 500 dpi vs. Card Scan 500 dpi	Gallery	Total Images	4961			
		Unique Subjects	497			
	Probe	Total Images	4961			
		Unique Subjects	497			
	Matches	Total Matched Pairs	4961			
		Matched Pair Subjects	497			
		True Match (Rank 1)	4961	100	1046	6660
		False Match (Rank 1)	0	0	n/a	n/a
		Error Match (Rank 1) (true mat not possible)	0			
		Total	24611521			

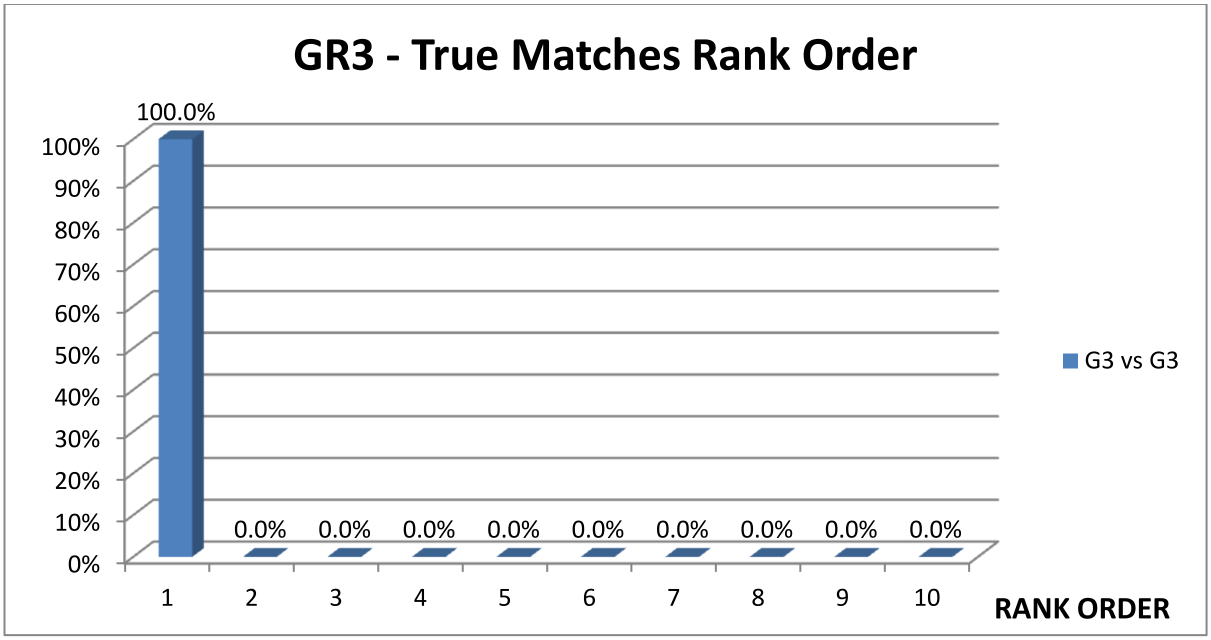


Figure 12 - GR3 True Matches Rank Order

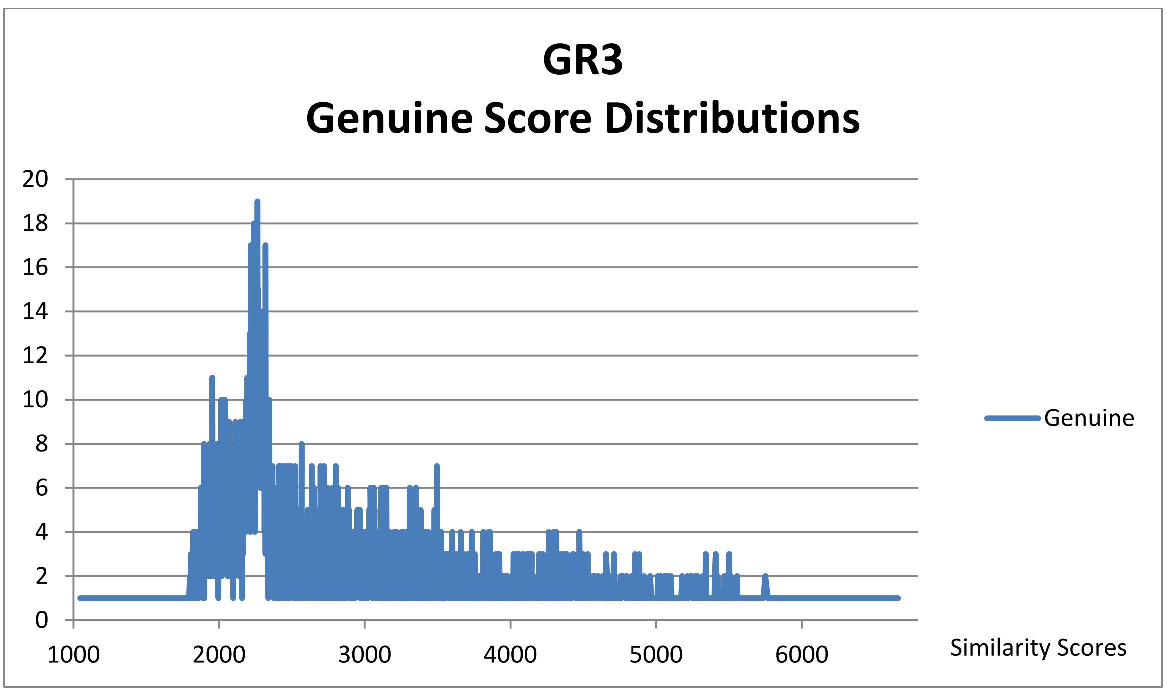


Figure 13 - GR3 Genuine Score Distributions

4.1.4 GR4 – FlashScan Single vs. FlashScan Single

The run consisted of probe images and gallery collected by the FlashScan Single Fingerprint device. The FlashScan Single (GR4) consisted of the probe set with 4898 images from 497 unique subjects matched against the enrolled Galley 4. This combination resulted in 4898 matched pairs (total possible true matches) from 497 unique subjects. The Match Error of 0 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate was 100% and the false accept rate was 0%. There were 4898 True Matches where all occurred in rank 1. The similarity scores for the genuine population ranged from a low of 1115 to a high of 6570. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine population of rank 1 score values from the fingerprint matcher. The first graph (Figure 14) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine population's graph (Figure 15) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
GR4						
FlashScan Single vs. FlashScan Single	Gallery	Total Images	4898			
		Unique Subjects	497			
	Probe	Total Images	4898			
		Unique Subjects	497			
	Matches	Total Matched Pairs	4898			
		Matched Pair Subjects	497			
		True Match (Rank 1)	4898	100	1115	6570
		False Match (Rank 1)	0	0	n/a	n/a
		Error Match (Rank 1) (true mat not possible)	0			
		Total	23990404			

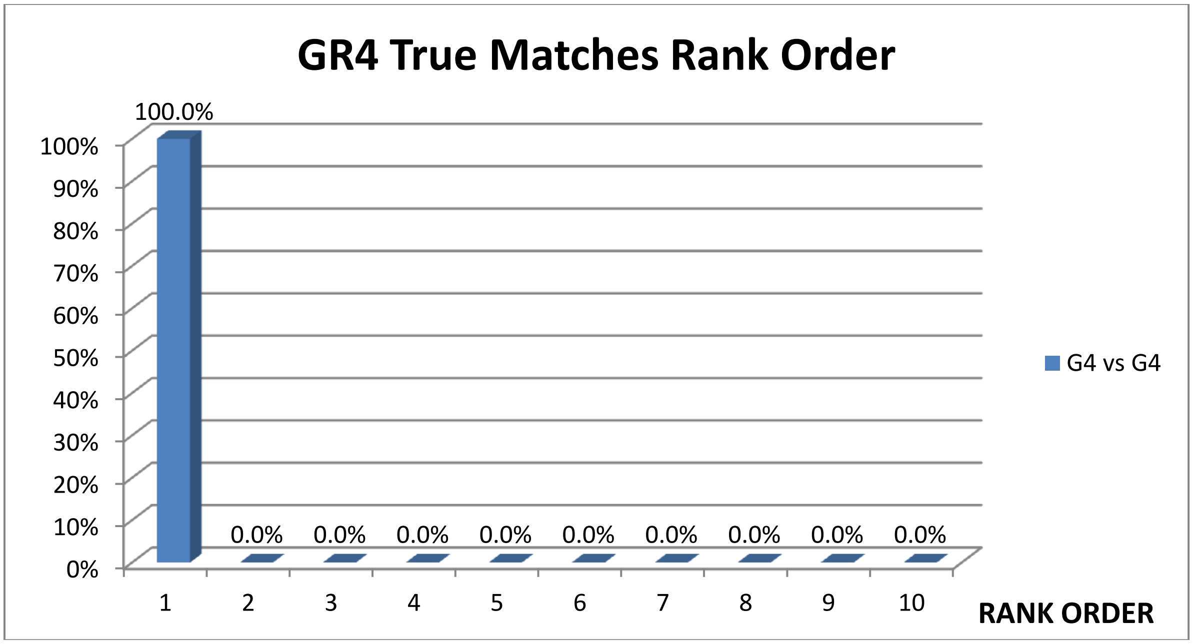


Figure 14 – GR4 True Matches Rank Order

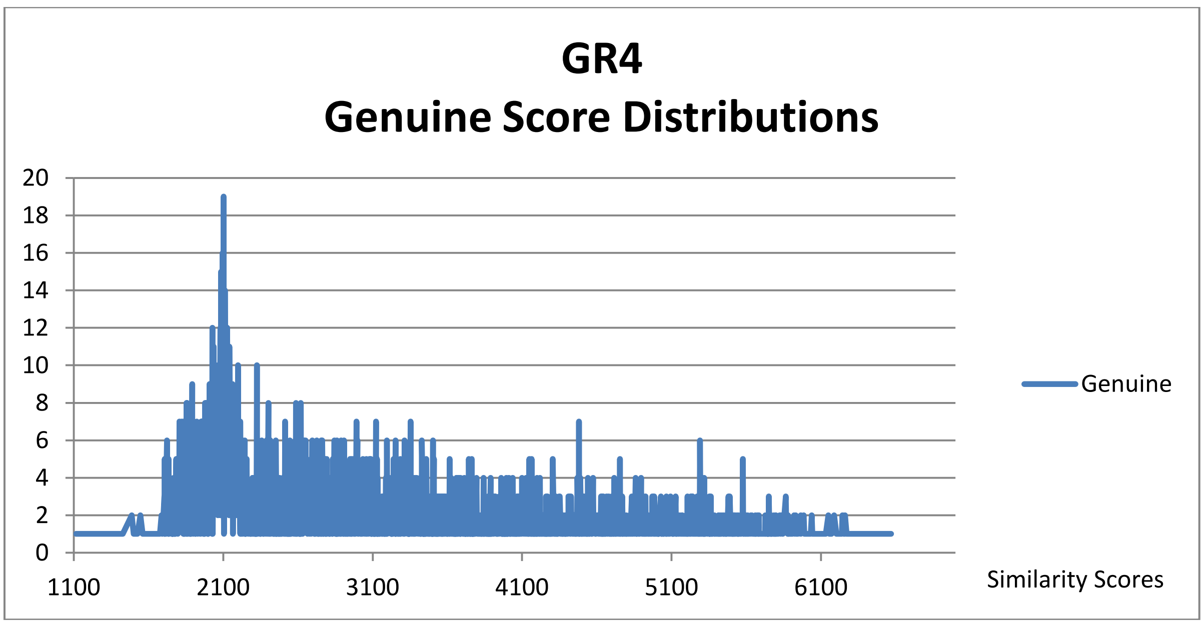


Figure 15 - GR4 Genuine Score Distributions

4.1.5 GR5 – TBS 3D Enroll (HT1) vs. TBS (HT1)

The run consisted of probe images and gallery collected by the TBS 3D Enroll fingerprint device, specifically the HT1 images. The TBS 3D Enroll (HT1) (GR5) consisted of the probe set with 4921 images from 495 unique subjects matched against the enrolled Galley 5. This combination resulted in 4921 matched pairs (total possible true matches) from 495 unique subjects. The Match Error of 0 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate was 100% and the false accept rate was 0%. There were 4921 True Matches where all occurred in rank 1. The similarity scores for the genuine population ranged from a low of 1823 to a high of 6831. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine population of rank 1 score values from the fingerprint matcher. The first graph (Figure 16) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine population's graph (Figure 17) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
GR5						
TBS 3D Enroll (HT1) vs. TBS 3D Enroll (HT1)	Gallery	Total Images	4921			
		Unique Subjects	495			
	Probe	Total Images	4921			
		Unique Subjects	495			
	Matches	Total Matched Pairs	4921			
		Matched Pair Subjects	495			
		True Match (Rank 1)	4921	100	1823	6831
		False Match (Rank 1)	0	0	n/a	n/a
		Error Match (Rank 1) (true mat not possible)	0			
		Total	24216241			

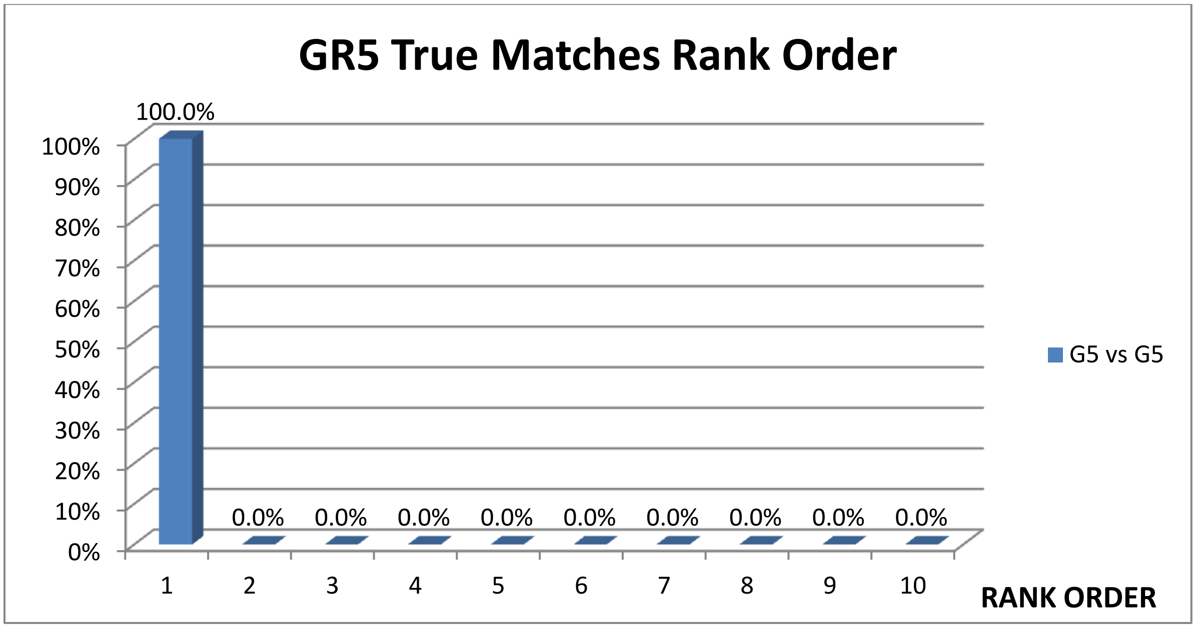


Figure 16 - GR5 True Matches Rank Order

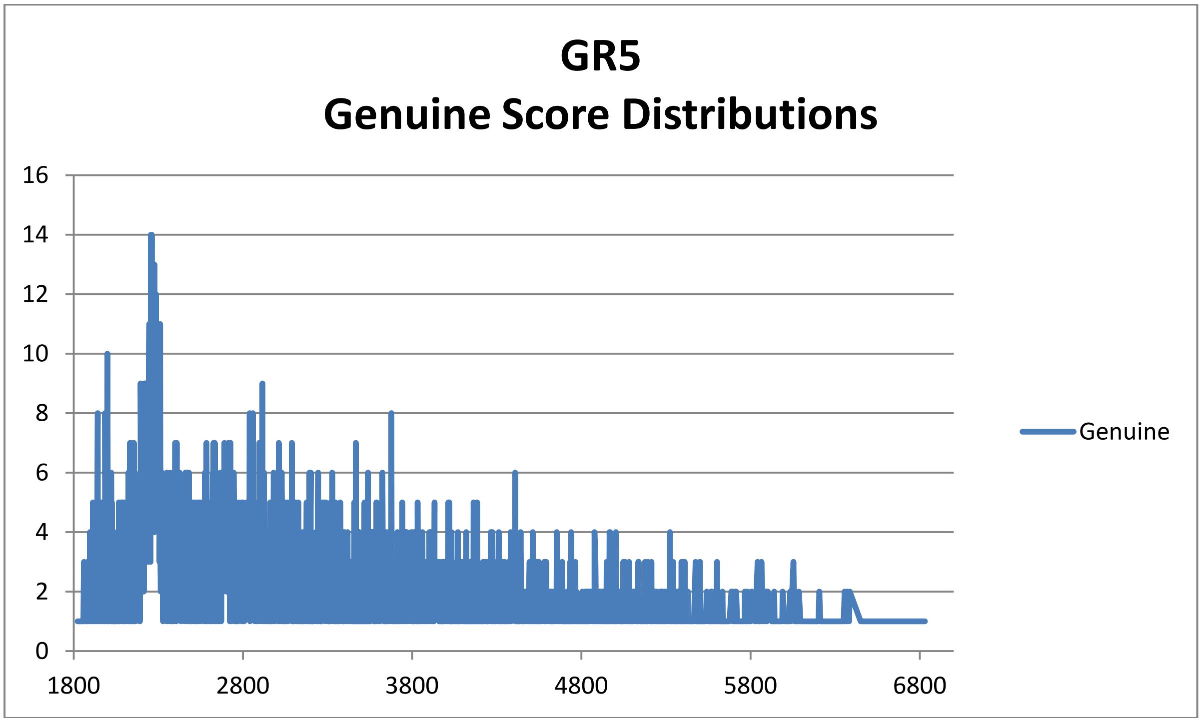


Figure 17 - GR5 Genuine Score Distributions

4.2 LFP Run Results

Data from different traditional LFP scanners (plus tenprint ink cards) were evaluated for match performance against the LFP gallery (Cross Match Guardian R2 Set 1 – GR1).

4.2.1 LFPR1 – i3 DigID Mini vs. Gallery 1

The i3 DigID Mini run (LFPR1) consisted of the probe set with 4990 images from 500 unique subjects matched against the enrolled Galley 1. This combination resulted in 4970 matched pairs (total possible true matches) from 498 unique subjects. The Match Error of 20 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a LFPR1 true accept rate of 92.66% and the false accept rate was 7.34%. There were 4605 True Matches where all occurred in rank 1 and 365 false matches. The similarity scores for the genuine population ranged from a low of 23 to a high of 1301. The similarity scores generated for the imposter population were a low of 15 and high of 35. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 18) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 19) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
LFPR1						
i3 DigID Mini vs. Gallery 1	Gallery	Total Images	4974			
		Unique Subjects	498			
	Probe	Total Images	4990			
		Unique Subjects	500			
	Matches	Total Matched Pairs	4970			
		Matched Pair Subjects	498			
		True Match (Rank 1)	4605	92.66	23	1301
		False Match (Rank 1)	365	7.34	15	35
		Error Match (true mat not possible)	20			
		Total	24820260			

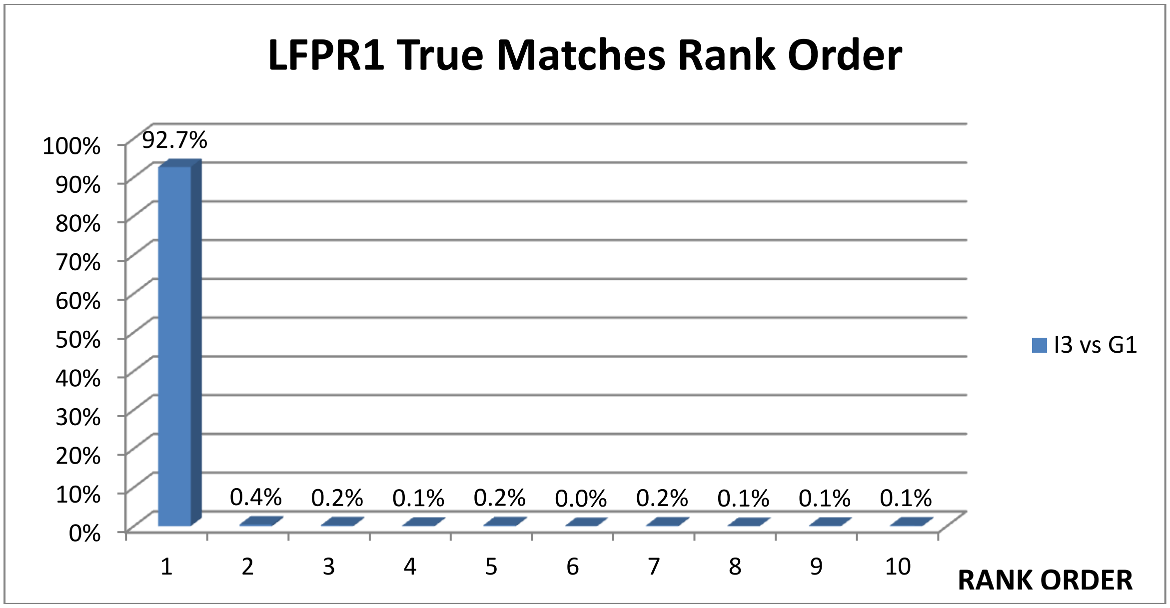


Figure 18 - LFPR1 True Matches Rank Order

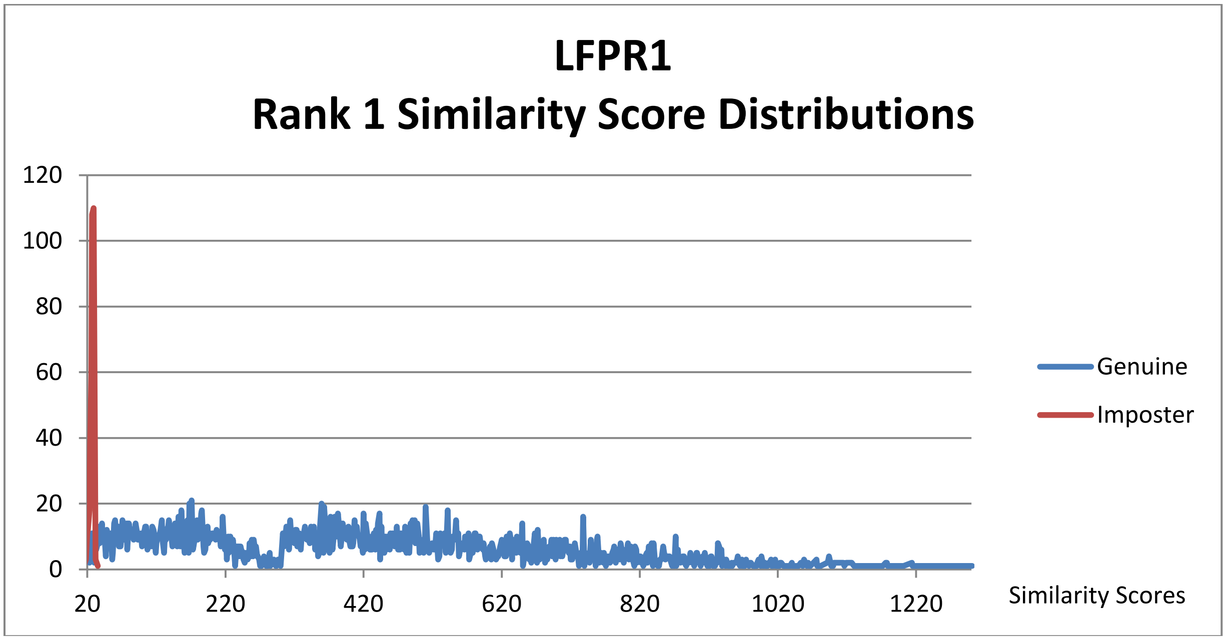


Figure 19 - LFPR1 Rank 1 Similarity Score Distributions

4.2.2 LFPR2 – L1 TouchPrint 5300 vs. Gallery 1

The L1 TouchPrint 5300 run (LFPR2) consisted of the probe set with 4992 images from 500 unique subjects matched against the enrolled Gallery 1. This combination resulted in 4972 matched pairs (total possible true matches) from 498 unique subjects. The Match Error of 20 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate of 96.58% and the false accept rate was 3.42%. There were 4802 True Matches where all occurred in rank 1 and 170 false matches. The similarity scores for the genuine population ranged from a low of 17 to a high of 1287. The similarity scores generated for the imposter population were a low of 17 and high of 38. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 20) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 21) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	Description		Results	Percent	Score Min	Score Max
LFPR2						
L1 TouchPrint 5300 vs. Gallery 1	Gallery	Total Images	4974			
		Unique Subjects	498			
	Probe	Total Images	4992			
		Unique Subjects	500			
	Matches	Total Matched Pairs	4972			
		Matched Pair Subjects	498			
		True Match (Rank 1)	4802	96.58	17	1287
		False Match (Rank 1)	170	3.42	17	38
		Error Match (true match not possible)	20			
		Total	24830208			

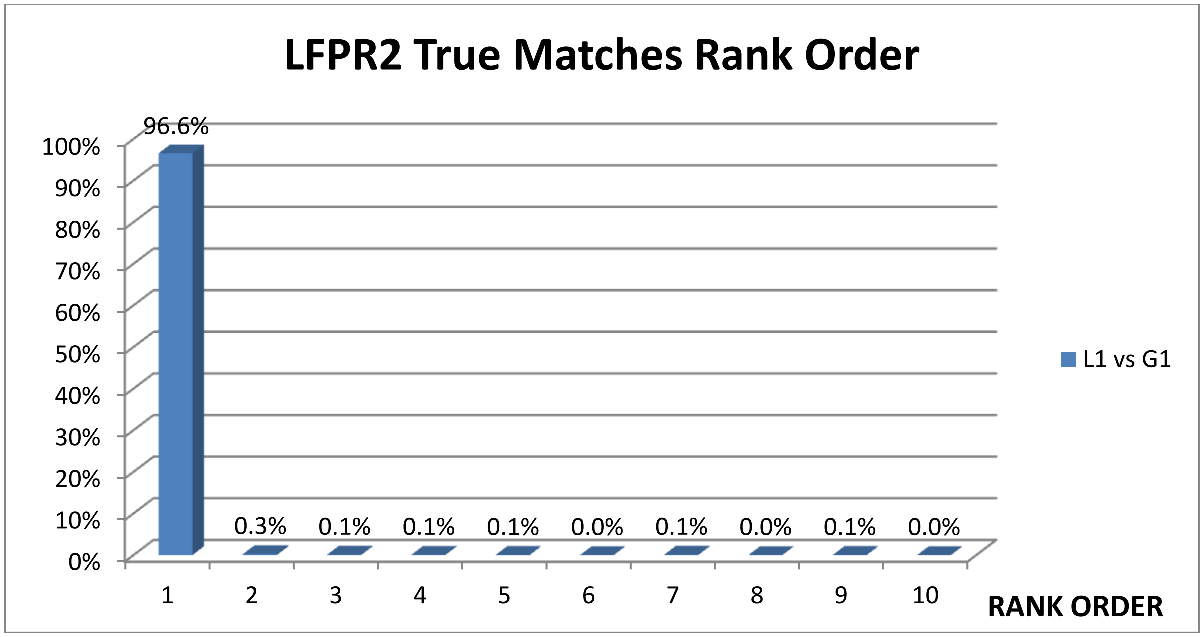


Figure 20 - LFPR2 True Matches Rank Order

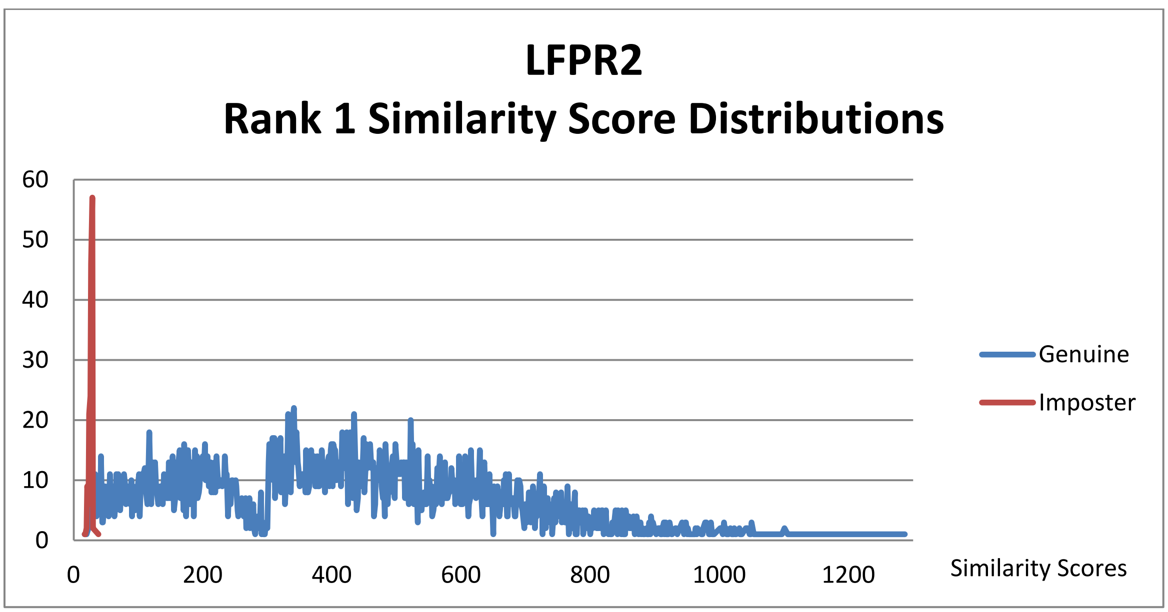


Figure 21 - LFPR2 Rank 1 Similarity Score Distributions

4.2.3 LFPR3 – Card Scan 500 dpi vs. Gallery 1

The Card Scan 500 dpi run (LFPR3) consisted of 500 dpi tenprint card probe images (scanned using AWARE AccuScan software and FBI Appendix-F Epson V700) with 4961 images from 495 unique subjects matched against the enrolled Galley 1. This combination resulted in 4941 matched pairs (total possible true matches) from 495 unique subjects. The Match Error of 20 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate of 91.34% and the false accept rate was 8.66%. There were 4513 True Matches in rank 1 and 428 false matches. The similarity scores for the genuine population ranged from a low of 24 to a high of 1187. The similarity scores generated for the imposter population were a low of 17 and high of 401. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 22) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 23) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
LFPR3						
Card Scan 500 dpi vs. Gallery 1	Gallery	Total Images	4974			
		Unique Subjects	498			
	Probe	Total Images	4961			
		Unique Subjects	497			
	Matches	Total Matched Pairs	4941			
		Matched Pair Subjects	495			
		True Match (Rank 1)	4513	91.34	24	1187
		False Match (Rank 1)	428	8.66	17	401
		Error Match (true mat not possible)	20			
		Total	24676014			

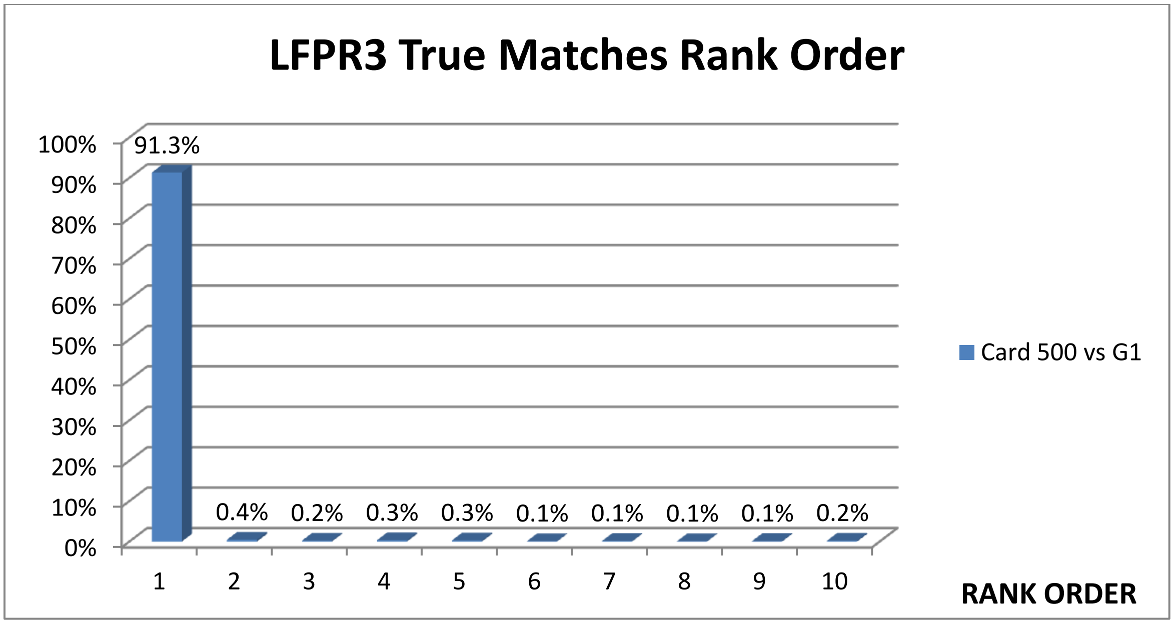


Figure 22 - LFPR3 True Matches Rank Order

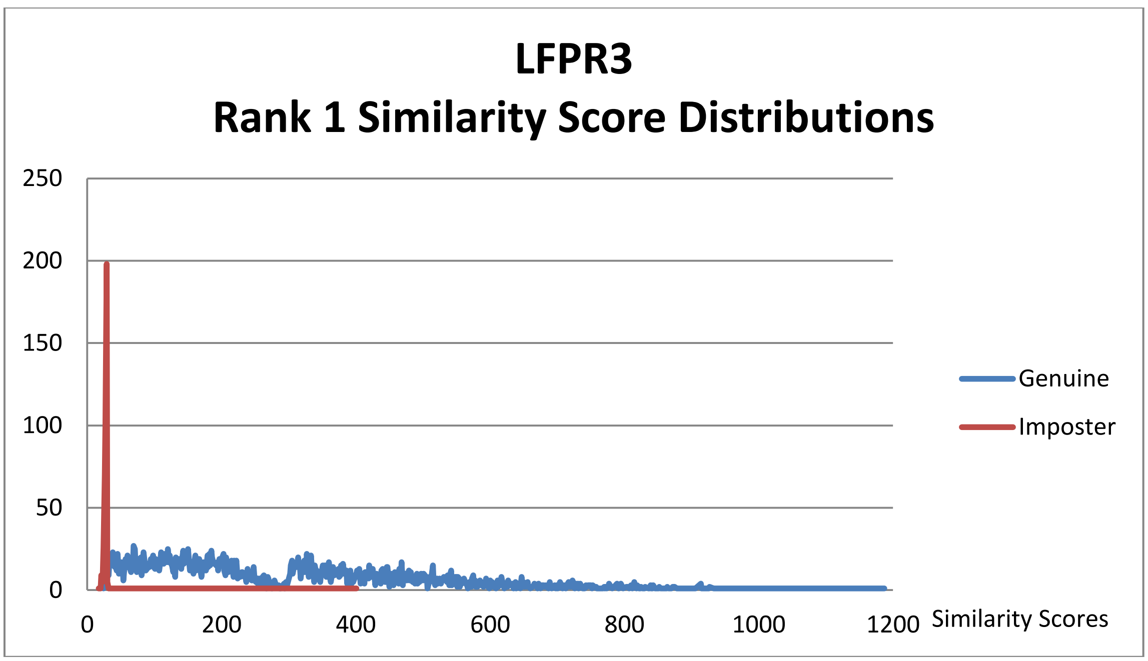


Figure 23 - LFPR3 Rank 1 Similarity Score Distributions

4.2.4 LFPR4 – Cross Match SEEK II vs. Gallery 1

The Cross Match SEEK II run (LFPR4) consisted of the probe set with 4963 images from 496 unique subjects matched against the enrolled Galley 1. This combination resulted in 4913 matched pairs (total possible true matches) from 496 unique subjects. The Match Error of 50 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate of 97.80% and the false accept rate was 2.20%. There were 4805 True Matches where all occurred in rank 1 and 108 false matches. The similarity scores for the genuine population ranged from a low of 21 to a high of 1365. The similarity scores generated for the imposter population were a low of 20 and high of 35. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 24) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 25) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
LFPR4						
Cross Match SEEK II vs. Gallery 1	Gallery	Total Images	4974			
		Unique Subjects	498			
	Probe	Total Images	4963			
		Unique Subjects	496			
	Matches	Total Matched Pairs	4913			
		Matched Pair Subjects	492			
		True Match (Rank 1)	4805	97.80	21	1365
		False Match (Rank 1)	108	2.20	20	35
		Error Match (true mat not possible)	50			
		Total	24685962			

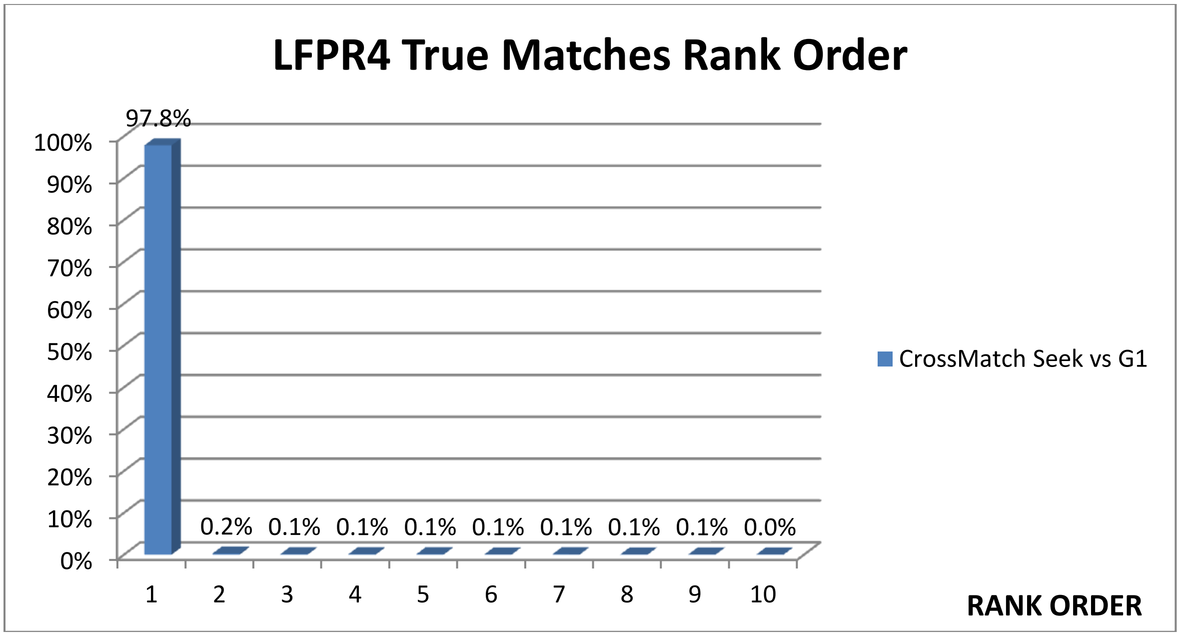


Figure 24 - LFPR4 True Matches Rank Order

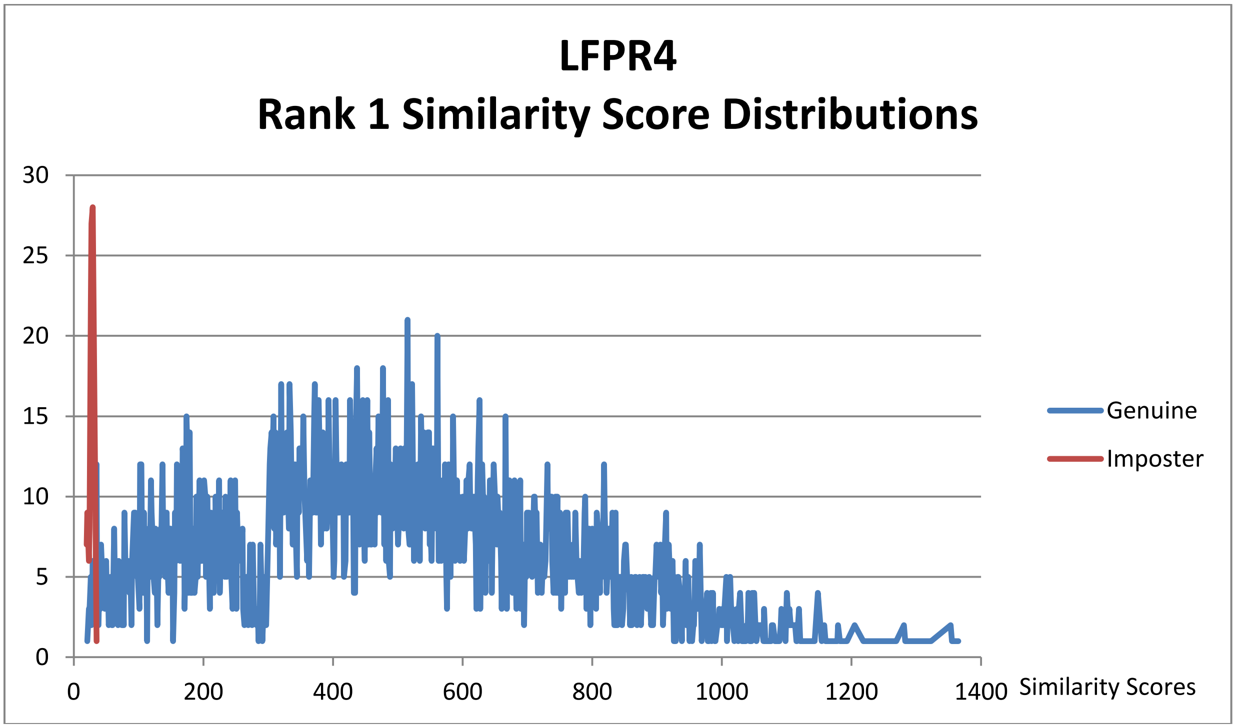


Figure 25 - LFPR4 Rank 1 Similarity Score Distributions

4.3 CFP Devices Run Results

NOTE: Raw 3D images are not directly compatible with existing fingerprint matching algorithms. As a result, all analysis discussed in this report does not utilize this 3D fingerprint data directly, rather the analysis is performed on images obtained from each 3D system's transformation of the scanned data into 2D grayscale images that are intended by their vendors to be matchable against existing fingerprint databases.

The TBS 3D Enroll produces three grayscale 2D grayscale images as part of the data output during a fingerprint collection – HT1, HT2, HT6. The vendor was unable to provide information on the post-processing or algorithms used to generate these images. TBS reported that those file conversions were developed by university partners during the development of the 3D Enroll, and that knowledge of the conversion details remained with the university researchers. TBS reported that HT1 or HT2 were found to produce the best matching results in their internal testing.

4.3.1 CFP to LFP Runs

4.3.1.1 CFPR1 – FlashScan Single vs. Gallery 1

The FlashScan Single run (CFPR1) consisted of the probe set with 4898 images from 497 unique subjects matched against the enrolled Galley 1. This combination resulted in 4878 matched pairs (total possible true matches) from 495 unique subjects. The Match Error of 20 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate of 71.40% and the false accept rate was 28.60%. There were 3483 True Matches where all occurred in rank 1 and 1395 false matches. The similarity scores for the genuine population ranged from a low of 15 to a high of 635. The similarity scores generated for the imposter population were a low of 12 and high of 32. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 26) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 27) and shows the matcher score values on the x axis and the frequency of each score value on the y axis.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
CFPR1	Gallery	Total Images	4974			
FlashScan Single vs. Gallery 1		Unique Subjects	498			
	Probe	Total Images	4898			
		Unique Subjects	497			
	Matches	Total Matched Pairs	4878			
		Matched Pair Subjects	495			
		True Mat (Match (Rank 1)	3483	71.40	15	635
		False Mat (Match (Rank 1)	1395	28.60	12	32
		Error Match (true mat not possible)	20			
		Total	24362652			

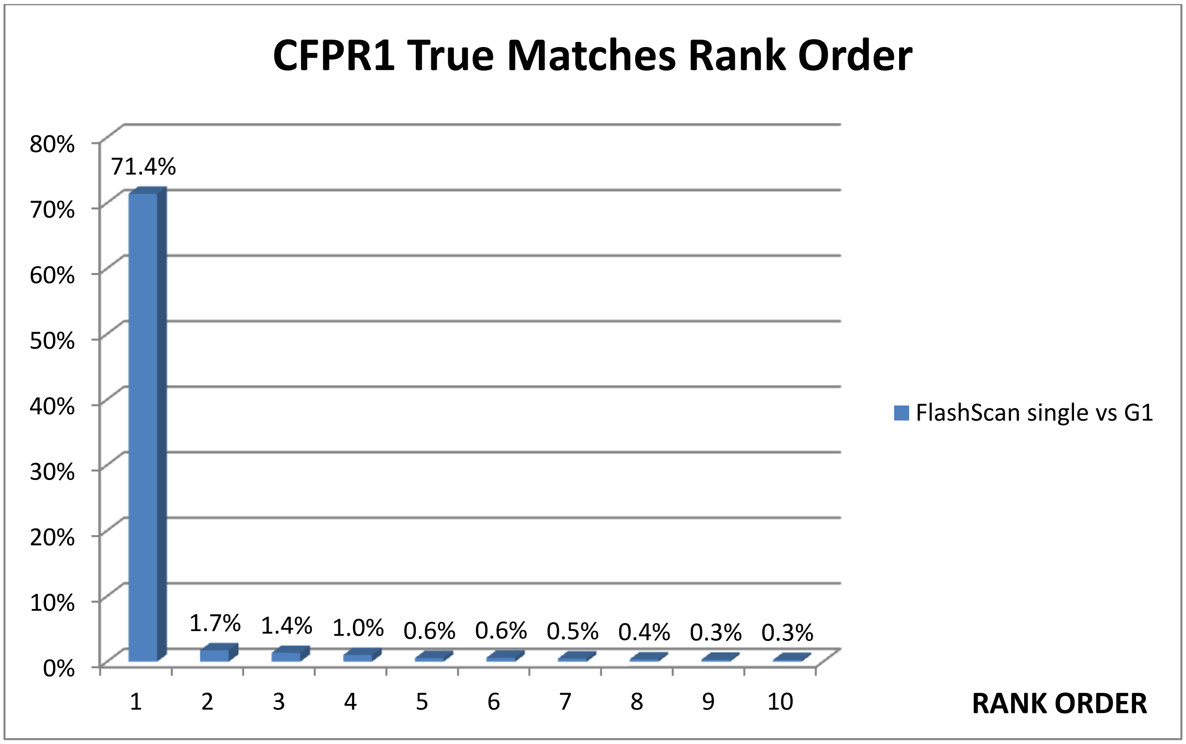


Figure 26 - CFPR1 True Matches Rank Order

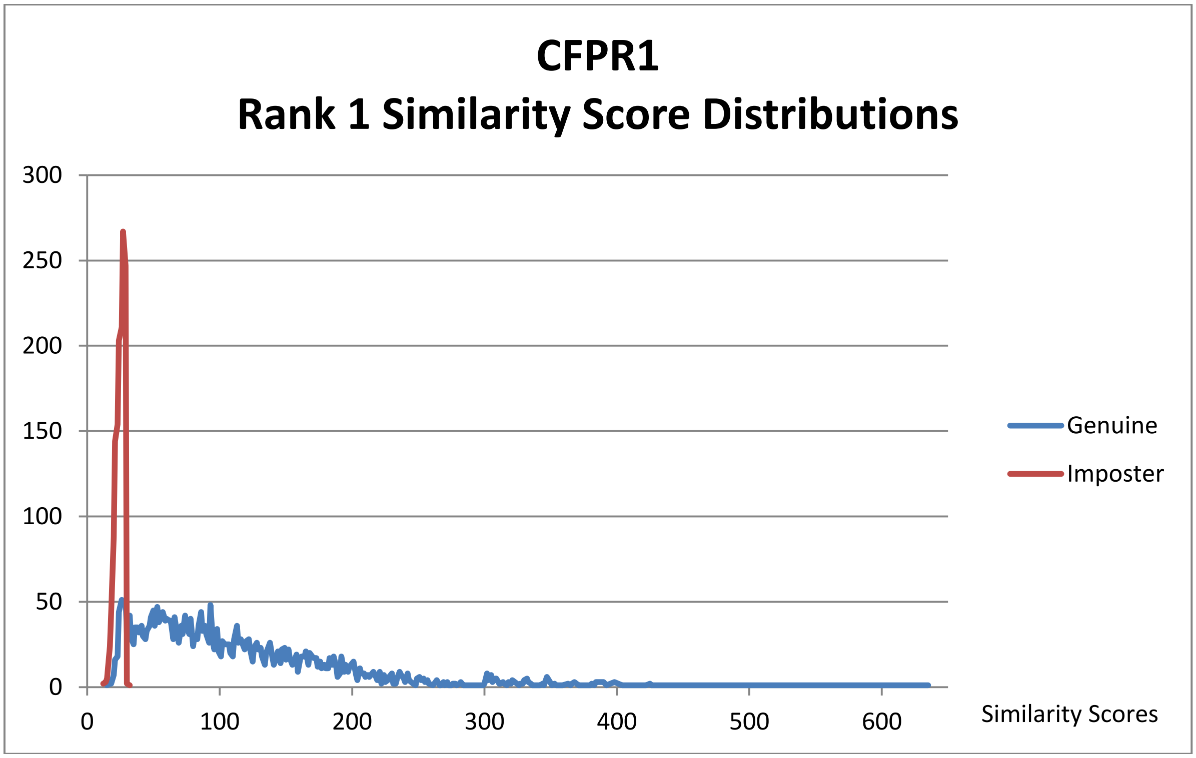


Figure 27 - CFPR1 Rank 1 Similarity Score Distributions

4.3.1.2 CFPR2 – FlashScan D4 vs. Gallery 1

The FlashScan D4 run (CFPR2) consisted of the probe set with 1734 images from 184 unique subjects matched against the enrolled Galley 1. This combination resulted in 1724 matched pairs (total possible true matches) from 183 unique subjects. The number of unique subjects is lower for this matching run because the FS3D D4 device was out of commission due to technical issues for a portion of the data collection. The Match Error of 10 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate of 17.05% and the false accept rate was 82.95%. There were 294 True Matches where all occurred in rank 1 and 1430 false matches. The similarity scores for the genuine population ranged from a low of 15 to a high of 417. The similarity scores generated for the imposter population were a low of 11 and high of 39. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 28) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 29) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
CFPR2						
FlashScan D4 vs. Gallery 1	Gallery	Total Images	4974			
		Unique Subjects	498			
	Probe	Total Images	1734			
		Unique Subjects	184			
	Matches	Total Matched Pairs	1724			
		Matched Pair Subjects	183			
		True Match (Rank 1)	294	17.05	15	417
		False Match (Rank 1)	1430	82.95	11	39
		Error Match (true mat not possible)	10			
		Total	8624916			

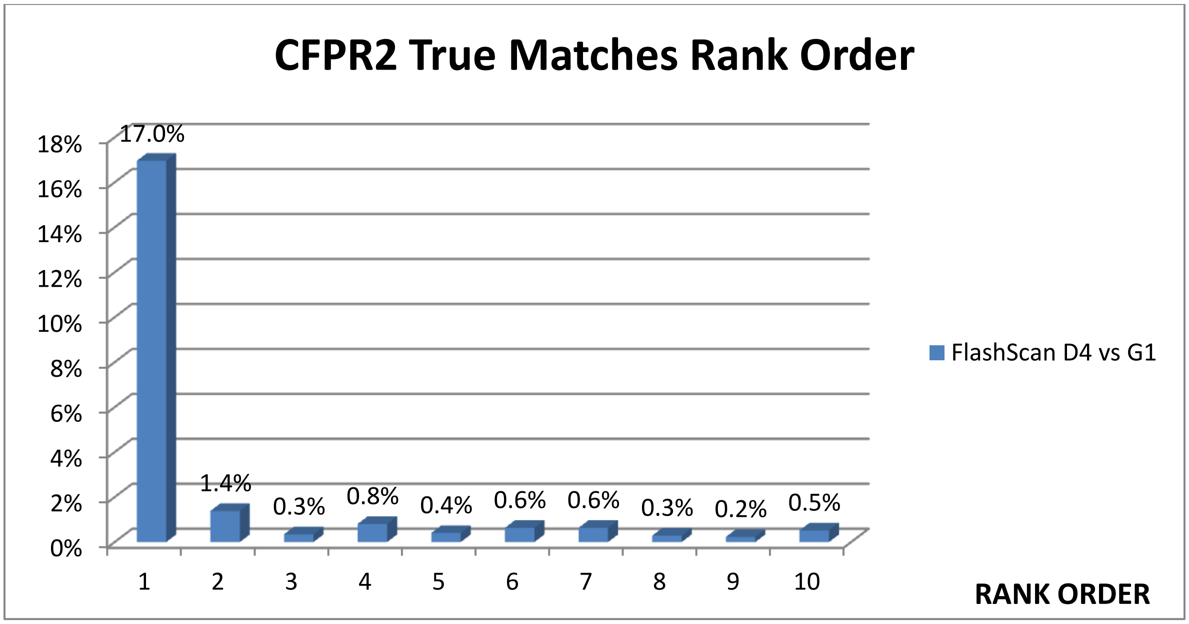


Figure 28 - CFPR2 True Matches Rank Order

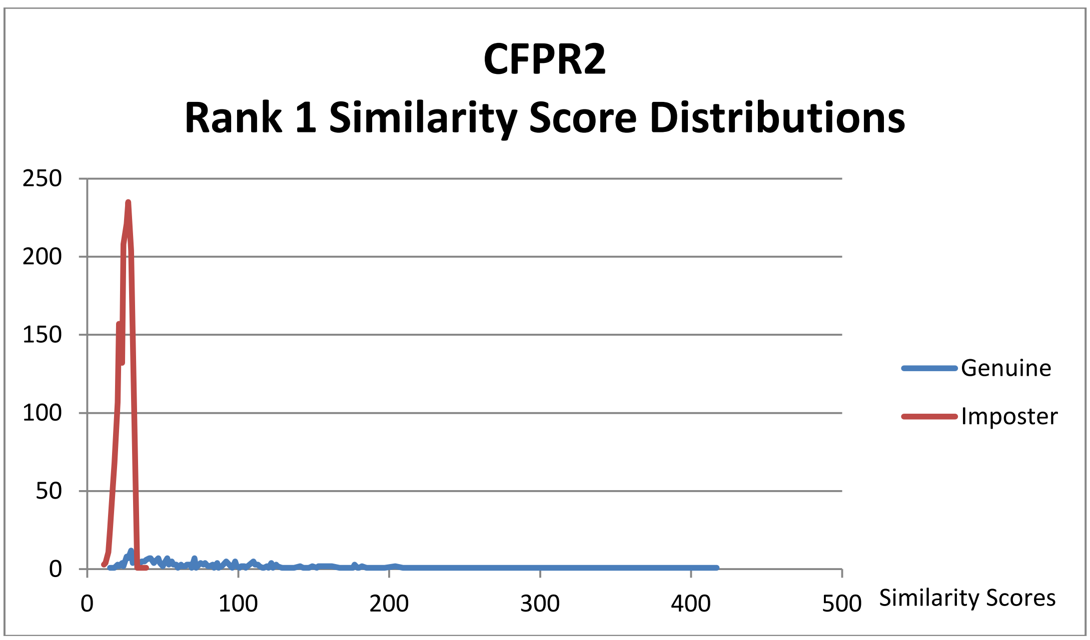


Figure 29 - CFPR2 Rank 1 Similarity Score Distributions

4.3.1.3 CFPR3 – TBS 3D Enroll (HT1) vs. Gallery 1

The TBS 3D Enroll (HT1) run (CFPR3) consisted of the probe set with 4949 images from 496 unique subjects matched against the enrolled Galley 1. This combination resulted in 4926 matched pairs (total possible true matches) from 494 unique subjects. The Match Error of 20 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate of 91.15% and the false accept rate was 8.85%. There were 4490 True Matches where all occurred in rank 1 and 436 false matches. The similarity scores for the genuine population ranged from a low of 18 to a high of 917. The similarity scores generated for the imposter population were a low of 14 and high outlier data point of 713. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 30) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 31) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
CFPR3						
TBS 3D Enroll (HT1) vs. Gallery 1	Gallery	Total Images	4974			
		Unique Subjects	498			
	Probe	Total Images	4949			
		Unique Subjects	496			
	Matches	Total Matched Pairs	4926			
		Matched Pair Subjects	494			
		True Match (Rank 1)	4490	91.15	18	917
		False Match (Rank 1)	436	8.85	14	713
		Error Match (true mat not possible)	20			
		Total	24601404			

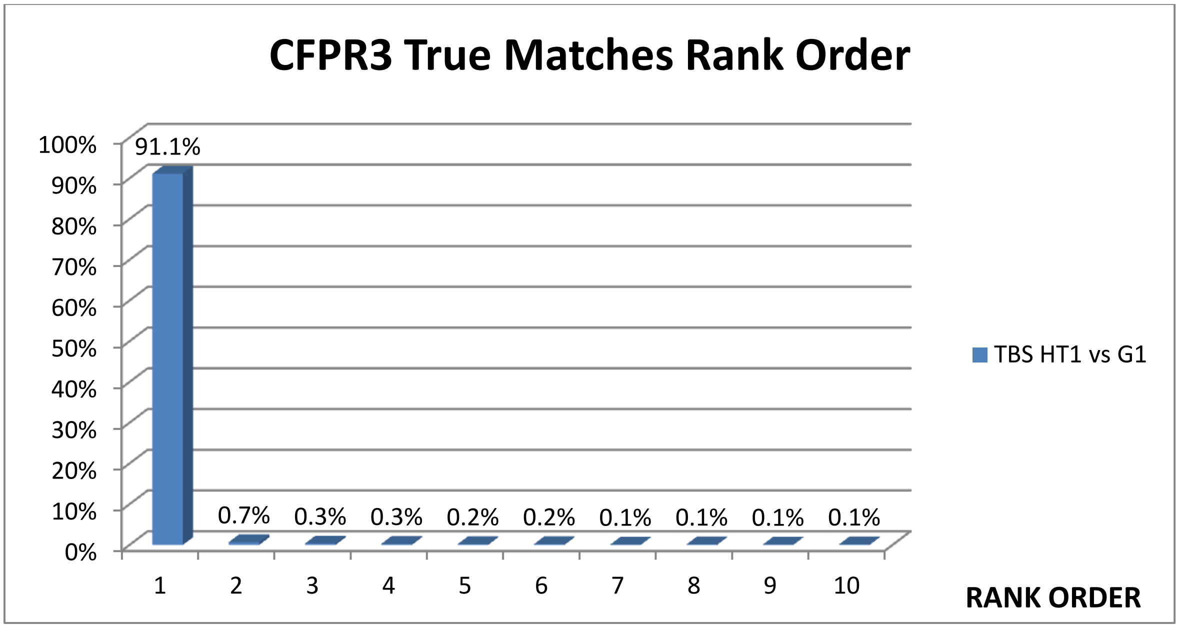


Figure 30 - CFPR3 True Matches Rank Order

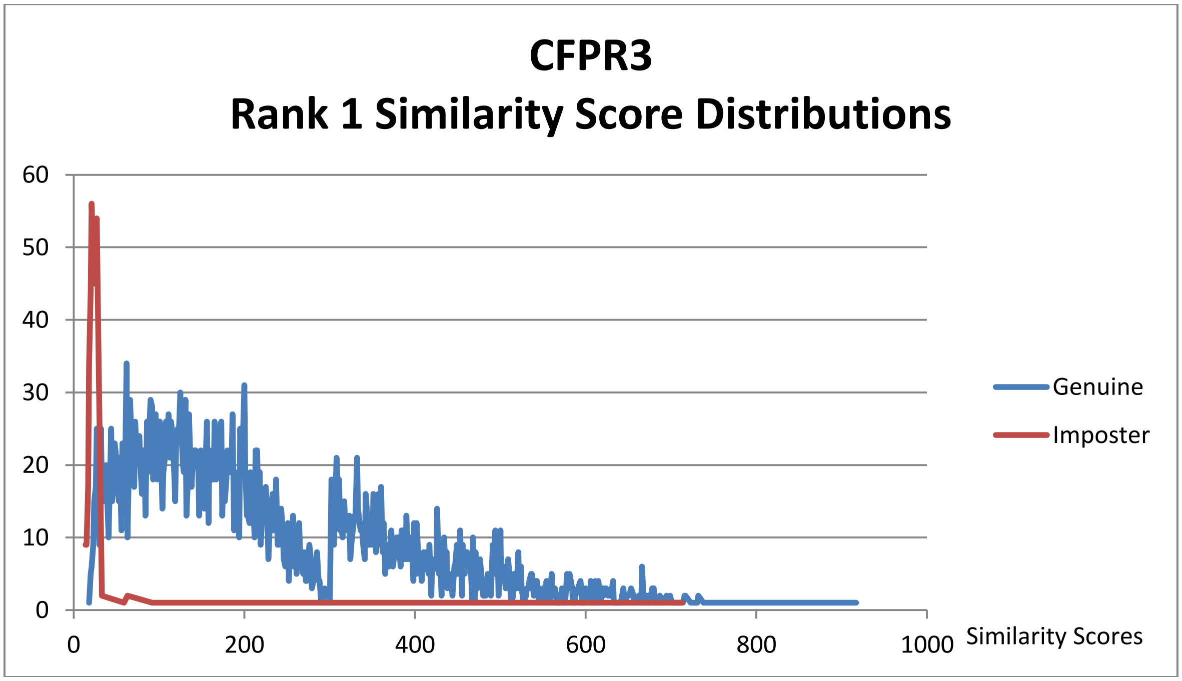


Figure 31 - CFPR3 Rank 1 Similarity Score Distributions

4.3.1.4 CFPR4 – TBS 3D Enroll (HT2) vs. Gallery 1

The TBS 3D Enroll (HT2) run (CFPR4) consisted of the probe set with 4948 images from 496 unique subjects matched against the enrolled Galley 1. This combination resulted in 4926 matched pairs (total possible true matches) from 494 unique subjects. The Match Error of 20 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate of 85.67% and the false accept rate was 14.33%. There were 4220 True Matches where all occurred in rank 1 and 706 false matches. The similarity scores for the genuine population ranged from a low of 17 to a high of 858. The similarity scores generated for the imposter population were a low of 11 and high outlier data point of 666. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 32) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 33) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
CFPR4						
TBS 3D Enroll (HT2) vs. Gallery 1	Gallery	Total Images	4974			
		Unique Subjects	498			
	Probe	Total Images	4948			
		Unique Subjects	496			
	Matches	Total Matched Pairs	4926			
		Matched Pair Subjects	494			
		True Match (Rank 1)	4220	85.67	17	858
		False Match (Rank 1)	706	14.33	11	666
		Error Match (true mat not possible)	20			
		Total	24601404			

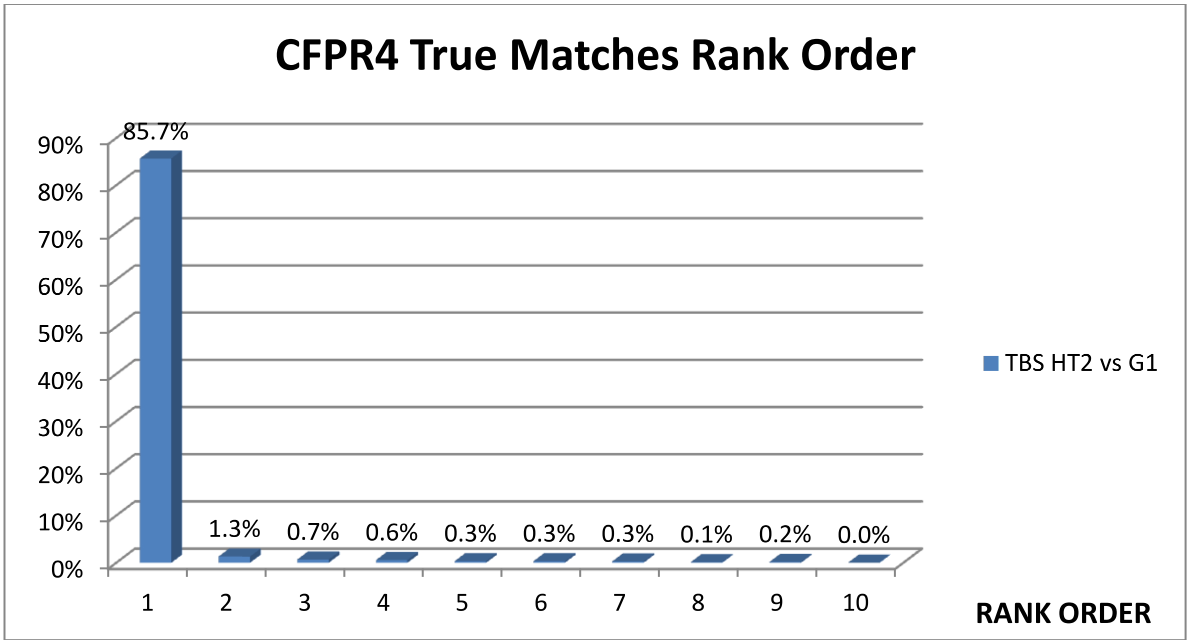


Figure 32 - CFPR4 True Matches Rank Order

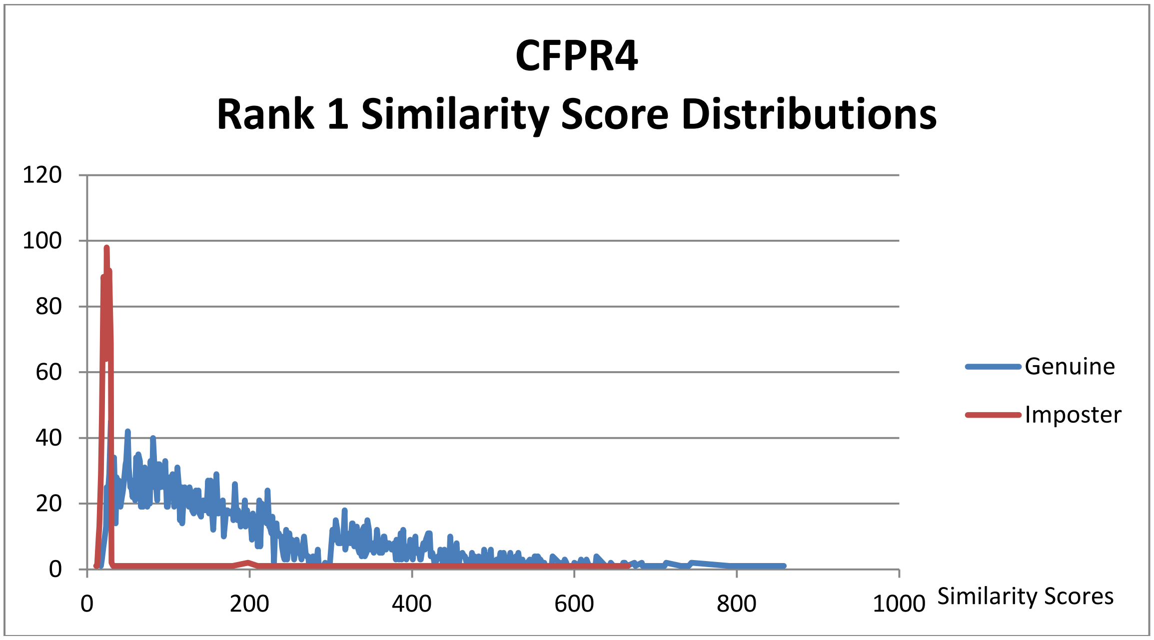


Figure 33 - CFPR4 Rank 1 Similarity Score Distributions

4.3.1.5 CFPR5 – TBS 3D Enroll (HT6) vs. Gallery 1

The TBS 3D Enroll (HT6) run (CFPR5) consisted of the probe set with 4949 images from 496 unique subjects matched against the enrolled Galley 1. This combination resulted in 4928 matched pairs (total possible true matches) from 494 unique subjects. The Match Error of 20 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate of 86.42% and the false accept rate was 13.58%. There were 4259 True Matches where all occurred in rank 1 and 669 false matches. The similarity scores for the genuine population ranged from a low of 17 to a high of 893. The similarity scores generated for the imposter population were a low of 11 and high outlier data point of 639. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 34) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 35) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
CFPR5						
TBS 3D Enroll (HT6) vs. Gallery 1	Gallery	Total Images	4974			
		Unique Subjects	498			
	Probe	Total Images	4949			
		Unique Subjects	496			
	Matches	Total Matched Pairs	4928			
		Matched Pair Subjects	494			
		True Match (Rank 1)	4259	86.42	17	893
		False Match (Rank 1)	669	13.58	11	639
		Error Match (true mat not possible)	20			
		Total	24611352			

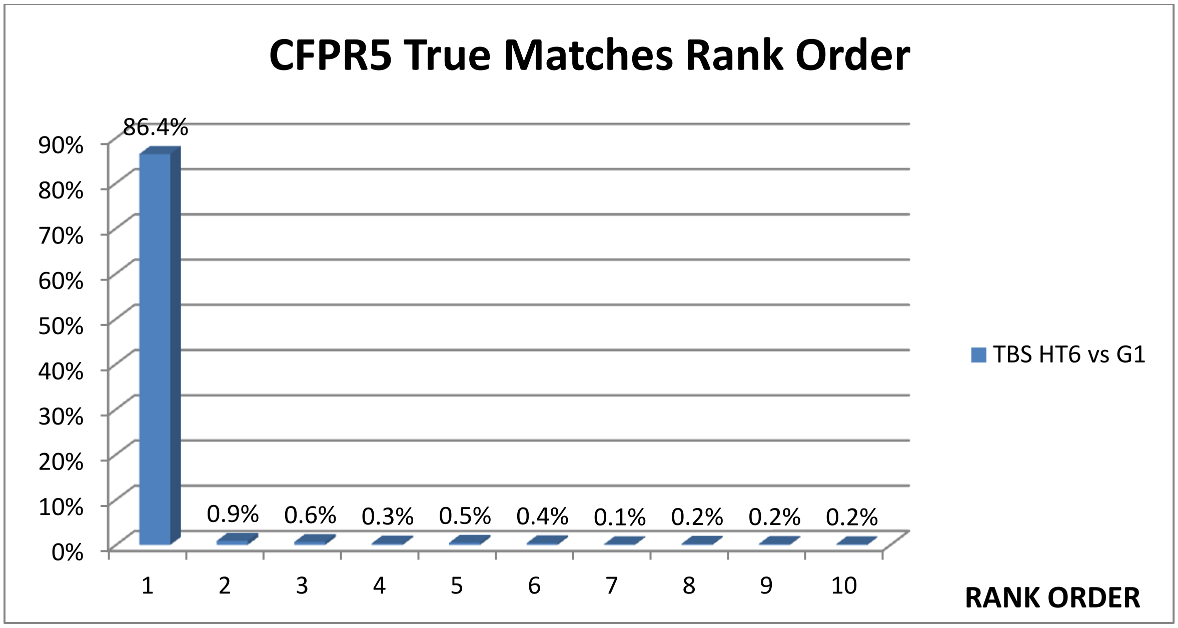


Figure 34 - CFPR5 True Matches Rank Order

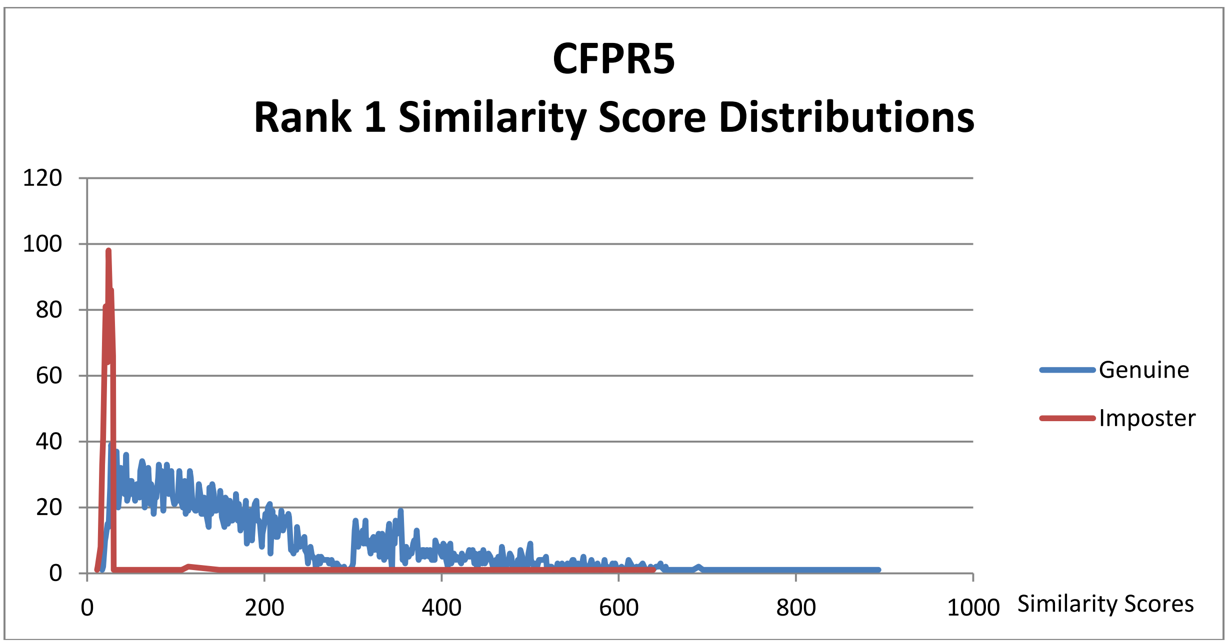


Figure 35 - CFPR5 Rank 1 Similarity Score Distributions

4.3.2 CFP to CFP Runs

4.3.2.1 CFPR6 – FlashScan D4 vs. Gallery 4

The FlashScan D4 run (CFPR6) consisted of the probe set with 1734 images from 184 unique subjects matched against the enrolled Galley 4. This combination resulted in 1712 matched pairs (total possible true matches) from 183 unique subjects. The number of unique subjects is lower for this matching run because the FS3D D4 device was out of commission due to technical issues for a portion of the data collection. The Match Error of 22 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate of 11.80% and the false accept rate was 88.20%. There were 202 True Matches where all occurred in rank 1 and 1510 false matches. The similarity scores for the genuine population ranged from a low of 24 to a high of 351. The similarity scores generated for the imposter population were a low of 17 and high of 54. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 36) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 37) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
CFPR6						
FlashScan D4 vs. Gallery 4	Gallery	Total Images	4898			
		Unique Subjects	497			
	Probe	Total Images	1734			
		Unique Subjects	184			
	Matches	Total Matched Pairs	1712			
		Matched Pair Subjects	183			
		True Match (Rank 1)	202	11.80	24	351
		False Match (Rank 1)	1510	88.20	17	54
		Error Match (true mat not possible)	22			
		Total	8493132			

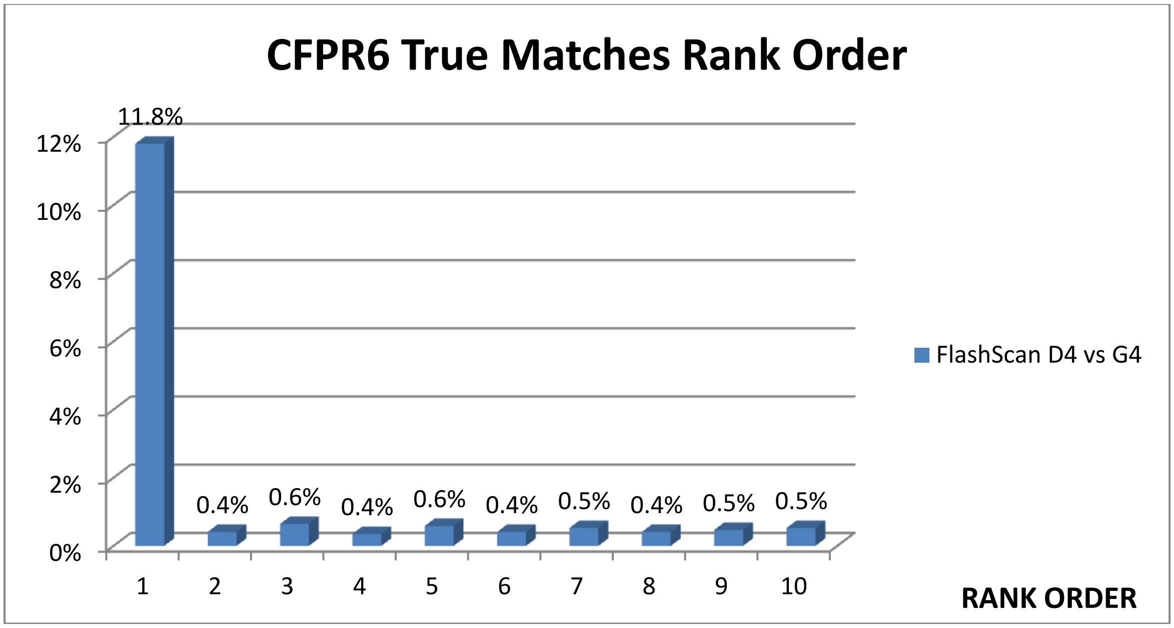


Figure 36 - CFPR6 True Matches Rank Order

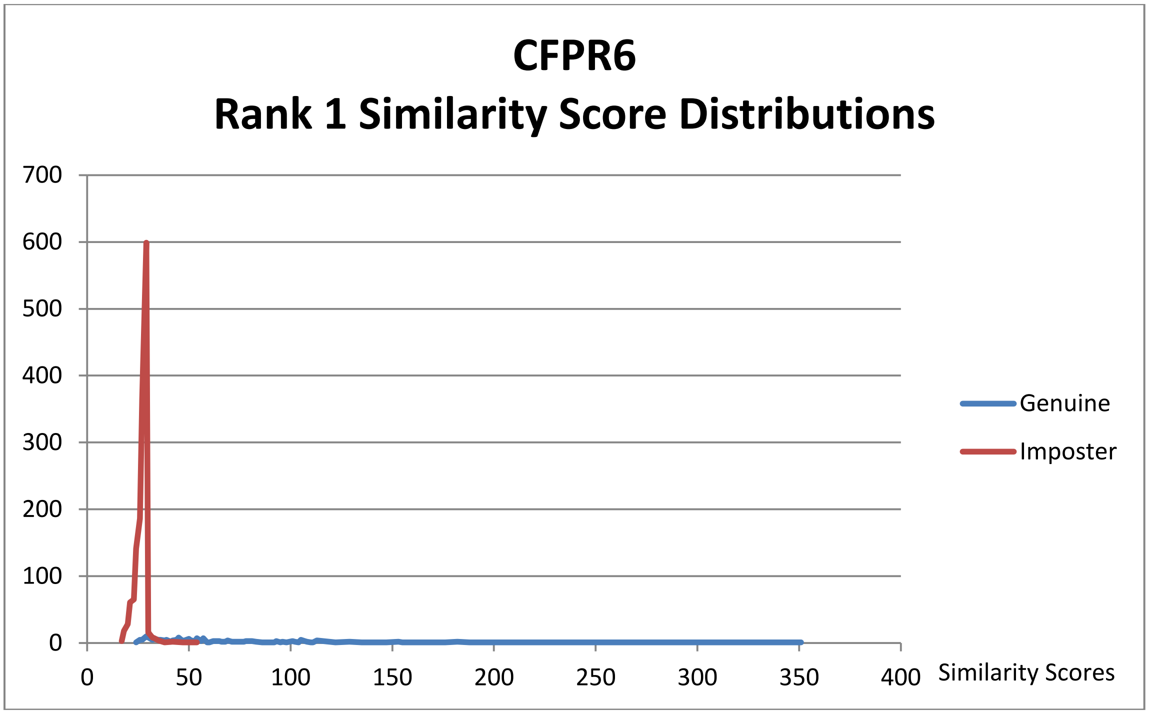


Figure 37 - CFPR6 Rank 1 Similarity Score Distributions

4.3.2.2 CFPR7 – TBS 3D Enroll (HT1) vs. Gallery 4

The TBS 3D Enroll (HT1) run (CFPR7) consisted of the probe set with 4949 images from 496 unique subjects matched against the enrolled Galley 4. This combination resulted in 4850 matched pairs (total possible true matches) from 493 unique subjects. The Match Error of 96 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate of 65.75% and the false accept rate was 34.25%. There were 3189 True Matches where all occurred in rank 1 and 1661 false matches. The similarity scores for the genuine population ranged from a low of 17 to a high of 506. The similarity scores generated for the imposter population were a low of 15 and high of 285. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 38) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 39) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
CFPR7						
TBS 3D Enroll (HT1) vs. Gallery 4	Gallery	Total Images	4898			
		Unique Subjects	497			
	Probe	Total Images	4949			
		Unique Subjects	496			
	Matches	Total Matched Pairs	4850			
		Matched Pair Subjects	493			
		True Match (Rank 1)	3189	65.75	17	506
		False Match (Rank 1)	1661	34.25	15	285
		Error Mat (true mat not possible)	96			
		Total	24225508			

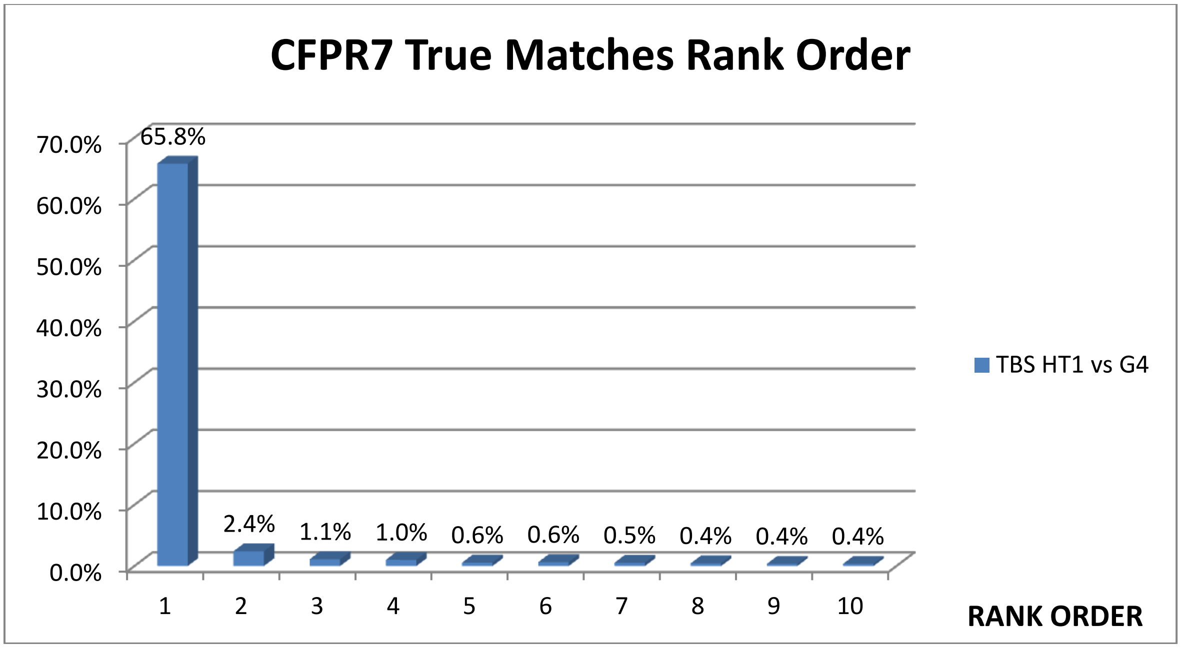


Figure 38 - CFPR7 True Matches Rank Order

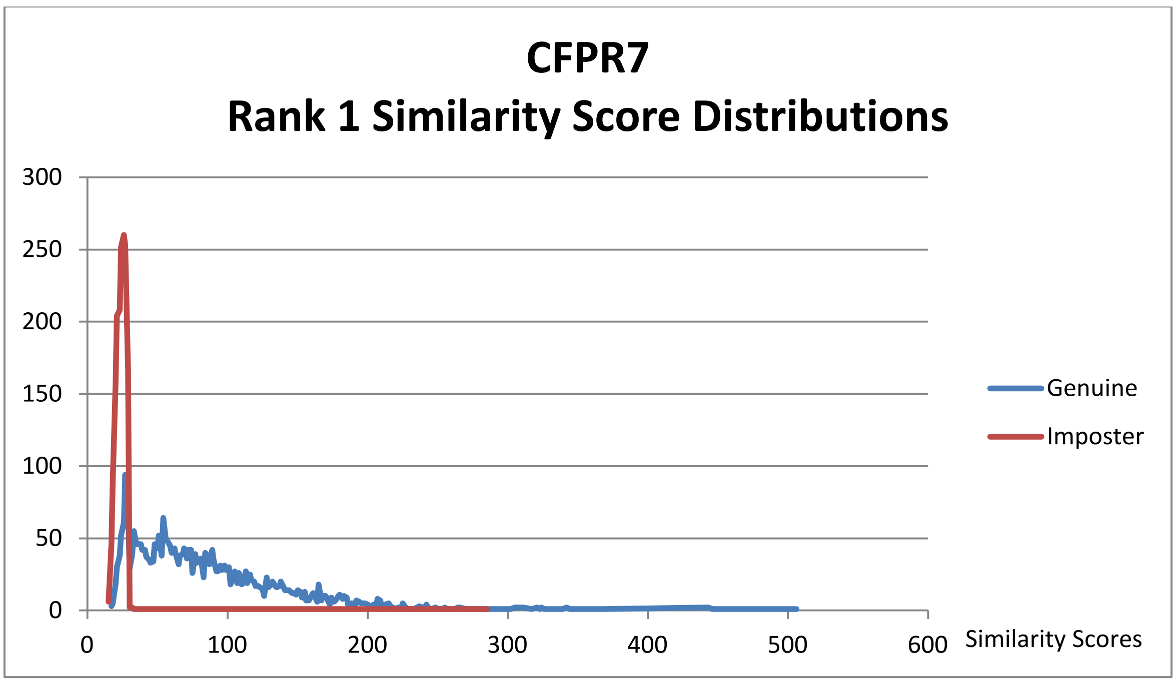


Figure 39 - CFPR7 Rank 1 Similarity Score Distributions

4.3.2.3 CFPR8 – TBS 3D Enroll (HT2) vs. Gallery 4

The TBS 3D Enroll (HT2) run (CFPR8) consisted of the probe set with 4949 images from 496 unique subjects matched against the enrolled Galley 4. This combination resulted in 4849 matched pairs (total possible true matches) from 493 unique subjects. The Match Error of 96 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate of 56.53% and the false accept rate was 43.47%. There were 2741 True Matches where all occurred in rank 1 and 2108 false matches. The similarity scores for the genuine population ranged from a low of 17 to a high of 381. The similarity scores generated for the imposter population were a low of 12 and high of 258. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 40) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 41) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
CFPR8						
TBS 3D Enroll (HT2) vs. Gallery 4	Gallery	Total Images	4898			
		Unique Subjects	497			
	Probe	Total Images	4949			
		Unique Subjects	496			
	Matches	Total Matched Pairs	4849			
		Matched Pair Subjects	493			
		True Match (Rank 1)	2741	56.53	17	381
		False Match (Rank 1)	2108	43.47	12	258
		Error Match (true mat not possible)	96			
		Total	24220610			

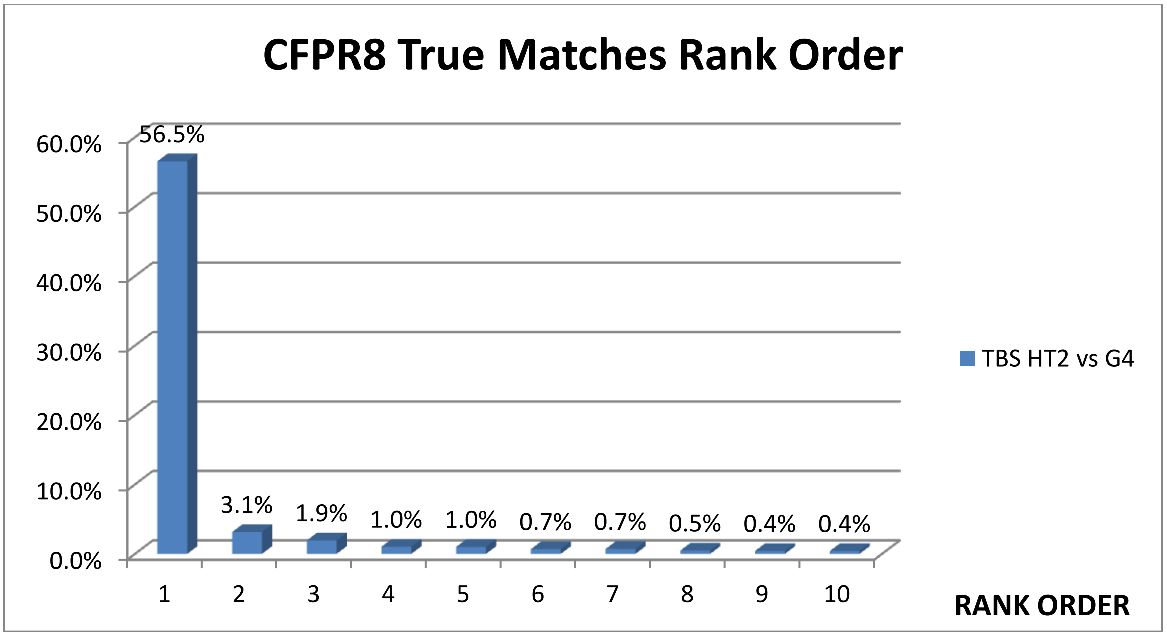


Figure 40 - CFPR8 True Matches Rank Order

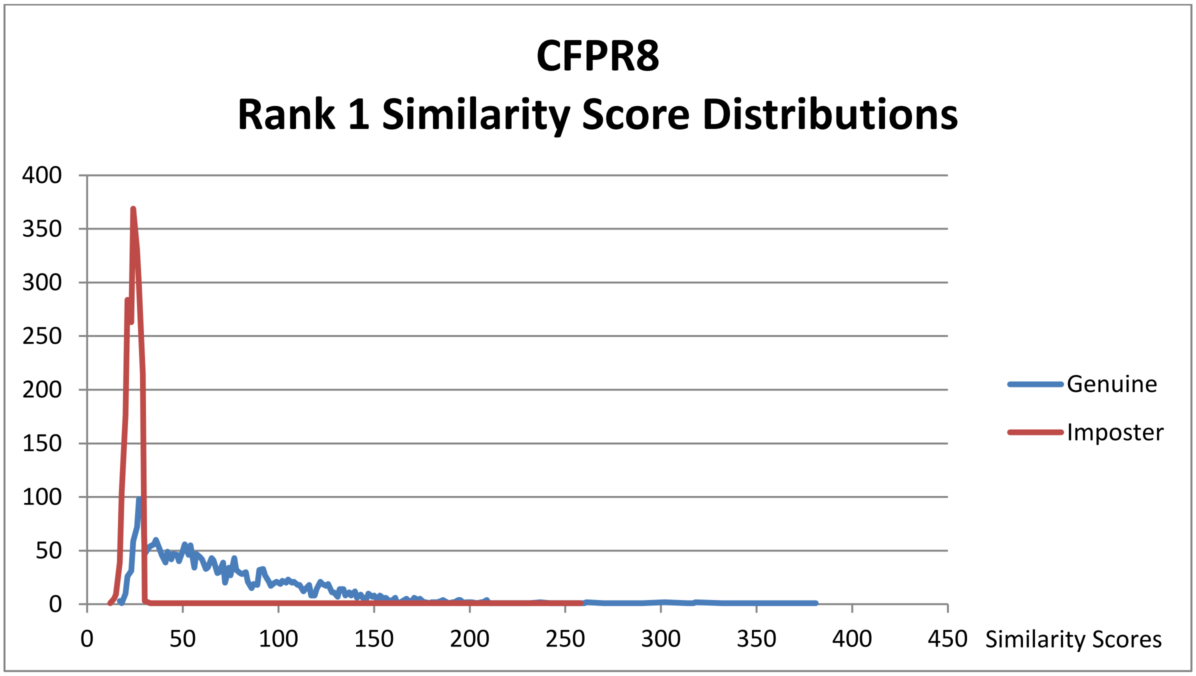


Figure 41 - CFPR8 Rank 1 Similarity Score Distributions

4.4 Additional Gallery 5 Run Results

Additional matching runs were conducted due to project schedule availability and an opportunity to explore matching 2D LFP datasets to a contactless rolled equivalent fingerprint gallery. These additional runs all use the TBS (HT1) image set as gallery. It was selected due to its match performance in the CFP to LFP (CFPR3) and its NFIQ score distribution (see Figure 30 and Figure 49). Run AR1 was selected as a compare and contrast to run CFPR7. These runs swap probe and gallery where results are not expected to be different. AR2 and AR3 use the Cross Match R2 Set 1 and Seek as probe sets for Gallery 5 (TBS (HT1)). These two runs explore match performance of 2D LFP device-collected images matched against a CFP device rolled equivalent gallery.

4.4.1 AR1 – FlashScan Single vs. Gallery 5

The FlashScan Single run (AR1) consisted of the probe set with 4896 images from 497 unique subjects matched against the enrolled Galley 5. This combination resulted in 4823 matched pairs (total possible true matches) from 492 unique subjects. The Match Error of 73 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate of 65.64% and the false accept rate was 34.36%. There were 3166 True Matches where all occurred in rank 1 and 1657 false matches. The similarity scores for the genuine population ranged from a low of 17 to a high of 506. The similarity scores generated for the imposter population were a low of 12 and high of 30. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 42) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 43) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	Description		Results	Percent	Score Min	Score Max
AR1						
FlashScan Single vs. Gallery 5	Gallery	Total Images	4921			
		Unique Subjects	495			
	Probe	Total Images	4896			
		Unique Subjects	497			
	Matches	Total Matched Pairs	4823			
		Matched Pair Subjects	492			
		True Match (Rank 1)	3166	65.64	17	506
		False Match (Rank 1)	1657	34.36	12	30
		Error Match (true mat not possible)	73			
		Total	24093216			

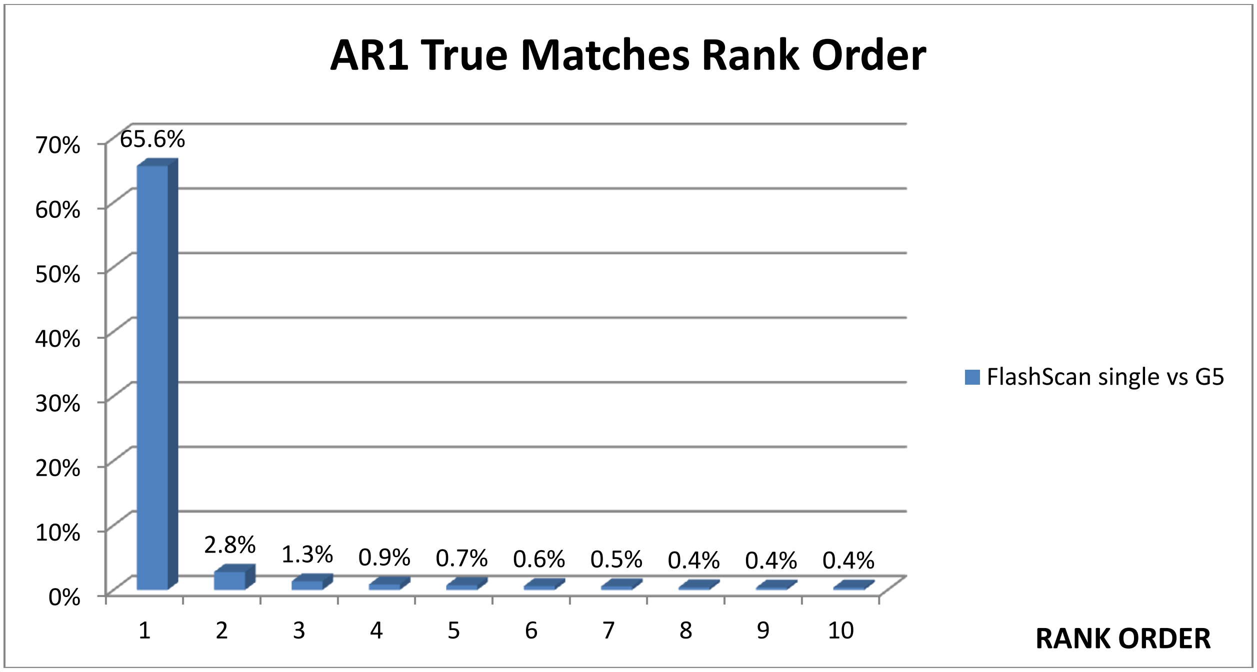


Figure 42 - AR1 True Matches Rank Order

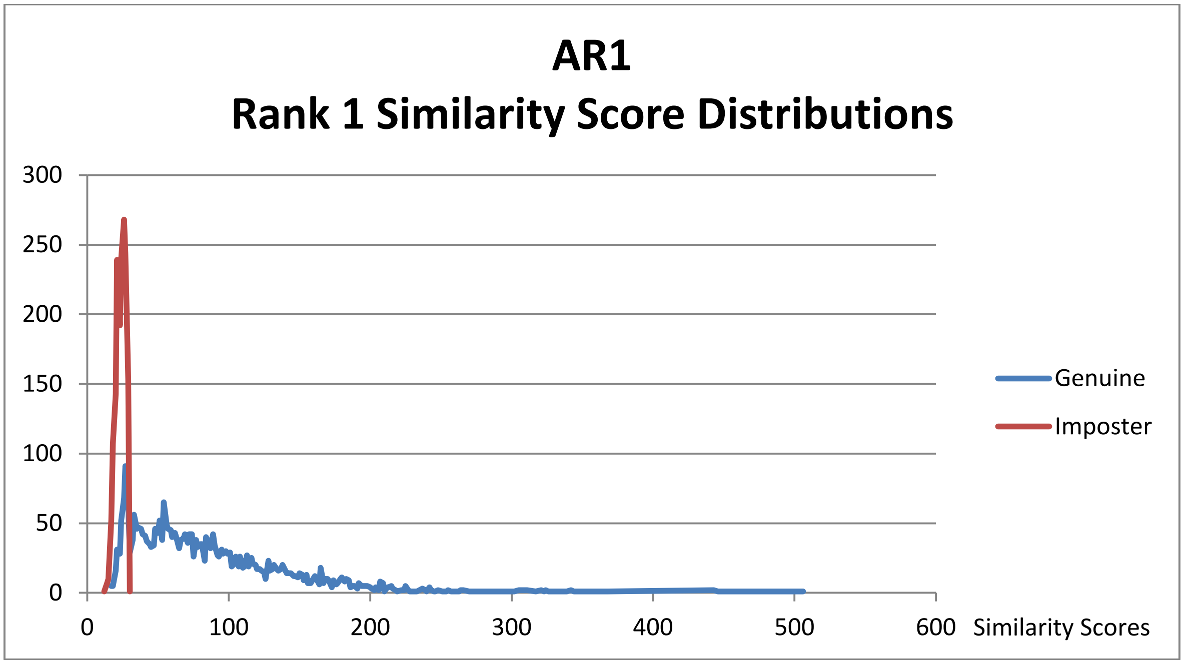


Figure 43 - AR1 Rank 1 Similarity Score Distributions

4.4.2 AR2 – Cross Match Guardian R2 Set 1 vs. Gallery 5

The Cross Match Guardian R2 Set 1 run (AR2) consisted of the probe set with 4971 images from 498 unique subjects matched against the enrolled Galley 5. This combination resulted in 4898 matched pairs (total possible true matches) from 493 unique subjects. The Match Error of 73 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate of 90.73% and the false accept rate was 9.27%. There were 4444 True Matches where all occurred in rank 1 and 454 false matches. The similarity scores for the genuine population ranged from a low of 20 to a high of 917. The similarity scores generated for the imposter population were a low of 14 and high of 33. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 44) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 45) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
AR2						
Cross Match Guardian R2 vs. Gallery 5	Gallery	Total Images	4921			
		Unique Subjects	495			
	Probe	Total Images	4971			
		Unique Subjects	498			
	Matches	Total Matched Pairs	4898			
		Matched Pair Subjects	493			
		True Match (Rank 1)	4444	90.73	20	917
		False Match (Rank 1)	454	9.27	14	33
		Error Match (true mat not possible)	73			
		Total	24462291			

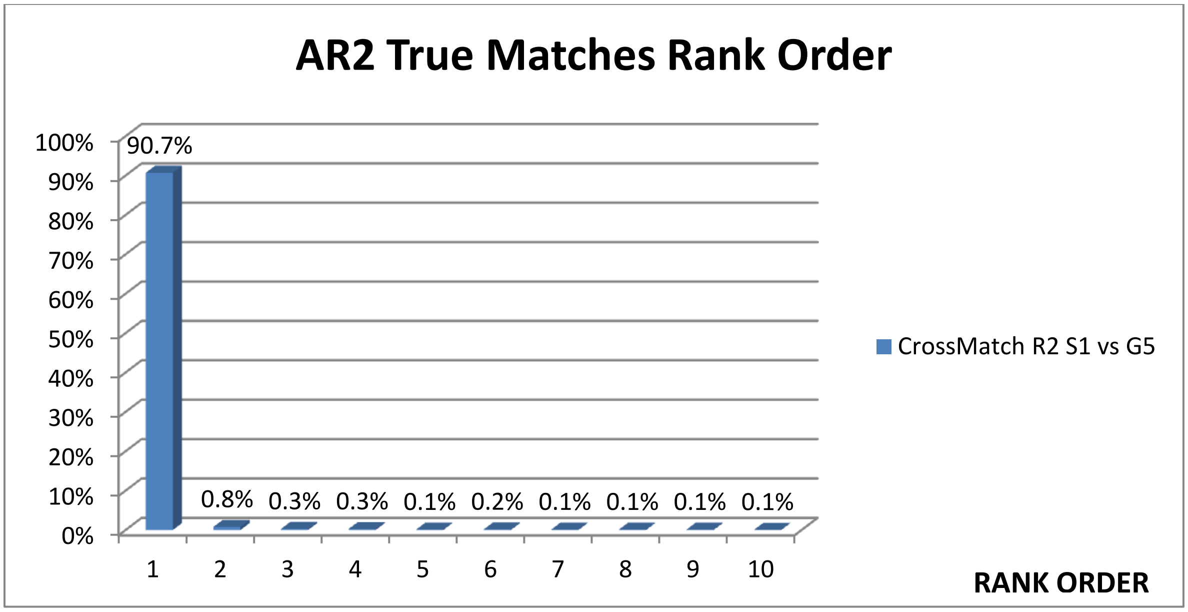


Figure 44 - AR2 True Matches Rank Order

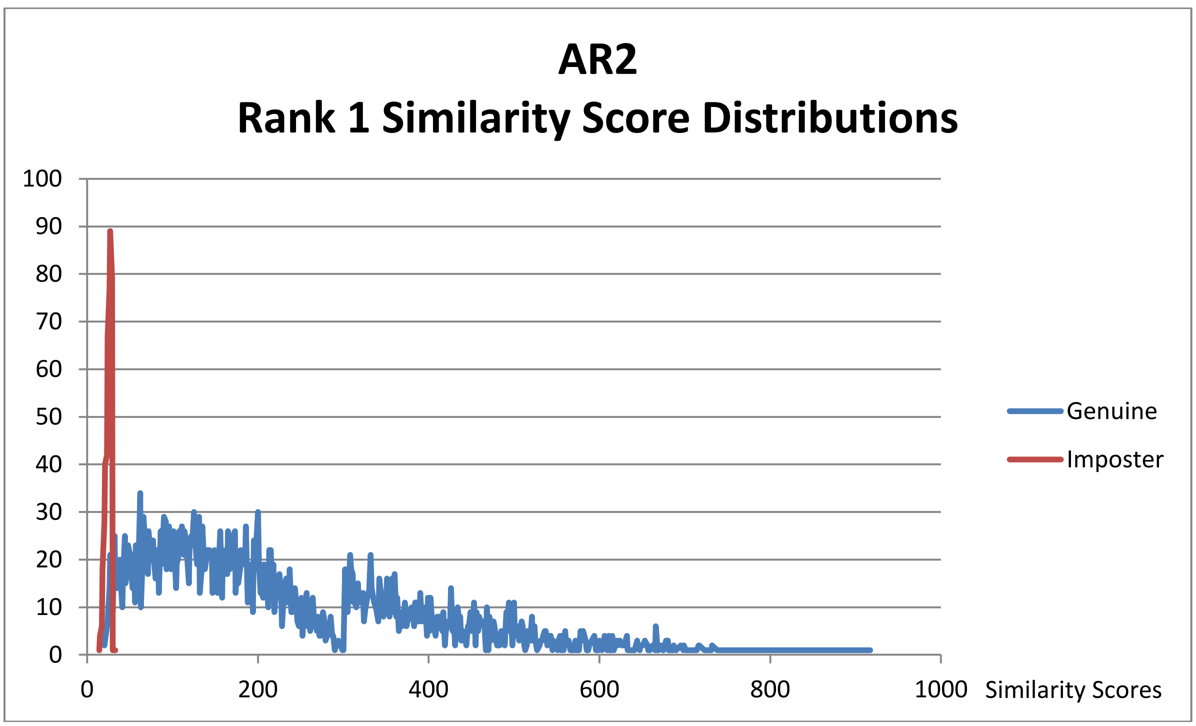


Figure 45 - AR2 Rank 1 Similarity Score Distributions

4.4.3 AR3 – Cross Match SEEK II vs. Gallery 5

The Cross Match SEEK II run (AR3) consisted of the probe set with 4963 images from 496 unique subjects matched against the enrolled Galley 5. This combination resulted in 4862 matched pairs (total possible true matches) from 489 unique subjects. The Match Error of 101 images was probes that did not have corresponding images in the gallery and were excluded. This run resulted in a true accept rate of 91.20% and the false accept rate was 8.80%. There were 4434 True Matches where all occurred in rank 1 and 428 false matches. The similarity scores for the genuine population ranged from a low of 18 to a high of 902. The similarity scores generated for the imposter population were a low of 15 and high of 32. In addition, there are two graphics below that depicts the true matches for ranks 1 thru 10 and a graphic that shows the distribution of genuine and imposter populations of rank 1 score values from the fingerprint matcher. The first graph (Figure 46) provided represents the frequency of True Matches for each Rank Order on the vertical axis and the True Match Rank Order to rank 10 on the horizontal axis. The second is a genuine and imposter population's graph (Figure 47) and shows the matcher score values on the x axis and the frequency of each score value on the y axis. A more detailed description of the run can be found in Section 5.0 Analysis & Discussion.

Run Description	**Description**		**Results**	**Percent**	**Score Min**	**Score Max**
AR3						
Cross Match SEEK II vs. Gallery 5	Gallery	Total Images	4921			
		Unique Subjects	495			
	Probe	Total Images	4963			
		Unique Subjects	496			
	Matches	Total Matched Pairs	4862			
		Matched Pair Subjects	489			
		True Match (Rank 1)	4434	91.20	18	902
		False Match (Rank 1)	428	8.80	15	32
		Error Match (true mat not possible)	101			
		Total	24422923			

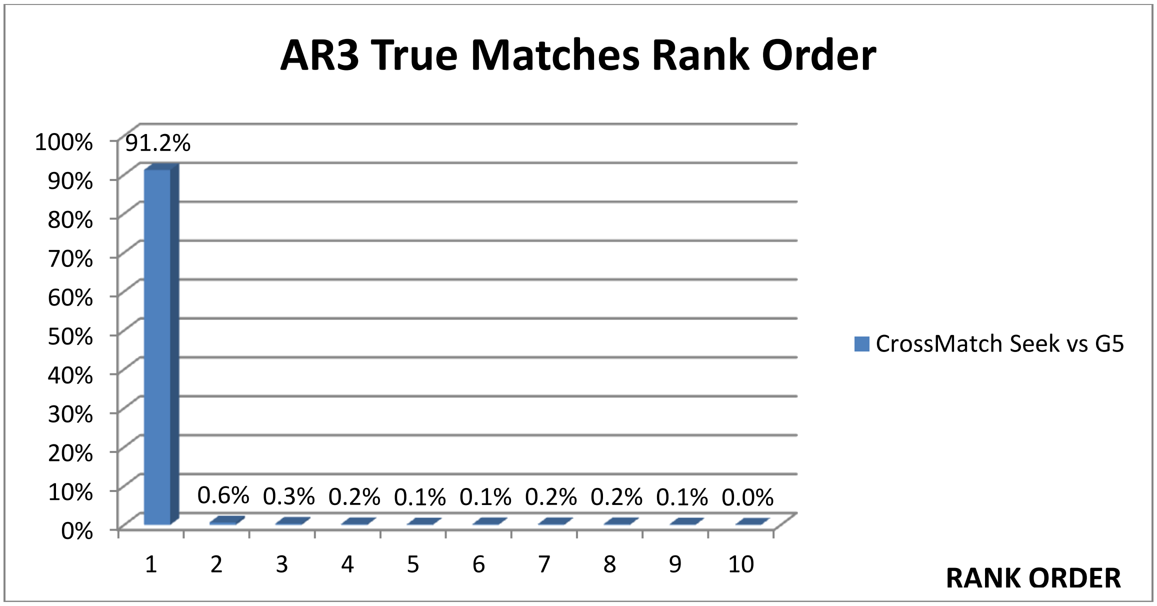


Figure 46 - AR3 True Matches Rank Order

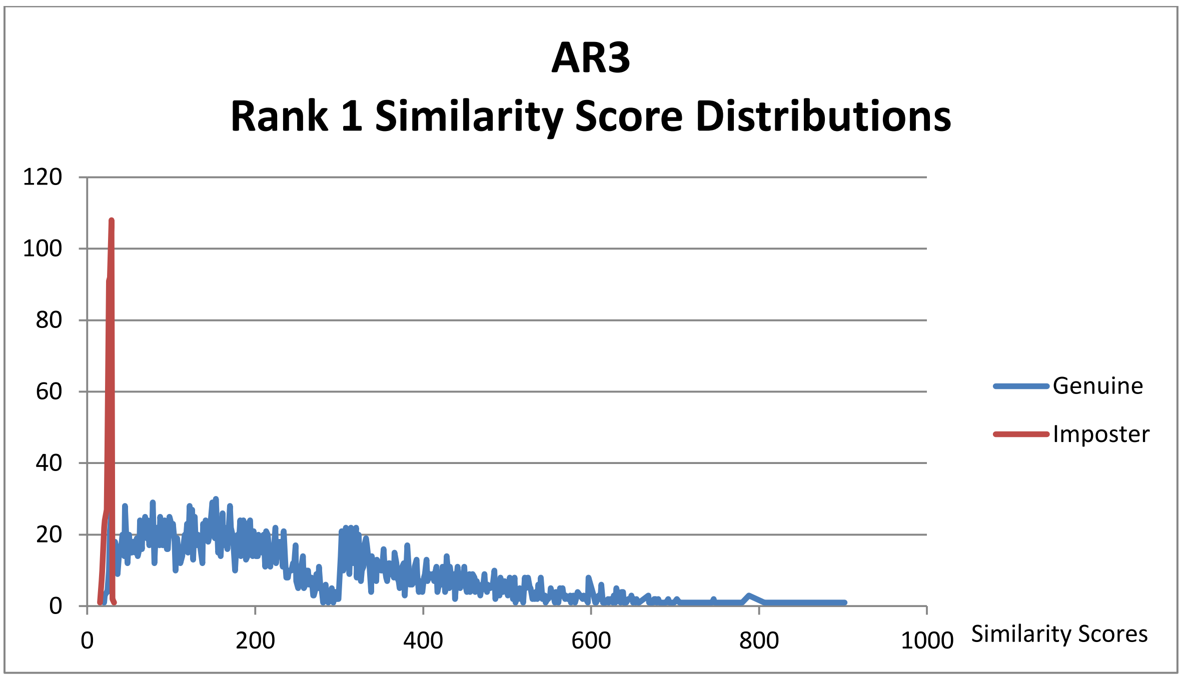


Figure 47 - AR3 Rank 1 Similarity Score Distributions

5.0 ANALYSIS & DISCUSSION

The evaluation team used a collected fingerprint data set consisting of contact and contactless collection devices as well as ink and paper. These image sets were evaluated with respect to matching performance, image quality, and interoperability. Matching performed was evaluated using the Neurotechnology Verifinger fingerprint matching algorithm. Image quality was determined using the NFIQ algorithm. Specific evaluation goals include:

1. Comparison of the 2D LFP image sets to each other
2. Comparison of the CFP collected rolled equivalent image sets to LFP datasets
3. Comparison of the CFP collected rolled equivalent image sets to CFP collected rolled equivalent image sets, and
4. Comparison of 2D LFP legacy image sets to CFP rolled equivalent image sets.

There were 20 evaluation runs conducted where 5 galleries were created and 15 matching runs to address project goals. A summary each matching run performance of the Rank 1 percent True and False Accept Rate is provided in the table below.

	Percent Accept Rate (Based on Matched Pairs)	
MATCHING RUNS	**Rank 1 True Match**	**Rank 1 False Match**
Gallery Runs		
GR1- Cross Match R2 Set 1 vs. Set 1	100%	0%
GR2- Cross Match R2 Set 2 vs. Set 2	100%	0%
GR3- Card Scan 500 dpi vs. 500 dpi	100%	0%
GR4- FlashScan Single vs. Single	100%	0%
GR5- TBS (HT1) vs. TBS (HT1)	100%	0%
2D LFP Runs		
LFPR1- I3 vs. G1	92.66%	7.34%
LFPR2- L1 vs. G1	96.58%	3.42%
LFPR3- Card Scan 500 dpi vs. G1	91.34%	8.66%
LFPR4- Cross Match SEEK vs. G1	97.80%	2.20%
CFP Devices Runs		
CFP to LFP Runs		
CFPR1- FlashScan Single vs. G1	71.40%	28.60%
CFPR2- FlashScan D4 vs. G1	17.05%	82.95%
CFPR3- TBS (HT1) vs. G1	91.15%	8.85%
CFPR4- TBS (HT2) vs. G1	85.67%	14.33%
CFPR5- TBS (HT6) vs. G1	86.42%	13.58%
CFP to CFP Runs		
CFPR6- FlashScan D4 vs. G4	11.80%	88.20%
CFPR7- TBS (HT1) vs. G4	65.75%	34.25%
CFPR8- TBS (HT2) vs. G4	56.53%	43.47%
Additional GR5 Runs		
AR1- FlashScan Single vs. G5	65.64%	34.36%
AR2- Cross Match R2 Set 1 vs. G5	90.73%	9.27%
AR3- Cross Match SEEK vs. G5	91.20%	8.80%

5.1 Analysis of Galleries

The initial task created and baselined the galleries used to measure performance for the 15 matching runs described in the following paragraphs. There were 5 galleries created from the Cross Match R2 Set 1, Cross Match R2 Set 2, the 500 dpi Card Scan, FlashScan Single, and the TBS (HT1) image sets. The 5 galleries match performance (see Figure 48) resulted in a 100% True Accept Rate with zero false matches. With the exception of the 500 dpi scanned fingerprint cards, all Gallery fingerprint image collections had reasonable NFIQ score distributions (see Figure 49). The poor ink and paper NFIQ scores were expected due to the difficulty in collecting and a lack of immediate feedback on fingerprint image quality. NFIQ scores from other rolled ink datasets support this explanation (Figure 50). Again, there were no false matches for any of the gallery matching runs so there were no matcher similarity scores to report for Imposter populations. The Gallery with the best mean matcher similarity score overall was the TBS HT(1) (see Figure 51). The Cross Match R2 Set 1 was used as the LFP gallery based on quality issues observed in collected tenprint ink cards – the TARs and NFIQ distributions supported this approach. Cross Match R2 image sets were compared and because of better matcher similarity scores, the Cross Match R2 Set 1 was selected for evaluation runs and the Cross Match R2 Set 2 was not used as a Gallery for any of the evaluation runs. The next set of evaluation runs conducted were to compare the matching performance of fingerprint images collected using different vendors' LFP devices and ink and paper using Gallery 1 (Cross Match R2 Set 1) for matching.

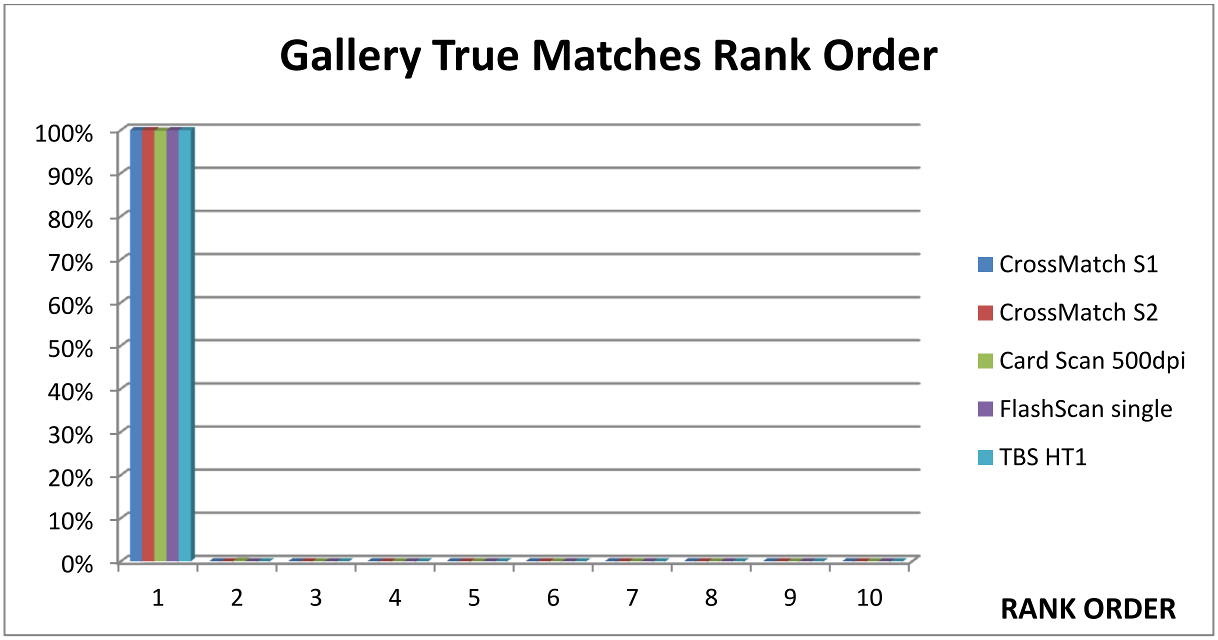


Figure 48 - Gallery True Matches Rank Order

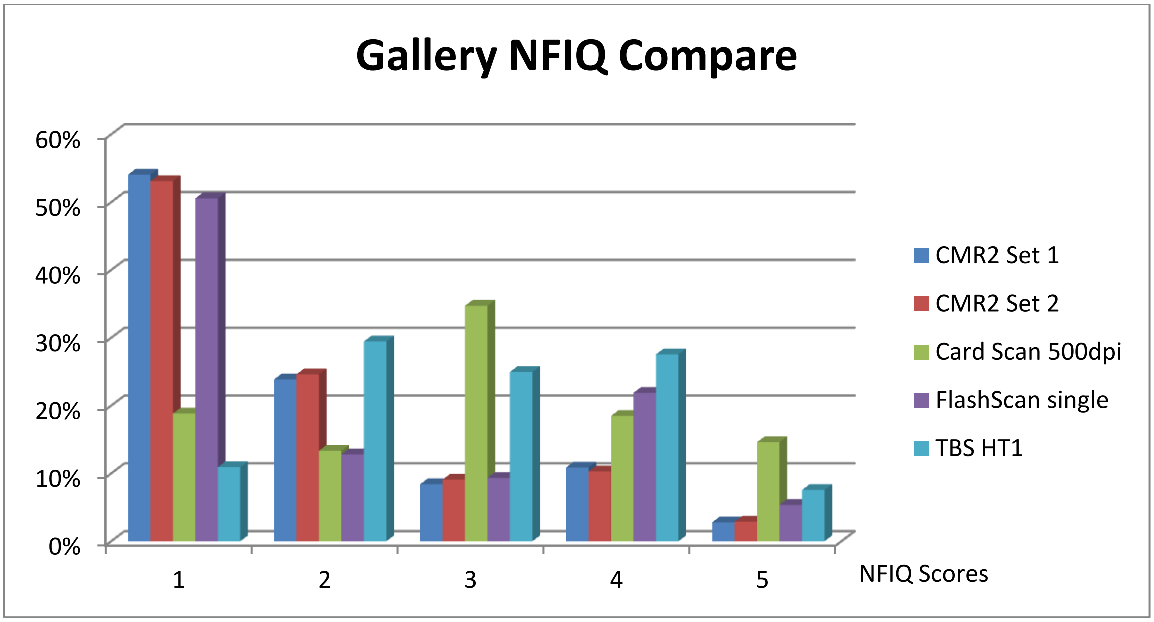


Figure 49 - Gallery NFIQ Compare

To provide context and comparison, the NFIQ scores for rolled prints from NIST SD27 and the WVU Latent Database are included from an external reference (Figure 50). Prints within NIST SD27 were collected by law enforcement professionals, while rolled prints in the WVU Latent Database were collected by students under similar circumstances to the Card Scan 500 dpi dataset from this effort. The NIST SD27 scores are better, while the WVU Latent Database print scores are comparable to Card Scan 500 dpi.

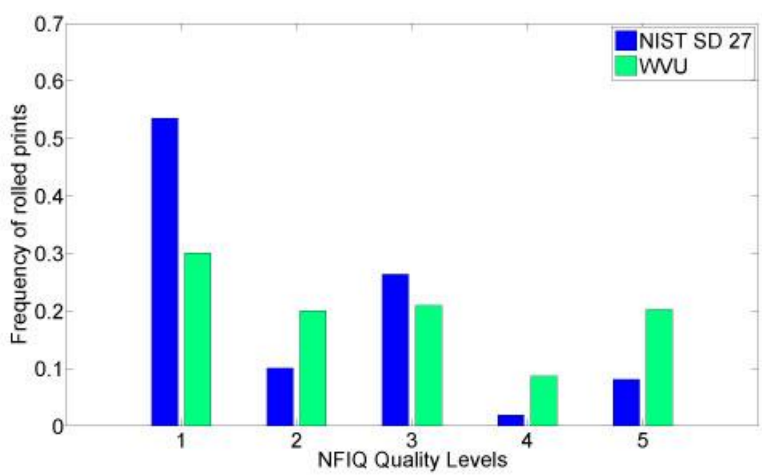
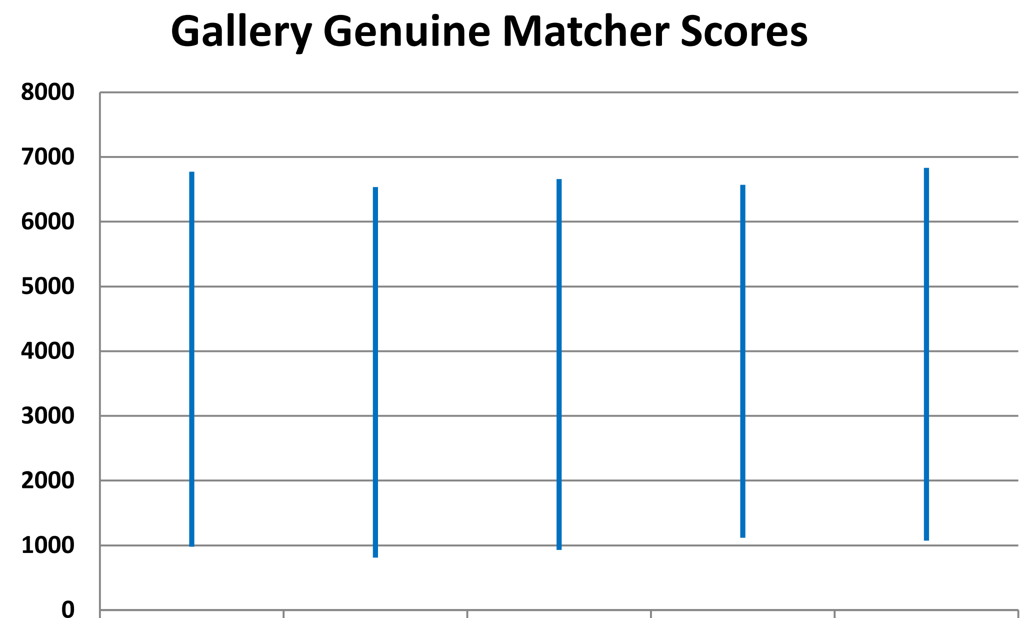


Figure 50 - NFIQ Distribution Examples of Rolled Print Databases



	CrossMatch R2 Set 1	CrossMatch R2 Set 2	Card 500dpi	FlashScan single	TBS HT1
Max	6774	6534	6660	6570	6831
Min	1724	812	1046	1115	1823
Mean	2734	2737	2869	3194	3281
Median	2277	2282	2520	2926	3003
SD	979.5	966	926.9	1166	1073

Figure 51 - Gallery Genuine Matcher Scores

It is interesting to note that the mean and standard deviation of the gallery genuine matcher scores are all approximately the same, while the NFIQ score distributions possess some notable differences (e.g., Cross Match R2 Set 1 vs. Card 500 dpi). This observation is not expanded upon in this report's analysis, but could be worthy of future investigations by third parties.

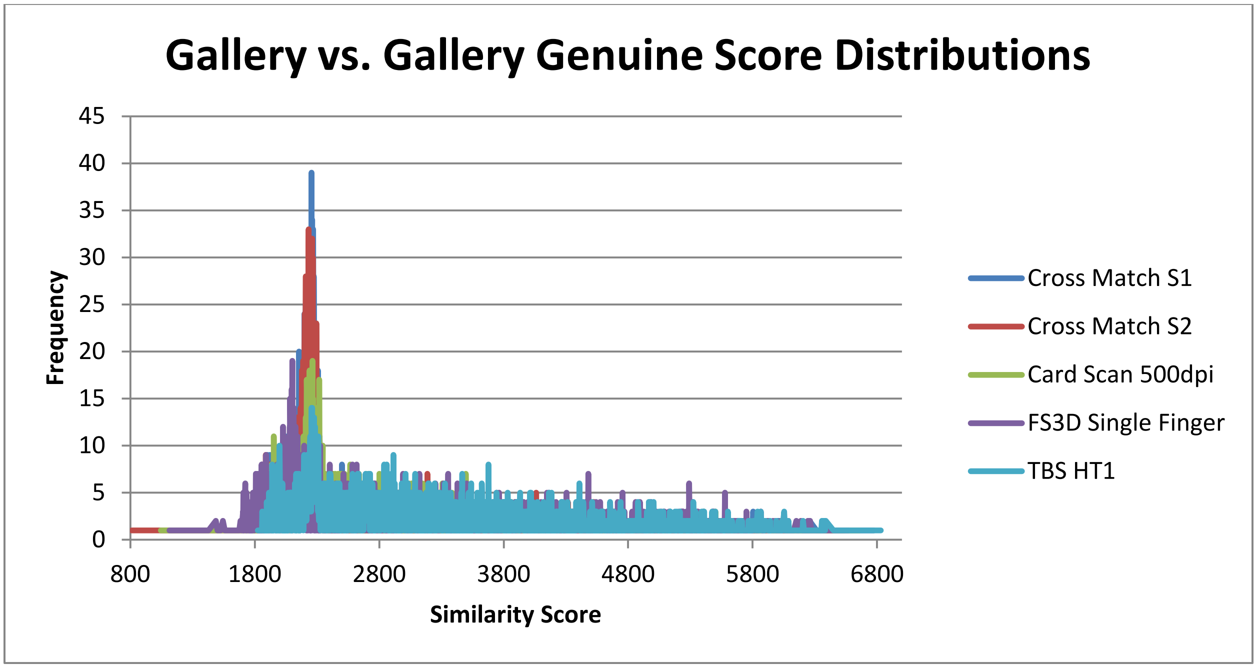


Figure 52 - Gallery vs. Gallery Matcher Score Distributions

5.2 Analysis of LFP vs. LFP

The evaluation team conducted 4 matching runs representing legacy 2D LFP collections and using Gallery 1 for matching. The 4 sets of probe fingerprint images were collected using the i3, L1, 500 dpi Card Scan, and the Cross Match SEEK II devices. The best probe image matching performance was collected by the Cross Match SEEK II (97.80% TAR) followed closely by the L1 TouchPrint device (96.58% TAR). The i3 DigID Mini device had a TAR of 92.66% and last was the ink and paper collection scanned at 500 dpi (91.34%) (see Figure 53). The higher match results for the Cross Match SEEK II device matching run was unexpected due to the smaller size of the fingerprint platen. The match performance for the 500 dpi Card Scan collection was relatively lower than the other LFP legacy collections due to the lower NFIQ scores (see Figure 54). The CFP devices were next matched to Gallery 1.

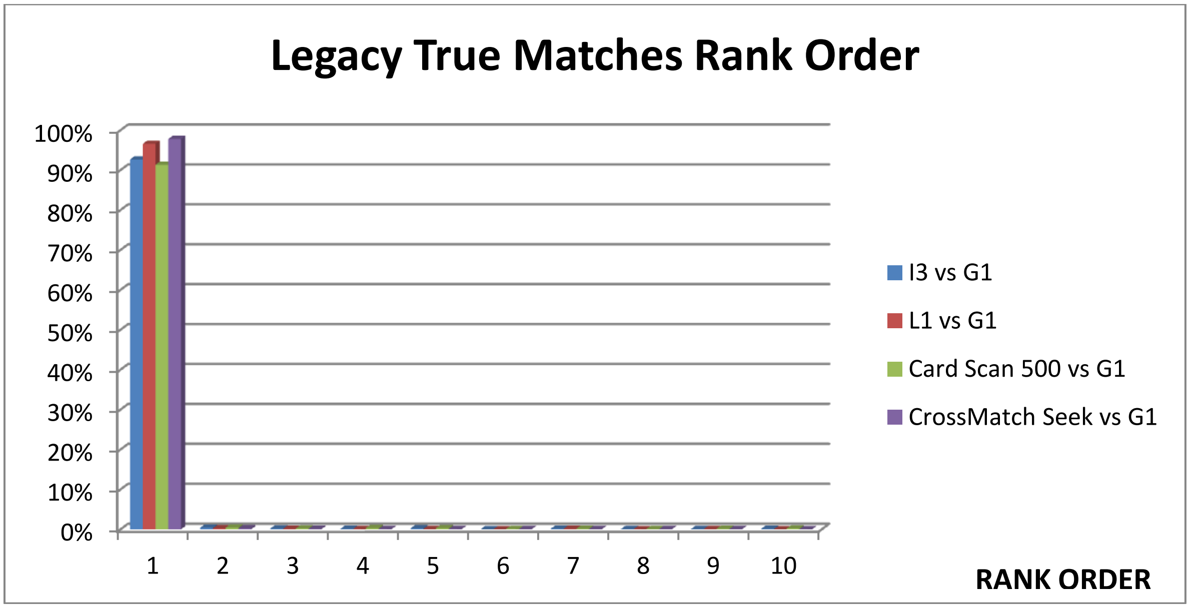


Figure 53 – Legacy True Matches Rank Order

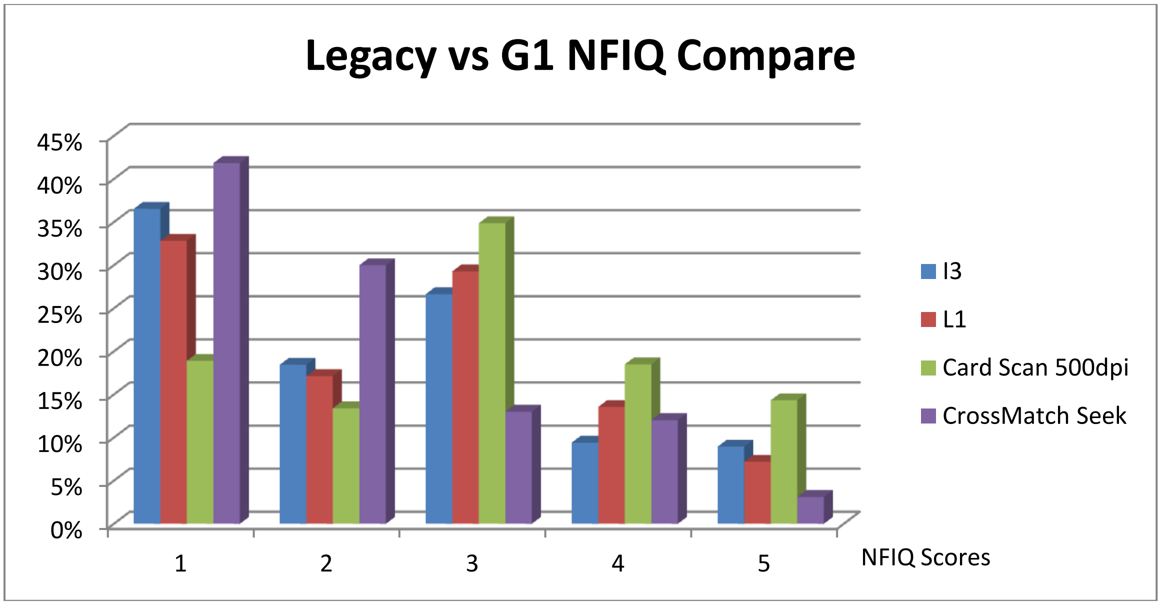
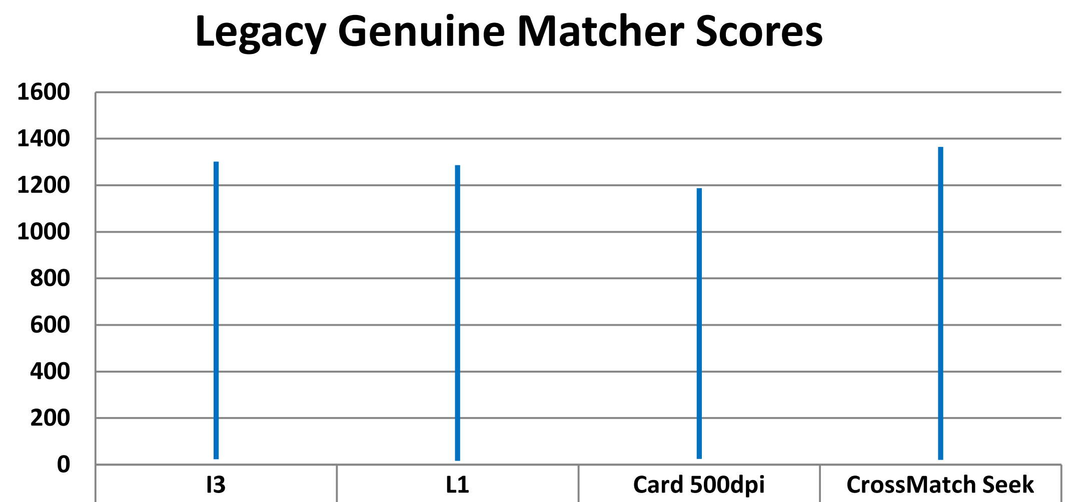
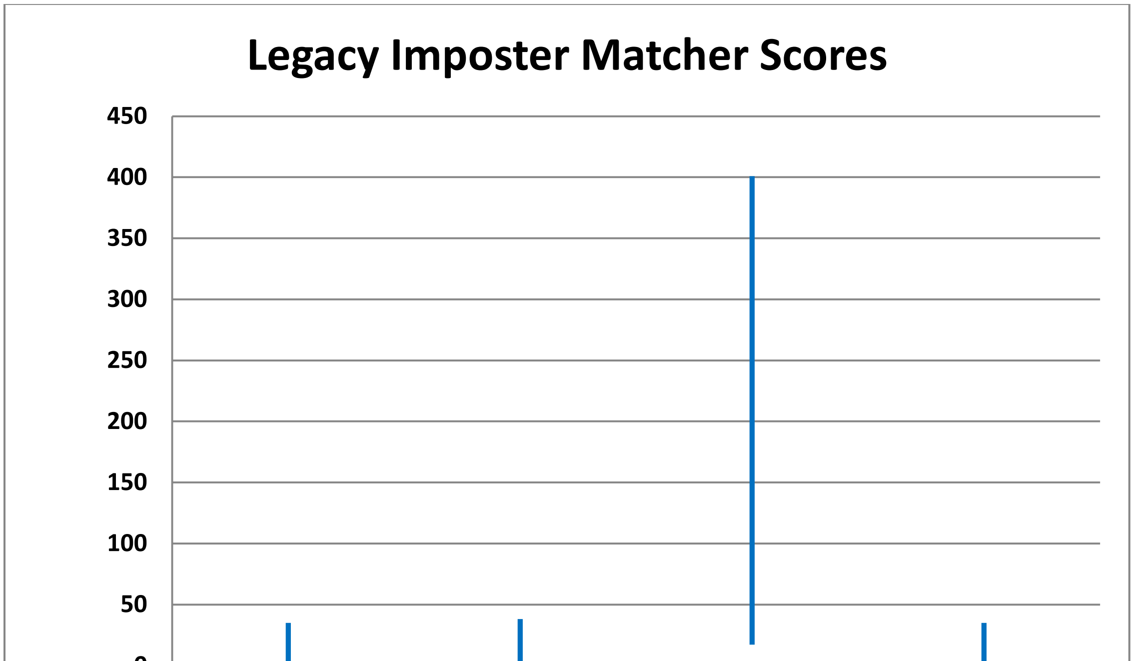


Figure 54 – Legacy vs. G1 NFIQ Compare



	I3	L1	Card 500dpi	CrossMatch Seek
Max	1301	1287	1187	1365
Min	23	17	24	21
Mean	431	422	300	504
Median	410	413	246	489
SD	267	233	205	263

Figure 55 – Legacy Genuine Matcher Scores



	I3	L1	Card 500dpi	CrossMatch Seek
High	35	38	401	35
Low	15	17	17	20
Mean	26.5	26.6	31.44	26
Median	27	27	27	27
SD	2.63	2.72	32.2	2.94

Figure 56 – Legacy Imposter Matcher Scores

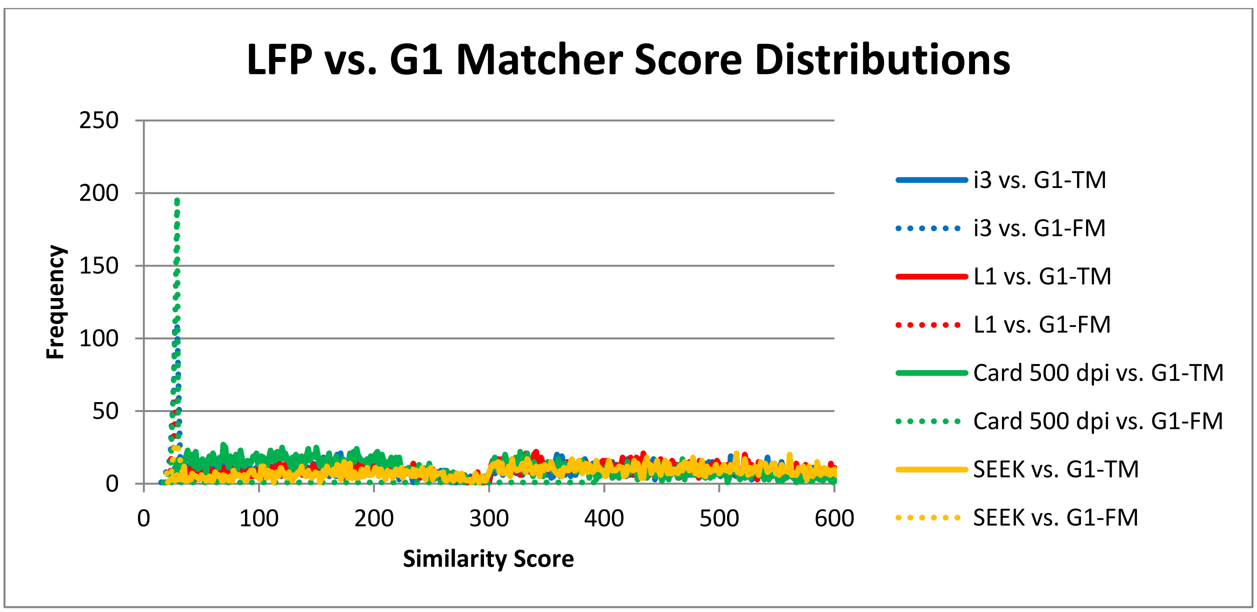


Figure 57 - LFP vs. G1 Matcher Score Distributions

5.3 Analysis of CFP vs. LFP

One of the evaluation goals was to determine the match performance of images collected on contactless devices to 2D LFP data sets. As stated previously, **the CFP images used for matching were not 3D images but 2D rolled equivalents of those collected images (see Section 4.3).** The CFP devices were the FlashScan Single, FlashScan D4, and the TBS. The TBS device created several images from a single collection event. Based on input from the TBS vendor, the evaluation team selected HT1, HT2, and HT6 to use as probe image sets against the Gallery 1 (Cross Match R2 Set 1). The 5 runs conducted used probe images collected by the FlashScan Single, FlashScan D4, TBS (HT1), TBS (HT2), and TBS (HT6). The best performer of the group was the TBS (HT1) probe set, confirming the advice of the vendor regarding image selection for legacy matching. Also note that the NFIQ score distribution of TBS (HT1) data (Figure 59) was comparable to that of the Card 500 dpi (Figure 54). The TBS (HT2) and TBS (HT6) probe sets performed about 5% poorer in TAR. Overall, the FlashScan devices, both the Single and D4, performed worst, with the D4 being significantly the poorest of the group (see Figure 58). However, given that these devices are prototypes, these results were not surprising. Note that the D4 required repairs by the vendor several times during the WVU collection effort, and that there may have been calibration errors with the device. The poor matching performance of the FlashScan D4 is supported by the NFIQ score distribution (see Figure 59).

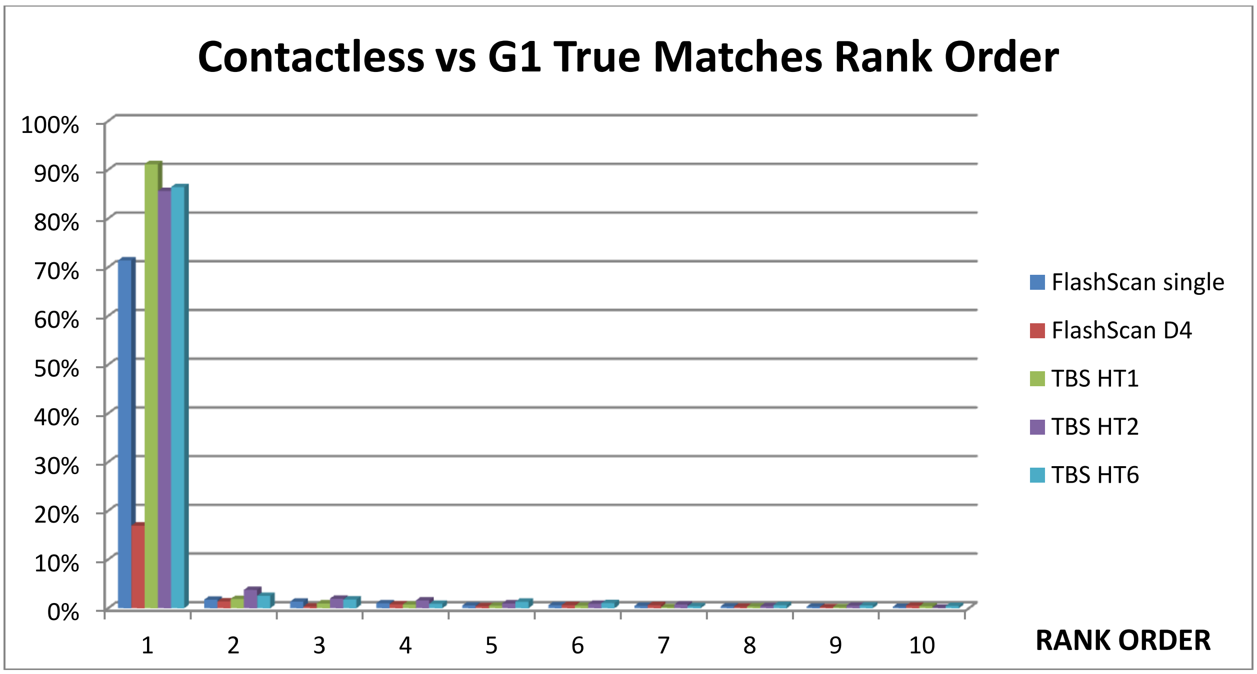


Figure 58 – Contactless vs. G1 True Matches Rank Order

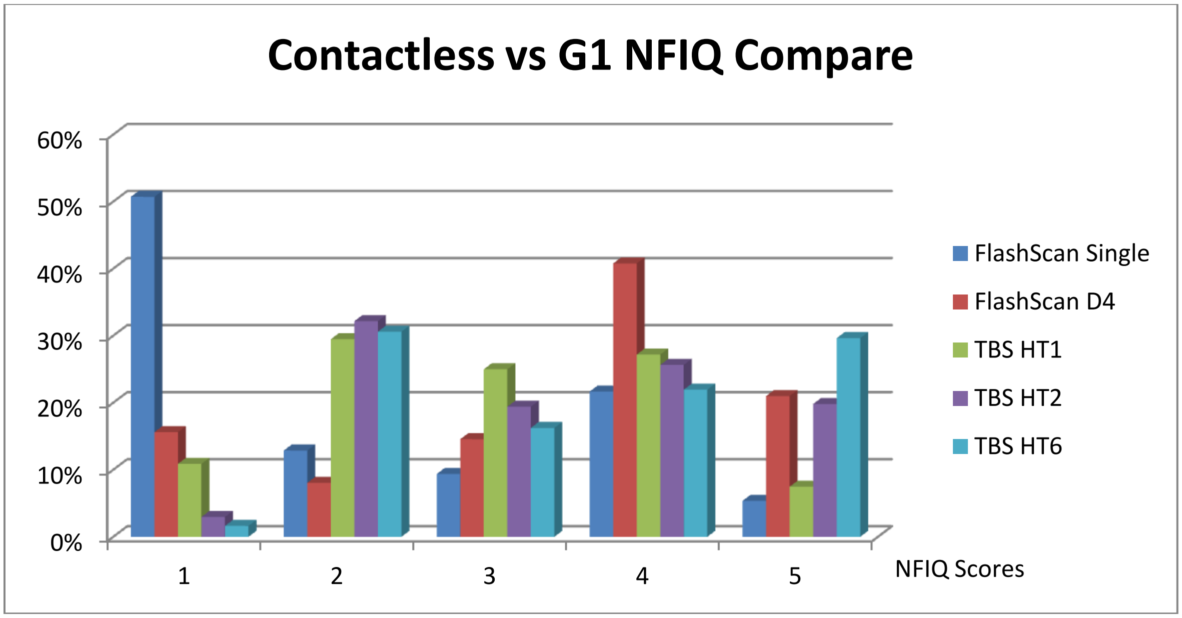
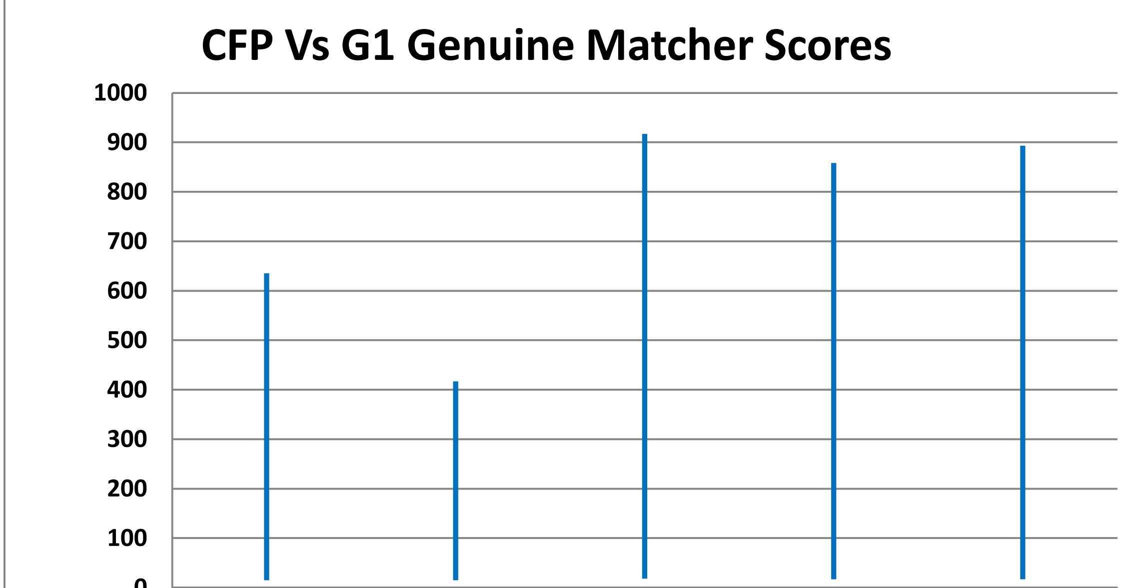
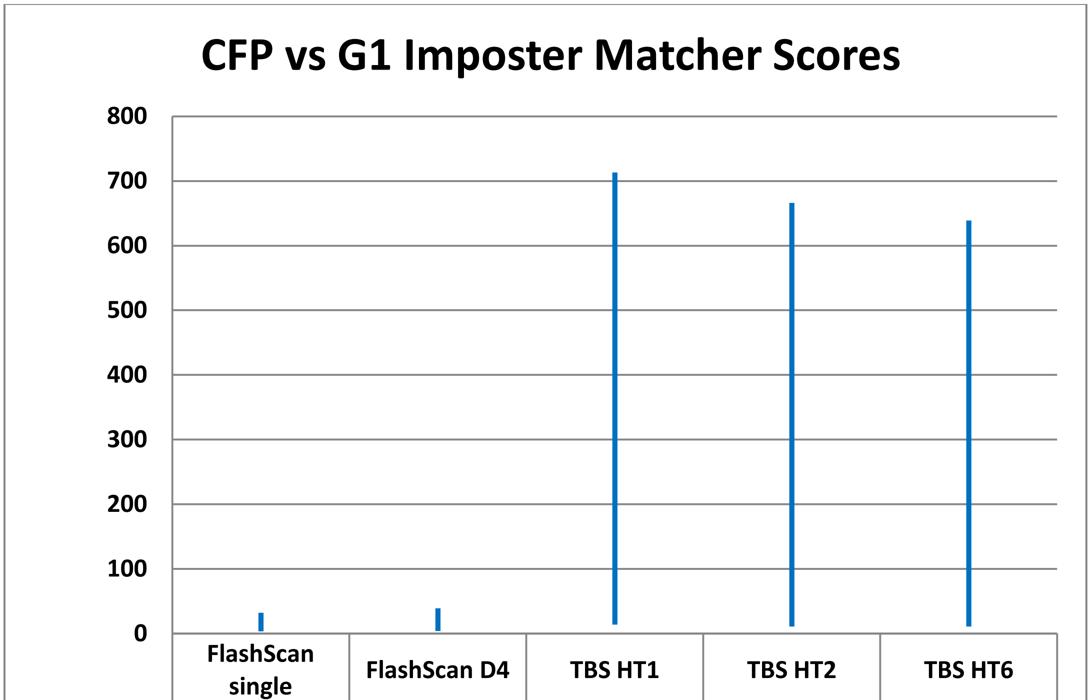


Figure 59 – Contactless vs. G1 NFIQ Compare



	FlashScan single	FlashScan D4	TBS HT1	TBS HT2	TBS HT6
Max	635	417	917	858	893
Min	15	15	18	17	17
Mean	113	83	231	192	195
Median	93	65.5	186	149	150
SD	77	62	160	145	148.5

Figure 60 – Contactless vs. G1 Genuine Matcher Scores



	FlashScan single	FlashScan D4	TBS HT1	TBS HT2	TBS HT6
Max	32	39	713	666	639
Min	12	11	14	11	11
Mean	25	24	41	32	33
Median	26	24	23.5	24	24
SD	3.33	3.83	82	56	57

Figure 61 – Contactless vs. G1 Imposter Matcher Scores

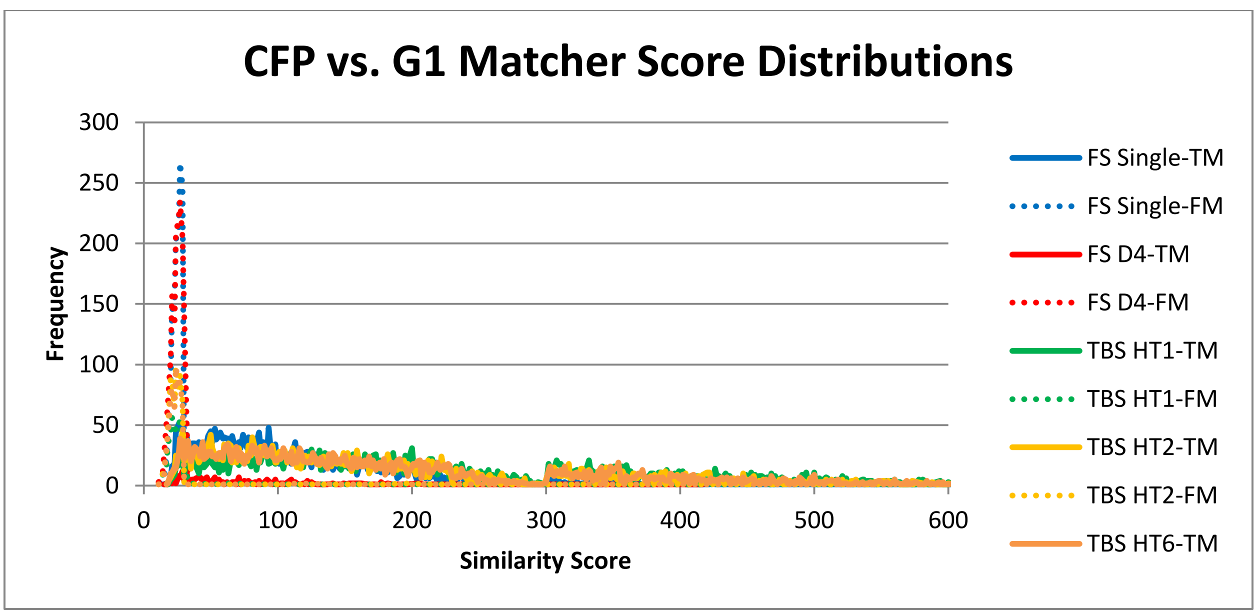


Figure 62 - LFP vs. G1 Matcher Score Distributions

5.4 Analysis of CFP vs. CFP

Another goal of the evaluation was to compare the performance of CFP device rolled equivalent fingerprints both as probe and as gallery. These runs compare CFP collected image sets as both probe and gallery. The three runs used the FlashScan Single Collection as gallery (Gallery 4) and as probe datasets the FlashScan D4, TBS HT1, and TBS HT2. Overall the matching results were very poor, with the FlashScan D4 probe set matching to the FlashScan Single providing the worst results, at only 11.80% TAR. The best performing of the group was the FlashScan Single at 65.75% (see Figure 63). The explanation for the poor matching could be in the CFP projection or unwrapping algorithms used by FlashScan and TBS to create the rolled equivalent images. The ability of the Verifinger matching algorithm to match CFP rolled equivalent fingerprint images to themselves is not in question due to the 100% TAR results for both Gallery 4 (FlashScan Single) and Gallery 5 (TBS (HT1). Also, consider that in both Gallery 4 and Gallery 5 the same 3D to rolled equivalent image projection algorithms were used.

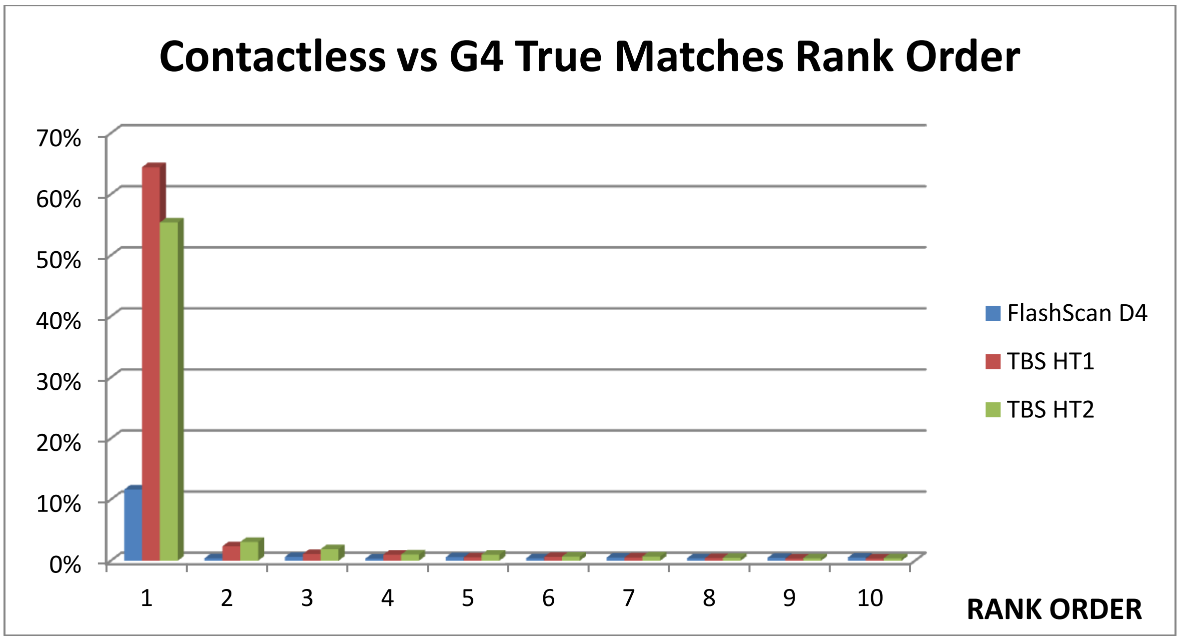


Figure 63 – Contactless vs. G4 True Matches Rank Order

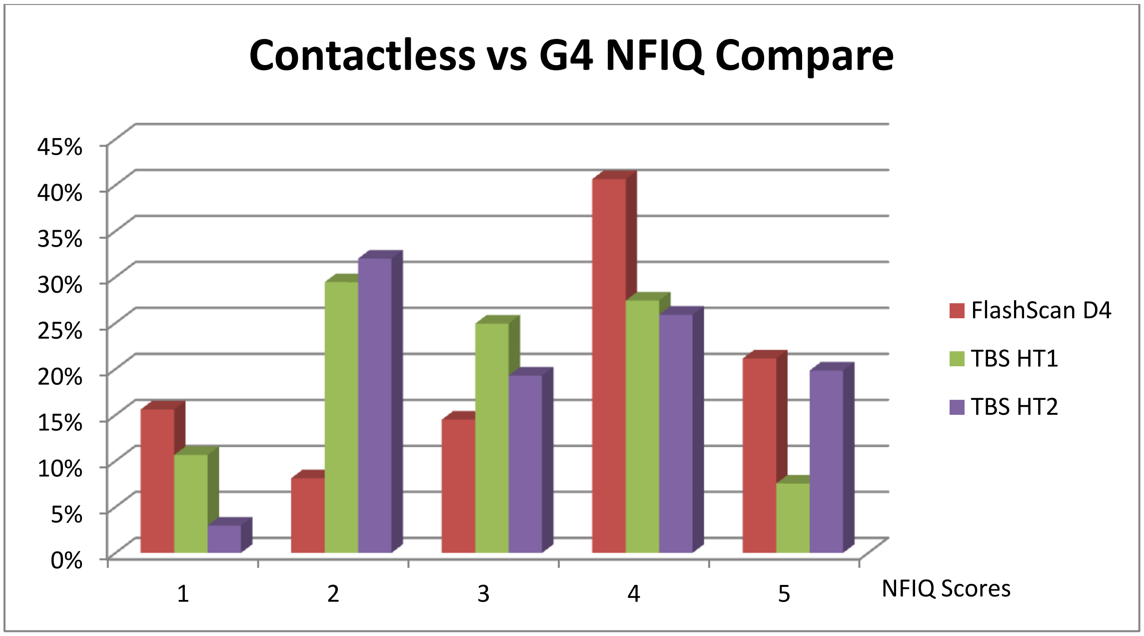
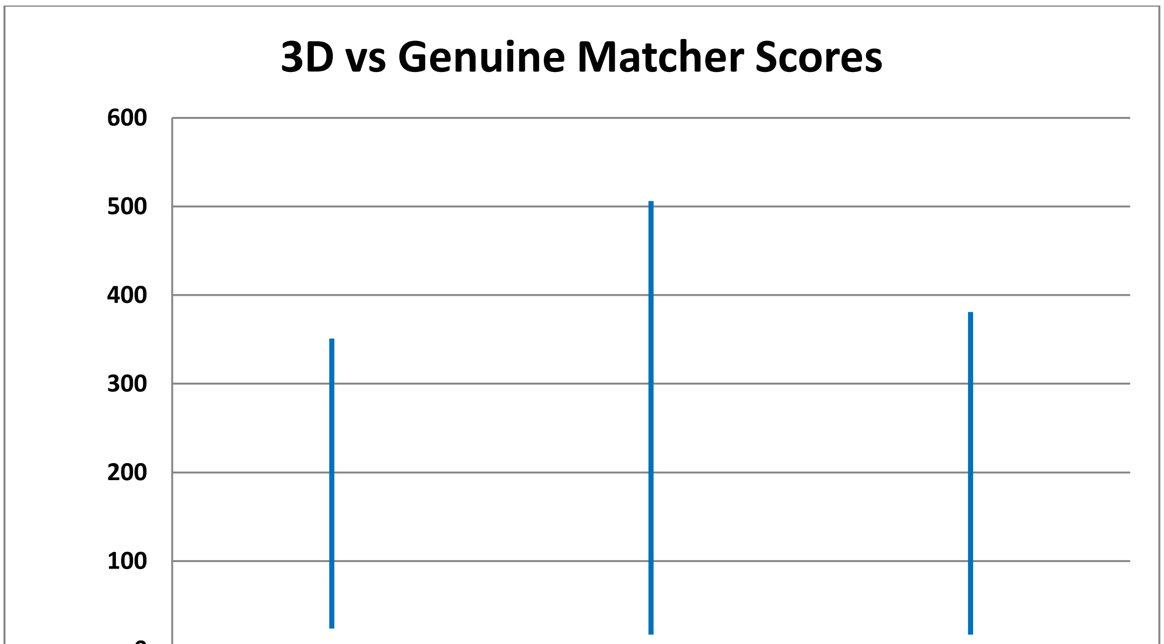
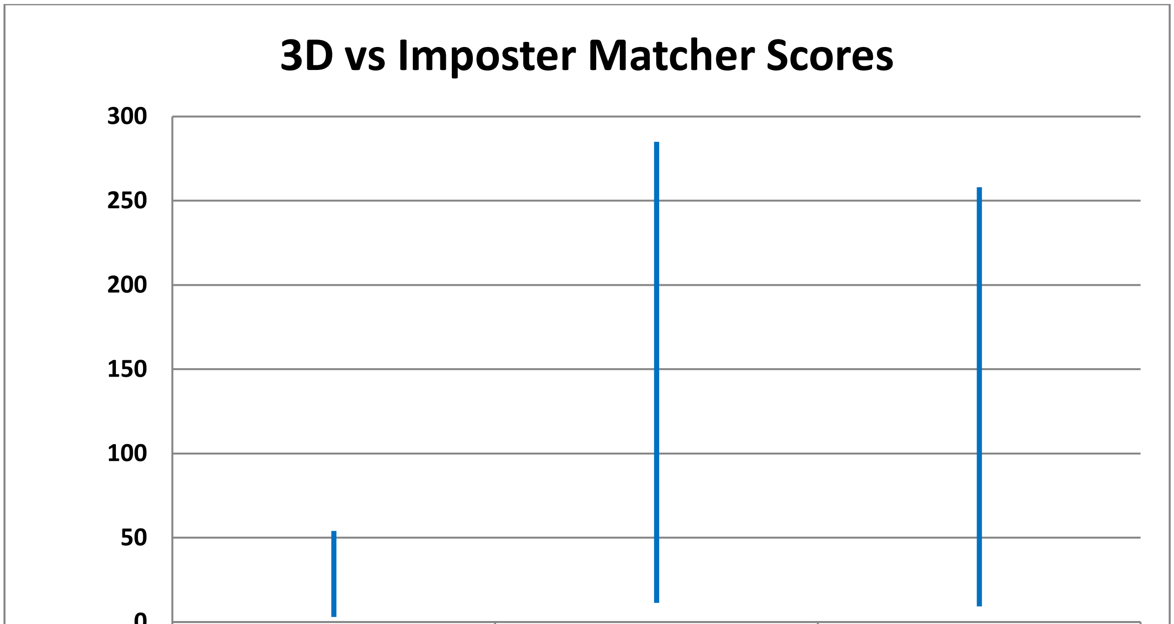


Figure 64 – Contactless vs. G4 NFIQ Compare



	FlashScan D4	TBS HT1	TBS HT2
Max	351	506	381
Min	24	17	17
Mean	75	86.5	72
Median	57	74	60
SD	51	53.36	45.14

Figure 65 – Contactless vs. G4 Genuine Matcher Scores



	FlashScan D4	TBS HT1	TBS HT2
Max	54	285	258
Min	17	15	12
Mean	27	25	24
Median	27	24	24
SD	2.94	11.4	9.29

Figure 66 – Contactless vs. G4 Imposter Matcher Scores

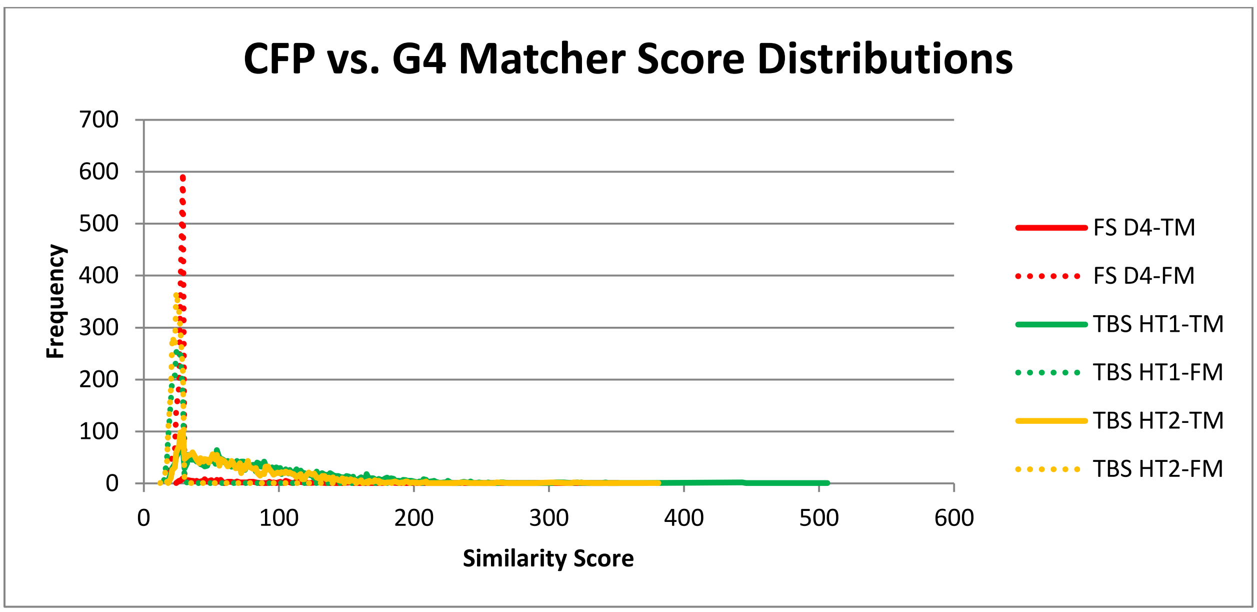


Figure 67 - CFP vs. G4 Matcher Score Distributions

5.5 Analysis of Additional Runs

The evaluation schedule provided an opportunity to measure the ability of 2D LFP devices to match to a CFP rolled equivalent gallery, and to explore the performance of a different CFP gallery. An additional 3 runs were conducted that shows matching performance of the FlashScan Single, Cross Match R2 (Set 1), and Cross Match SEEK to a CFP rolled equivalent gallery. Gallery 5 TBS (HT1) matched probe images collected from the FlashScan Single, Cross Match R2 Set 1, and Cross Match SEEK II. This provided the best opportunity for the highest TAR based on previous evaluations of the datasets match and NFIQ performance. These runs produced good match performance for the Cross Match devices but not the FlashScan. The Cross Match R2 Set 1 and Cross Match SEEK II provided a 90.73% and 91.20% TAR and the FlashScan Single 65.64% TAR (see Figure 68). The evaluation team considered one possible explanation is that both of the Cross Match probe image sets were collected with finger pressure on the platen and the gallery was collected using the TBS device which is contactless. Perhaps the matching algorithm could be improved to account for the elasticity of skin for the probe images. This investigation was beyond the scope of this evaluation but could be a topic for future research.

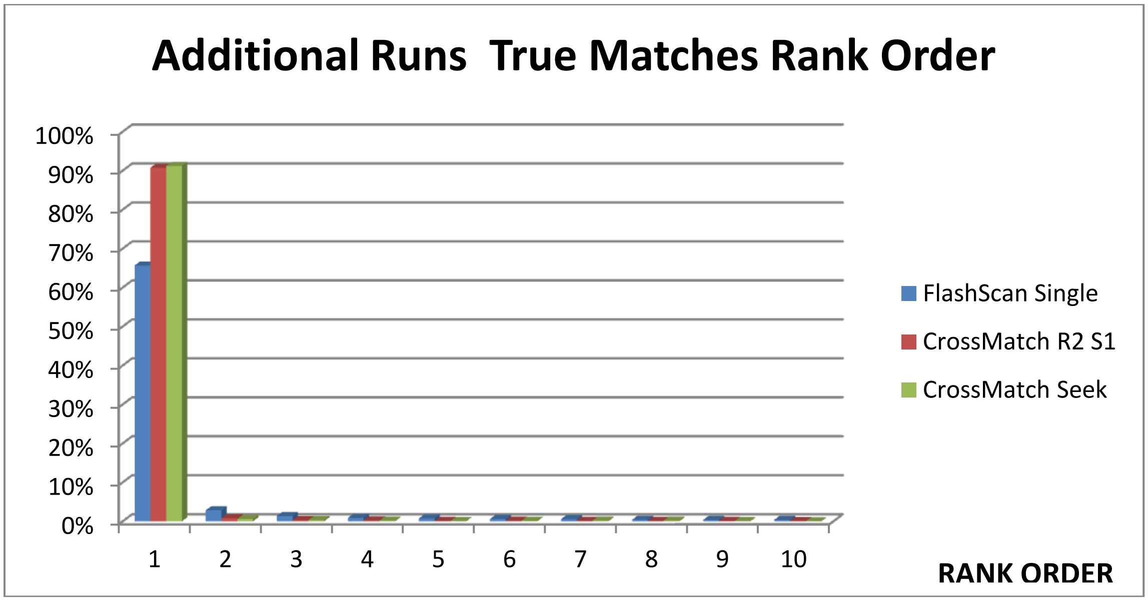


Figure 68 - Additional Runs True Matches Rank Order

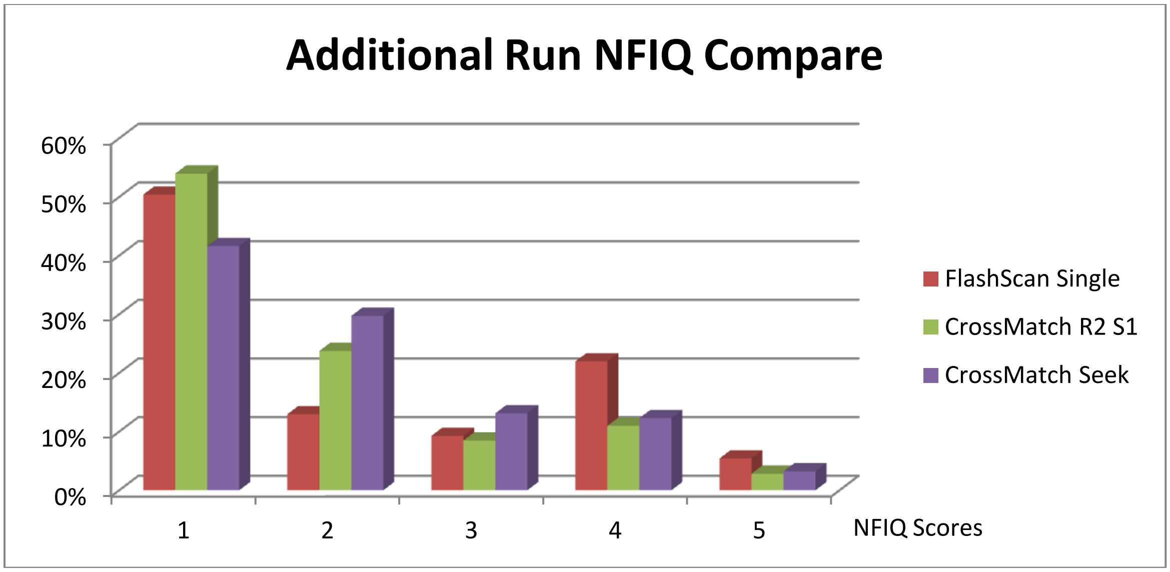
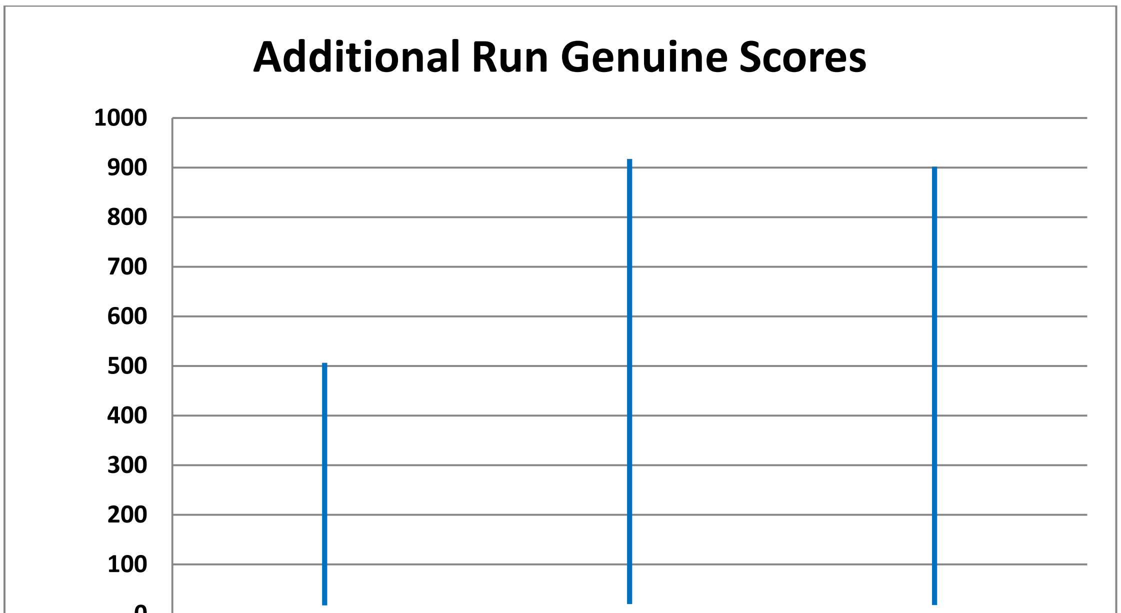
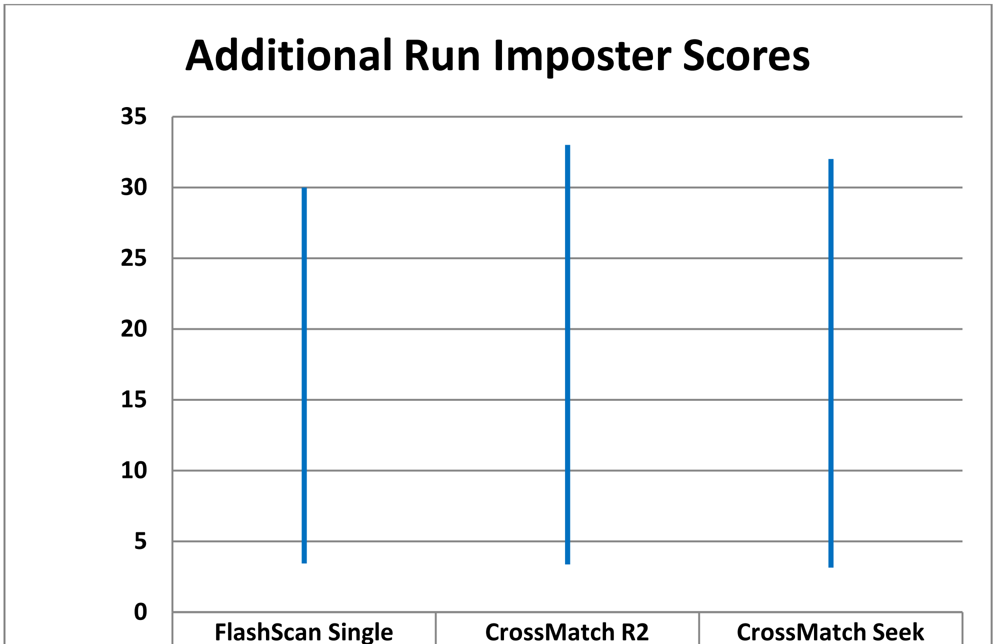


Figure 69 - Additional Run NFIQ Compare



	FlashScan Single	CrossMatch R2	CrossMatch Seek
High	506	917	902
Low	17	20	18
Mean	87	233	242
Median	74	188	200
SD	41	159.3	160.5

Figure 70 - Additional Runs Genuine Matcher Scores



	FlashScan Single	CrossMatch R2	CrossMatch Seek
High	30	33	32
Low	12	14	15
Mean	23.63	25	25.67
Median	24	26	26
SD	3.44	3.38	3.14

Figure 71 - Additional Runs Imposter Matcher Scores

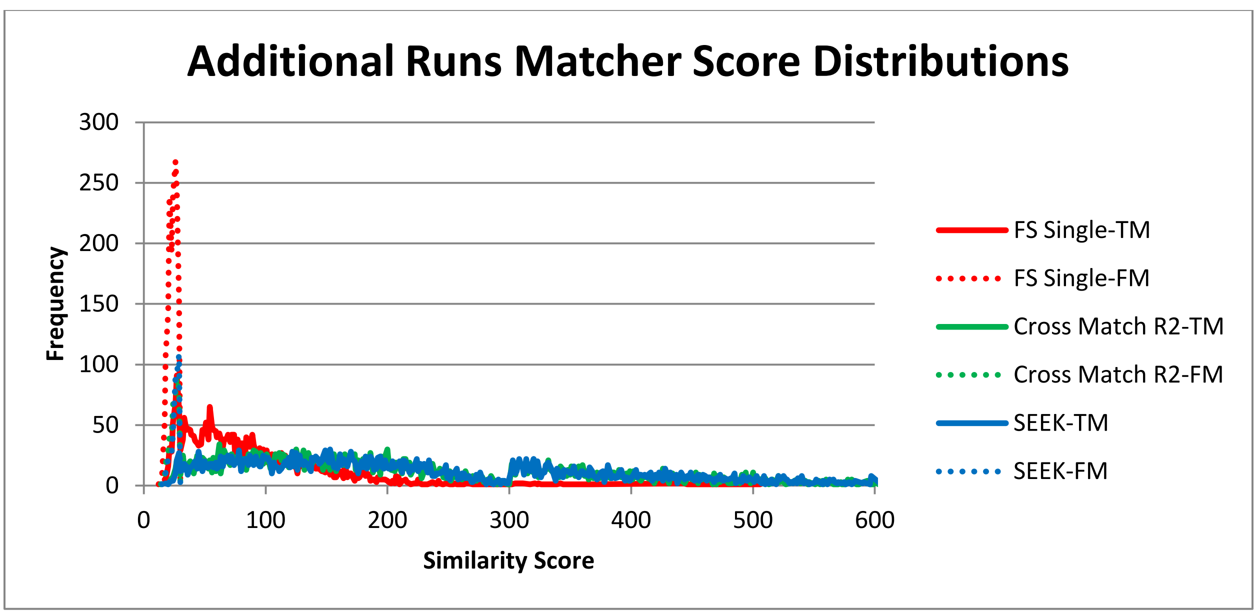


Figure 72 - Additional Runs Matcher Score Distributions

6.0 CONCLUSIONS

In general, seven key observations/conclusions were identified as a result of this evaluation effort:

- This effort is the first quantitative demonstration by a third party that fingerprints collected under ideal conditions from LFP and CFP devices can be matched against each other in a statistically meaningful way.
    - Conclusion: The experimental methodology employed (data collection and analysis) can be used to determine a comparative match performance among LFP and CFP using 2D projections.

- Matching CFP legacy-equivalent images to LFP images provides less match performance than LFP images to LFP images.
    - Conclusion: More work is needed to improve the quality of captured images or the quality of 2D legacy-equivalent conversions. Additional research opportunities may exist in developing or modifying fingerprint matching algorithms that are less sensitive to skin elasticity.

- Matching CFP legacy-equivalent images between the various contactless devices provided very poor results as compared to currently available technologies.
    - Conclusion: Additional research may be necessary to provide better CFP to LFP conversion algorithm accuracy.

- The ink and paper collection provided lower similarity scores from the fingerprint matcher and had poorer NFIQ scores. We assume from this finding that ink and paper fingerprinting requires more skill and experience than collecting on live scan devices. Additionally, live scan fingerprint collection devices generally provide immediate quality feedback and the opportunity to recollect a poor fingerprint.
    - Conclusion: Rolled-ink tenprint cards may not be the “gold standard” ground-truth gallery for biometric testing or research

- The Cross Match SEEK II performed better than expected as a livescan collection device, as compared to the other legacy CFP systems. The reason for expectations of lower match performance was due to the smaller platen surface area.
    - Conclusion: SEEK may be suitable for field enrollments, and is more than adequate for field queries.

- The FlashScan D4 performed very poorly. The device had several failures during collection efforts and required vendor support. Also, due to the failures this device had the fewest number of collection subjects.
    - Conclusion: Data from prototypes can be significantly poorer than commercial systems using similar capture approaches, and therefore the purpose/objective of data collections should be taken into account when considering the inclusion of prototypes.

- The images collected by the TBS 3D Enroll are mirrored along the vertical axis, causing an inability to match against standard datasets. The Test Team corrected the images locally prior to testing. Images in the WVU dataset remain unchanged.
    - Conclusion: Devices developed for civilian access control applications, or for foreign markets, may not follow standard Appendix F requirements. Research, Development, Test, and Evaluation (RDT&E) must be aware of potential issues.

6.1 Future RDT&E Directions

As one of the first research efforts to investigate the match performance and interoperability of contact and contactless fingerprint data, this work has made important first steps. However, there are many related areas or follow-on tasks that could be pursued. Resource limitations have precluded the SSBT CoE team from pursuing these, but given the general availability of the WVU collection dataset, it would be easy to continue the work with minimal lag or learning curve.

- **Determine accuracy and precision of minutia from matcher for LFP vs. CFP** – Involving latent fingerprint examiners, research could be performed to explicitly map out deviations or errors in algorithm minutia markups when processing LFP vs. CFP converted prints. This would improve understanding of algorithm performance and aid in developing next generation algorithms.

- **Research methods of projecting 3D images to 2D** – Current prototype and commercial 3D systems use a variety of off-the-shelf and proprietary methods for creating 2D grayscale images from contactless captured fingerprints. Research could include the accuracy and geometric distortions of open source projection algorithms as applied to fingerprints. Investigating the efficacy of different methods and developing a recommended standard would benefit the research community, improve comparative T&E, and enhance interoperability.

- **Expand collection to include additional livescan, 3D, and Contactless devices** – Additional 2D, 3D, and contactless devices, utilizing different collection technologies and configurations, would further enhance and improve the dataset. Because of standardized protocols and data collection outreach, much of the same study participant population could likely be recruited for repeat collections.

- **Additional matching algorithms** – Individual matchers have varying methods of ingesting fingerprint images, conducting markup of minutia, and executing matching against a gallery. Research using different algorithms may present trends or variations that can aid future contactless to legacy conversion matching algorithm development.

- **Investigate algorithm template generation processes to improve 3D converted image matching** – Research to understand the subprocesses and methodologies involved in specific algorithm template generation could provide insight into what templates produce improved matching with 3D or contactless converted images, and therefore identify challenges and optimal strategies when using 3D or contactless fingerprint images.

- **Research and model how skin deforms while collecting fingerprints on paper and glass platens** – Fingerprints collected on LFP and CFP devices from the same population set allows for investigations into how minutia and features translate and deform during normal fingerprint pressure.

- **Develop algorithm metrics for measuring and understanding performance of 3D or contactless fingerprint matching** – All fingerprint algorithms have been developed using existing legacy galleries of 2D latent and livescan images. Developing metrics to deconvolute the performance of matchers with 3D or contactless converted images would increase understanding of challenges, assumptions, and limitations affecting performance.
- **Exploration of FBI Next Generation IAFIS (NGI) or DoD Automated Biometric Identification System (ABIS) match performance and NFIQ distribution for rolled-ink tenprint cards vs. livescan systems** – Determining whether operational fingerprint data supports the hypothesis that rolled-ink tenprint cards have statistically lower NFIQ distributions than livescan enrollments would have relevance to law enforcement and military application and technology practices.

- **Development of an operational AFIS-equivalent database for research purposes – The WVU dataset includes a range of device sources and NFIQ scores. Using source and NFIQ statistics from FBI and then reproducing using WVU dataset in proper ratios would result** in a unique resource that could improve the real-world relevancy of biometric research of device prototypes and algorithms.

6.2 Known Dataset Errors

Three errors were discovered in the WVU fingerprint dataset. They have been discussed elsewhere in this report, but to assist future research, they are summarized here:

1. The 500 dpi Card Scan image set includes a collection error (see Section 4.1.3). The same card was scanned twice, but assigned different subject ID numbers. The subject IDs are 9384043 and 6583110. Subject 9384043 card scan images do not match its Guardian R2 images, therefore researchers are advised to delete the 500 dpi card scan images for Subject 9384043 from probe and gallery datasets prior to using the data.
   NOTE: This error does not exist in the 1000 dpi Card Scan collection.

2. The TBS fingerprint images are mirrored versions of standard fingerprint image representations (see Section 3.2.1). The error does not lie with the WVU collection, but with the engineering design of the TBS 3D Enroll. The images can be easily corrected by producing mirrored versions prior to use of the data.

3. The dataset possesses data integrity issues for five subjects. These issues include missing fingerprint images for certain devices, duplicate images with both retained in the dataset and possessing different NFIQ scores, and finger position numbering errors. In the interest of only using reliable, consistent data, some images were excluded from the matching run results. The matching run tables summarize the gallery, probes, etc. in detail to avoid any confusion. Users of the dataset should double check the data integrity for the following subject IDs: 3175520, 3870709, 4953069, 6408154, and 8011022.

APPENDIX A – ACRONYMS AND ABBREVIATIONS

Acronym	Definition
2D	Two Dimensional
3D	Three Dimensional
ABIS	Automated Biometric Identification System
AFIS	Automated Fingerprint Identification System
AR	Additional Run
BIMA	Biometrics Identity Management Agency
CFP	Contactless Fingerprint
CFPR	Contactless Fingerprint Run
CJIS	Criminal Justice Information Services
CoE	Center of Excellence
DoD	Department of Defense
DOJ	Department of Justice
dpi	Dots per inch
FAR	False Acceptance Rate
FBI	Federal Bureau of Investigation
GR	Gallery Run
IAFIS	Integrated Automated Fingerprint Identification System
LFP	Legacy/Livescan Fingerprint
LFPR	Legacy Fingerprint Run
NFIQ	NIST Fingerprint Image Quality
NGI	Next Generation IAFIS
NIJ	National Institute of Justice
NIST	National Institute of Standards and Technology
ppi	Pixels per inch
R&D	Research and Development
RDT&E	Research, Development, Test and Evaluation
SSBT	Sensor, Surveillance, and Biometric Technologies
T&E	Test and Evaluation
TAR	True Accept Rate
TBS	Touchless Biometric Systems
WVU	West Virginia University

APPENDIX B – WVU DATA TYPES AND ORGANIZATION

Data Types and Organization:

Each participant in the data collection provided two sequential sessions of fingerprints for each sensor. Inked prints were collected once and scanned at 500 and 1000ppi. The following were collected for each sensor device:

Guardian

- two sessions each of: rolled individual fingers on right and left hands, left slap, right slap, and thumb slap

i3 digID Mini

- two sessions each of: rolled individual fingers on right and left hands, left slap, right slap, and thumb slap

TouchPrint

- two sessions each of: rolled individual fingers on right and left hands, left slap, right slap, and thumb slap

SEEK II

- two sessions each of: rolled individual fingers on right and left hands, left index + middle slap and left ring + little slap (to create left slap), right index + middle slap and right ring + little slap (to create right slap), and thumb slap

TBS

- two sessions of each individual finger on right and left hands

FlashScan Single-Finger

- two sessions of each individual finger on right and left hands

FlashScan Four-Finger

- two sessions each of right slap, left slap, and thumb slap

File Structure:

The file structure of the data is as follows:

ManTech_Fingerprint
- Date
  - Random ID
    - Fingerprint
      - Cross Match R2
        - Session 1
          - RandomID_Date_session

.bmp files
Session 2
same as session 1
Flashscan 3D
Session 1
ten folders named as RandomID_date_session_digit
.bmp & .byt files
Session 2
same as session 1
Flashscan 3D – D4
Session 1
vmrl folder
.bmp & .byt files
Session 2
same as session 1
i3 Digi ID Mini
Session 1
.png files
Session 2
same as session 1
L1 Touchprint 5300
Session 1
.png files
Session 2
same as session 1
Seek
Session 1
.eft file
Session 2
.efts files
TBS
Session 1
Raw
.ini file & .bmp files
Session 2
Same as session 1
Ten Print Scans
500
.eft file and .bmp files (500ppi scans)
1000
.eft file and .bmp files (1000ppi scans)

Note: All images saved with format:

RandomID_Date_Session_dataID

except for those from the Flashscan D4 Device.

APPENDIX C – WVU NONCONTACT FINGERPRINT COLLECTION REPORT

Non-Contact Multi-Sensor Fingerprint Collection
4/2012 - 8/2012

FINAL REPORT

<u>For:</u>
ManTech International Corp.

Dr. Bojan Cukic, PRINCIPLE INVESTIGATOR
Dr. Jeremy M. Dawson, Co-PI
Dr. Simona Crihalmeanu Co-PI

Contents

1. Project Overview

The purpose of this data collection was to obtain data to enable the evaluation of prototype non-contact fingerprint acquisition systems developed by FlashScan3D by comparing to data captured using conventional livescan fingerprint systems, inked rolled prints, and a commercial non-contact fingerprint device. In addition, human factors information was collected from operators performing the data collection to assess the operability of the prototype devices and how the general public interacted with these devices. The target number of participants for this collection was 500. An initial cohort of data was provided after 200 participants were collected, followed by a second cohort of 300. Data collection took place between 4/18 and 8/17/2012, with 500 participants providing data.

The following is a description of the data collection effort, a summary of data collected and participant demographics, and operator feedback from four WVU staff members.

2. Data Collection

Data collection was performed on the WVU Evansdale Campus. The collection utilized livescan and non-contact fingerprint devices provided by ManTech. An indoor laboratory space (164 ESB Addition) was used as the collection area, with all sensors and rolled ink impressions collected in the same space. Data was collected from each device and assembled in a common data repository on a regular basis.

2.1 Fingerprint Devices

Data collection was performed using seven different fingerprint devices (both livescan and non-contact systems), as well as rolled ink impressions. The following is a list of the electronic devices used in this data collection

<u>Livescan Systems:</u>

- Crossmatch Guardian R2
- Crossmatch SEEK II
- i3 DigID Mini
- L1 Touchprint 5300

<u>Non-Contact Systems:</u>

- TBS 3D-Enroll (commercial; Series 11)
- FlashScan3D D1 single-finger device (prototype)
- FlashScan3D D4 four-finger device (prototype)

Images of these devices are shown in Fig. 1.

Figure 1: Fingerprint devices (from top left): Crossmatch Guardian R2, Crossmatch SEEK II, i3 DigID Mini, L1 Touchprint 5300, TBS 3D-Enroll, FlashScan3D D1, FlashScan3D D4.

2.2 Collection Site

Fig. 2 illustrates the arrangement of the equipment in the laboratory used for the data collection.

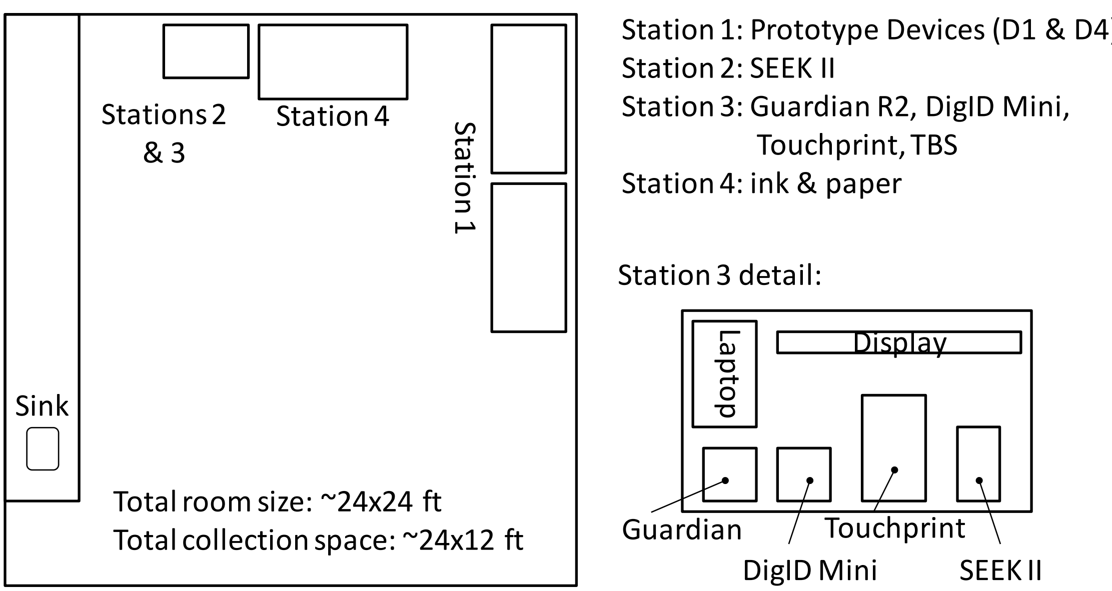


Figure 2: Collection laboratory and station arrangement.

The laboratory space was approximately 24x24ft, with the collection area encompassing ~12x24 ft of this space. Station 1 was spread across two standard laboratory work benches, each accommodating one prototype sensor and the interface PC (D4) or laptop (D1). Stations 2 & 3 were located on an adjustable height table (Workrite Sonoma) to make rolled livescan prints easier to obtain from individuals of varying height. A display was added as well to aid in participant and operator interaction with the devices. Station 4 consisted of an additional standard workbench with a plywood riser with ink plate and card bracket for inked fingerprint impression collection. Butcher paper was applied to the workbench surface to reduce the mess caused by the inking procedure. A sink was available in the room for cleanup, as well as standard ink remover pads. The restrooms were located nearby for additional hand-washing if needed.

2.3 Data Types & Organization

Each participant in the data collection provided two sequential sessions of fingerprints for each sensor. Inked prints were collected once and scanned at 500 and 1000ppi. The following were collected for each sensor device:

Guardian
- two sessions each of: rolled individual fingers on right and left hands, left slap, right slap, and thumb slap

i3 DigID Mini
- two sessions each of: rolled individual fingers on right and left hands, left slap, right slap, and thumb slap

Touchprint
- two sessions each of: rolled individual fingers on right and left hands, left slap, right slap, and thumb slap

SEEK II
- two sessions each of: rolled individual fingers on right and left hands, left index + middle slap and left ring + little slap (to create left slap), right index + middle slap and right ring + little slap (to create right slap), and thumb slap

TBS
- two sessions of each individual finger on right and left hands

FlashScan Single-Finger
- two sessions of each individual finger on right and left hands

FlashScan Four-Finger
- two sessions each of right slap, left slap, and thumb slap

The file structure of the data is as follows:

- ManTech_Fingerprint
  - Date
    - Random ID
      - Fingerprint
        - Crossmatch R2
          - Session 1
            - RandomID_Date_session
              - .bmp files
          - Session 2
            - same as session 1
        - Flashscan 3D
          - Session 1
            - ten folders named as RandomID_date_session_digit
              - .bmp & .byt files
          - Session 2
            - same as session 1
        - Flashscan 3D - D4
          - Session 1
            - vrml folder
            - .bmp & .byt files
          - Session 2
            - same as session 1
        - i3 Digi ID Mini
          - Session 1
            - .png files
          - Session 2
            - same as session 1
        - L1 Touchprint 5300
          - Session 1
            - .png files
          - Session 2
            - same as session 1
        - Seek
          - Session 1
            - .eft file
          - Session 2
            - .eft files
        - TBS
          - Session 1
            - Raw
            - .ini file & .bmp files
          - Session 2
            - Same as session 1

Ten Print Scans
500
.eft file and .bmp files (500ppi scans)
1000
.eft file and .bmp files (1000ppi scans)

Note: All images are saved with format:

"RandomID_Date_Session_additionalinfo.fileextension"

except for those from the FlashScan D4 Device.

Due to operator error and sensor malfunction, some data may be missing or corrupted. A list of errors and missing data was provided as an addendum to the dataset upon delivery to ManTech. In instances where a particular sensor was malfunctioning or away for repair (such as the FlashScan D4 scanner), collection was continued and this data will be missing from the subject's data record.

2.4 Collection Procedure

The following is a description of the collection procedure the participant experiences from consent to remuneration. It is written as an instructional document describing to staff members the standard operating procedure of each data collection station. Total time through the collection was 45 minutes to 1 hour.

2.4.1 Consent

Greet the participant and provide the consent form. Explain each section of the consent form, including all locations on the form that need to be initialed, dated, or signed. Ensure that your explanation includes the following:

- The purpose of the study is to collect data for biometrics research funded by ManTech International and the National institute of Justice.
- Data collection consists of fingerprints captured by multiple electronic fingerprint devices and on paper with ink.
- Participation is strictly voluntary; they may opt out of the process at any time.
- Inform the participant that they will be receiving gift cards upon completion of data collection and that if they choose to not complete the study they will not receive the gift cards.

Once the participant has read and completed the consent form, ask if they have any further questions and direct them to the Enrollment workstation.

2.4.2 Enrollment

Once the participant has arrived at the Enrollment Workstation, ask them for a photo ID to verify their identity. Participants may already be in the Enrollment database from another study, so ask if they have participated before. If they have participated before they will already have an RID number, if not they will need a new RID generated in the system. Using the Enrollment interface, search the database to see if the basic information (name, date of birth, etc.) exists in the database. Searching the database can be completed by using the participant's first or last name, date of birth, or all three. Typically it is most efficient to search by last name and identify the correct person based on the date of birth that appears after searching. If the participant already has an RID in the system, make a note of the RID for use while completing the enrollment process. If the participant is not in the system proceed to enter new data for the participant. Once you have completed the enrollment form, print the barcode and save the information. Instruct the participant to proceed to the fingerprint collection laboratory.

2.4.3 Station 1: Prototype Devices

The prototype devices were typically initialized at the beginning of each collection day based on the standard procedures supplied by FlashScan3D and ManTech, and operated continuously until all appointments scheduled for that day were completed.

2.4.3a - FlashScan3D D4

1. Create a sub-folder named according to the participant's 7-digit RID number in the folder 'ManTechFingerprint' located on the desktop. Use the barcode scanner to scan the RID number when naming the folder.
2. Inside the 7-digit RID folder, create two additional folders named '1' and '2.'
3. In the 'mat5_debug' folder, add a new folder named 'vrml.'
4. Click on 'fscan.exe,' located on the desktop, to begin data collection with the D4 device. The interface shown in Fig 3 will initialize.

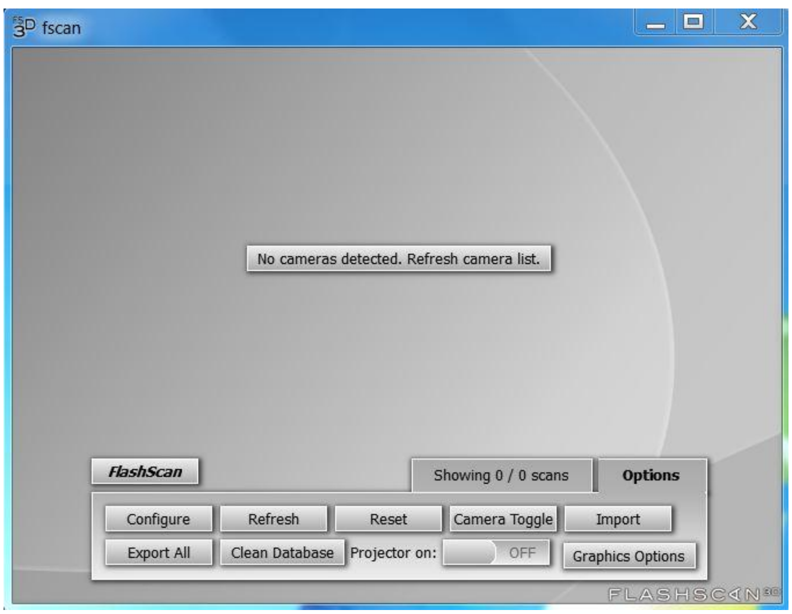


Figure 3: Collection interface for the FlashScan3D D4 device.

NOTE: An issue causing the collection interface software to crash may occur at any given time while the FlashScan software is running. The issue causes a window to open stating "Error In Function BiCirWaitDoneFrame. Timed out while waiting for circular acquisition." To resolve this issue: exit the FlashScan software; unplug the camera, cooling fan, and projector power supply cables from the device; unplug the framegrabber sync-cable from the computer; and shut down the computer. Make sure the projector VGA connector and both CableLink cables (Red and Blue) are properly connected then follow the setup guidelines as shown in the manual provided by FlashScan and ManTech.

5. Ask the participant to place their right four fingers under the protective, cover as shown in Fig. 4.

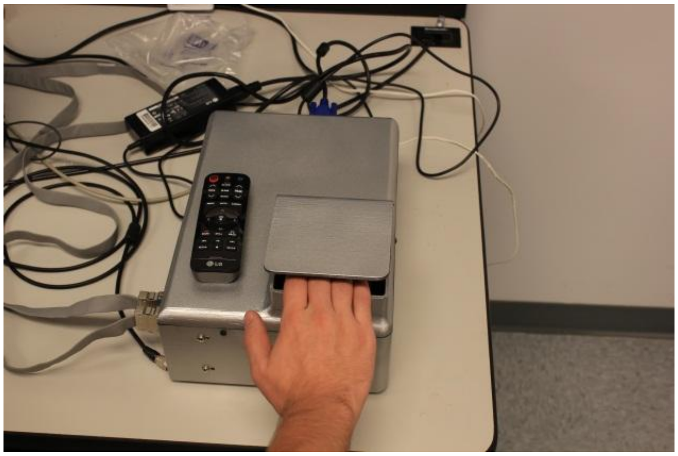


Figure 4: Finger placement for D4 slap capture.

6. After the fingers are placed as shown, click the 'FlashScan' button in the user interface to initiate capture. *Note:* Due to improper finger placement, motion, or skin tone, the scan may fail. If so, repeat until a successful scan has been completed.
7. A successful capture will place 21 files into the 'mat5_debug' folder at this point.
8. Repeat steps 5 & 6 for the left hand
9. A successful capture will place 21 additional files into the 'mat5_debug' folder, giving a total of 41 files in the folder at this point.
10. Repeat steps 5 & 6 for both thumbs, as shown in Fig. 5.

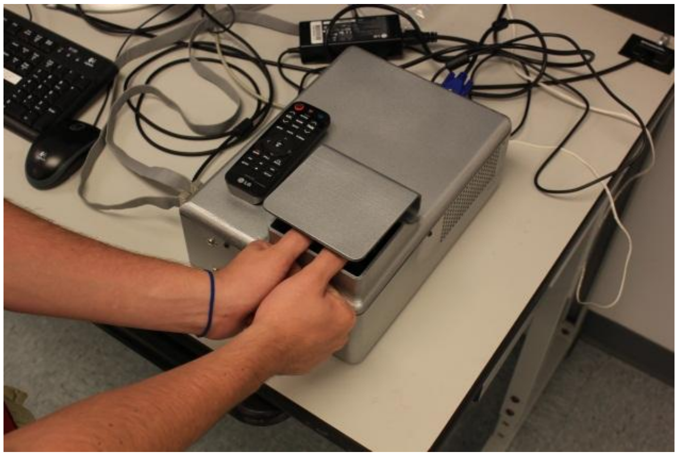


Figure 5: Finger placement for D4 thumb slap capture.

11. After the thumb slap capture is completed, there should be a total of 81 files in the debug folder.

12. Move All 81 of these files (including the vrml folder) into the folder named “1” in the ‘ManTechFingerprint’ folder located on the Desktop.
13. In the now empty ‘mat5_debug’ folder create a new empty folder named ‘vrml’.
14. Repeat steps 5-11.
15. Move all 81 files (including the vrml folder) in the ‘mat5_debug’ folder to the file named “2” in the ‘ManTech Fingerprint’ folder located on the Desktop. Collection is now complete for this device.

2.4.3b - FlashScan3D D1

1. Create a sub-folder named according to the participant’s 7-digit RID number in the folder ‘ManTechData’ located on the desktop. Use the barcode scanner to scan the RID number when naming the folder.
2. Inside the 7-digit RID folder, create two additional folders named ‘1’ and ‘2.’
3. Click on ‘fscan.exe,’ located on the desktop, to begin data collection with the D1 device. An interface similar to the D4 device (shown in Fig. 4) will initialize.
4. Ask the participant to insert their right thumb face down under the protective cover. General finger placement is demonstrated in Fig. 6.

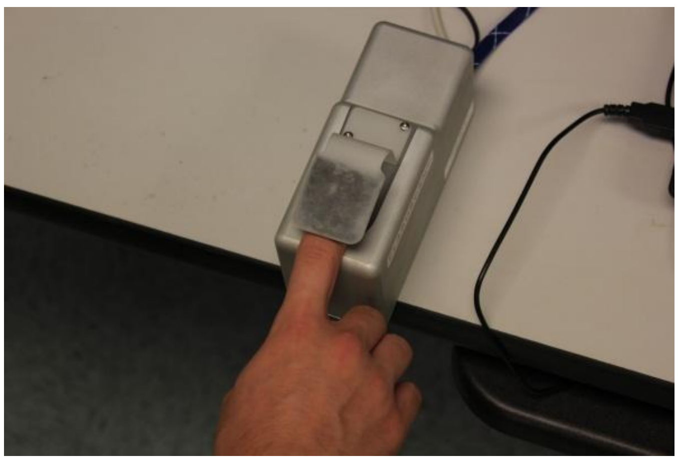


Figure 6: Finger placement for D1 scanner

5. Click the ‘FlashScan’ button in the user interface to initiate capture. Data is saved in the ‘FS3D_Database’ folder, located on the desktop. *Note:* Due to improper finger placement, motion, or skin tone, the scan may fail. If so, repeat until a successful scan has been completed.
6. Instruct the participant to proceed to the index finger, and repeat steps 4 and 5.
7. After the right hand is completed, instruct the participant to repeat the procedure, starting with the left thumb. Repeat steps 4 and 5 for all fingers on the left hand.
8. 10 images should now be saved in the ‘FS3D_Database’ folder. Move these images to folder ‘1’ located in the participant’s RID folder in the ‘ManTechData’ folder.
9. Repeat steps 4-7 for a second set of prints.
10. Move the 10 images saved in the ‘FS3D_Database’ folder to folder ‘2’ located in the participant’s RID folder created in the ‘ManTechData’ folder. Collection is now complete for this device.

2.4.4 Station 2: Crossmatch SEEK II

1. On the SEEK II mobile computer desktop, select ‘MOBS’
2. From within the ‘MOBS’ program, select Enrollment.
3. Select the ‘CAR’ folder.
4. Select ‘Enrollment.’
5. Select ‘Fingerprints.’
6. Select ‘Capture,’ as shown in Fig. 7.

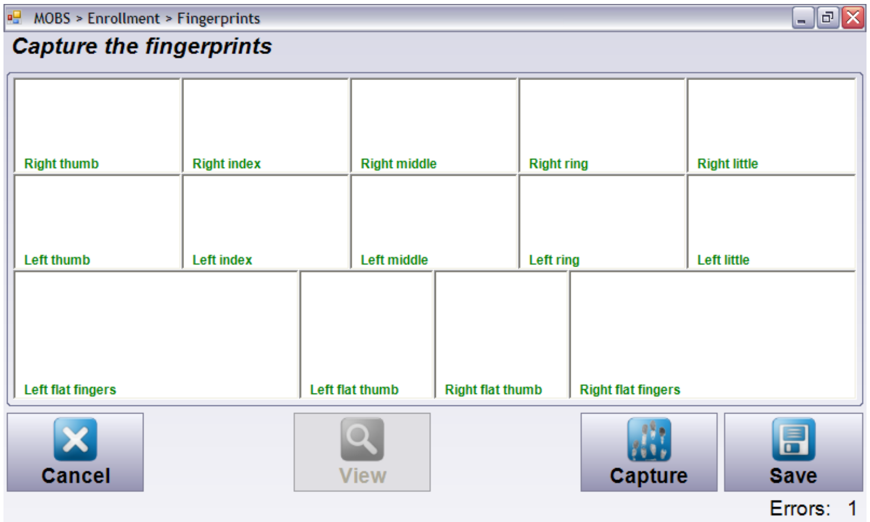


Figure 7: MOBS fingerprint capture interface.

7. The participant will place right index and right middle fingers on the platen to capture the slaps.
8. The participant will then place right ring and right little fingers on the platen to capture the slaps.
9. The participant will then place right and left thumb on the screen to capture the slaps.
10. The participant will then place the right thumb flat on the platen. The staff member will roll the thumb from nail to nail to capture the rolled fingerprint image.
11. Repeat step 10 for all four fingers on the right hand.
12. Repeat steps 7-11 for the left hand.
13. If, at any time, partial or low quality prints are captured, you may go back and recollect a new image. If print quality has been assured, select ‘Save’ as shown in Fig. 8.

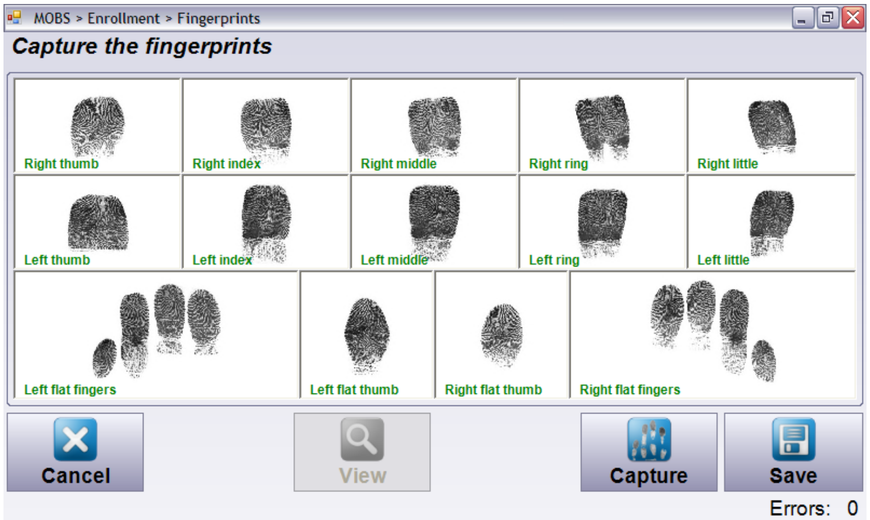


Figure 8: Completed MOBS fingerprint capture. The 'Save' option is located in the lower right.

14. Select 'Save' again on the next screen.
15. From there, a new notification will pop up. Select 'Later.'
16. Navigate back to the SEEK II Desktop.
17. Select 'Computer.'
18. Select 'My Computer.'
19. Select 'C Drive.'
20. Select 'Documents and Settings.'
21. Select 'All Users.'
22. Select 'Application Data.'
23. Select 'Cross Match Technologies.'
24. Select 'MOBS.'
25. Select 'Pendings.'
26. Rename the most recent file with the format 'RID_DATE_SESSIONNUMBER.eft.' Since the random ID is manually entered, double check the number to ensure no errors are made in file naming.
27. Repeat steps 2-26 for session number 2. Collection with this device is now completed. If necessary, clean the platen of the device using lift tape.

2.4.5 Station 3: Laptop

Four different devices: Crossmatch Guardian R2, i3 DigID Mini, L1 Touchprint 5300, and the TBS 3D-Enroll, were connected to a laptop so that data could be saved in a common repository. The Guardian and TBS devices were operated through a sample collection interface provided by the device manufacturer. The i3 and L1 devices were integrated into a common collection interface. The following is a description of fingerprint collection in each of these platforms.

2.4.5a - Crossmatch Guardian R2

1. Select the 'ManTechData' folder on the Desktop.
2. Create a folder labeled 'CrossmatchR2' inside the participant's RID folder. Use the barcode scanner to scan the RID number when naming the folder.
3. Inside the 'CrossmatchR2' folder, create two separate folders labeled '1' and '2.'

4. Start the Crossmatch software by clicking on the Crossmatch L-SCAN Essentials icon on the computer desktop.
5. Select the 'Save Images' radio button shown on the left side of Fig. 9.

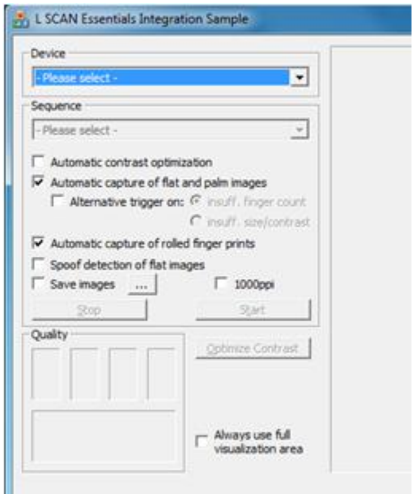


Figure 9: Guardian fingerprint collection interface.

6. Select the Save images radio button, and then select the '…' box, shown in Fig. 9.
7. Select the folder '1' that you created in step 4.
8. Select the 'Always use full visualization area' radio button, shown at the bottom of Fig. 9.
9. The participant places both thumbs on the platen to capture the thumb slap (Fig 10(a)).
10. The participant places the right four fingers on the platen to capture the right slap (Fig 10(b)).
11. The participant then places the left four fingers on the platen to capture the left slap (Fig 10(c)).
12. Place the participant's right thumb on the platen and roll the thumb, nail to nail, to capture the rolled fingerprint. A general demonstration of this is shown in Fig 10(d).

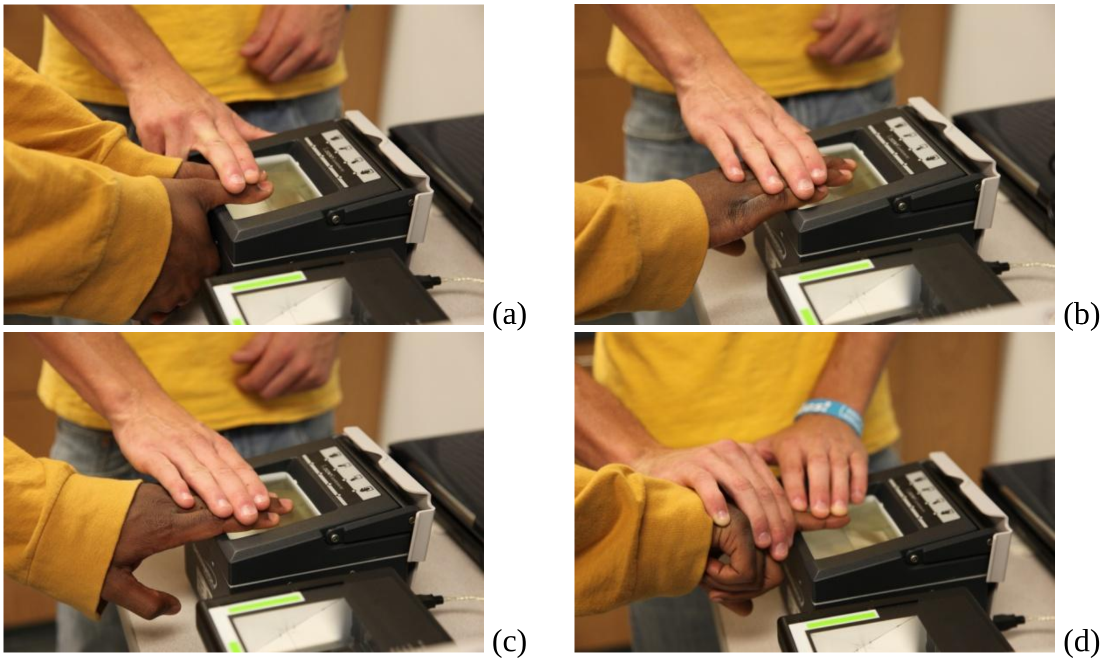


Figure 10: Fingerprint collection using Crossmatch Guardian R2: (a) thumb slap, (b) right slap, (c) left slap, and (d) rolled prints.

13. Repeat step 11 for all fingers on the right hand, beginning with index and ending with little.
14. Repeat step 11 for all fingers on the left hand, starting with the thumb and ending with little.
15. Once the rolled left little capture is completed, repeat step 6 to change the folder to ‘2’ created in step 4.
28. Repeat steps 7-15 for collection session 2. Collection with this device is now completed. If necessary, clean the platen of the device using lift tape.

2.4.5b - i3 DigID Mini

1. Click on ‘Fingerprint Capture’ on the Desktop.
2. Select the “i3 digID Mini” radio button in the user interface, shown in Fig 11.

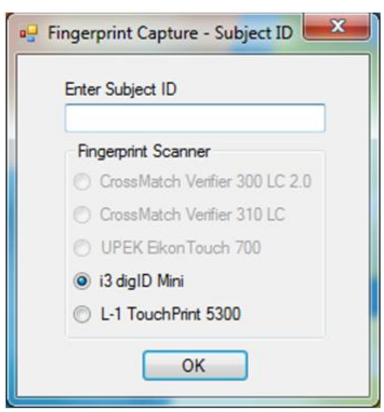


Figure 11: Sensor interface for i3 and L1 fingerprint devices.

3. Place the cursor in the field labeled “Enter Subject ID” and scan the RID using the barcode scanner.
4. Click ‘OK’ to initialize the capture interface.
5. Place the participant’s right thumb in the middle of the platen, similar to the Crossmatch Guardian sample shown in Figure 10. Roll the thumb from nail to nail to complete fingerprint capture.
6. Proceed to the right index finger, and roll as described in step 5 for the remaining fingers on the right hand.
7. Repeat steps 5 & 6 for the left hand.
8. Once each individual fingerprint is captured, the participant places both thumbs on the machine to capture the thumb slap.
9. The participant then places the right four fingers on the machine to capture the right slap.
10. The participant repeats step 9 with the left four fingers to capture the left slap.
11. Once all fingerprints are captured, the operator performs any necessary re-captures and clicks ‘Save.’
12. Repeat this process for the second session of fingerprints. Collection with this device is now completed. If necessary, clean the platen of the device using spray cleaner and a lint-free cloth.

2.4.5c - L1 Touchprint

1. Click on ‘Fingerprint Capture’ on the Desktop.
2. Select the “L-1 TouchPrint 5300” radio button in the user interface, shown in Fig. 11.
3. Place the cursor in the field labeled “Enter Subject ID” and scan the RID using the barcode scanner.
4. Click ‘OK’ to initialize the capture interface.
5. Place the participant’s right thumb in the middle of the platen, similar to the Crossmatch Guardian sample shown in Figure 10. Roll the thumb from nail to nail to complete fingerprint capture.
6. Proceed to the right index finger, and roll as described in step 5 for the remaining fingers on the right hand
7. Repeat steps 5 & 6 for the left hand
8. Once each individual fingerprint is captured, the participant places both thumbs on the machine to capture the thumb slap.
9. The participant then places the right four fingers on the machine to capture the right slap.
10. The participant repeats step 9 with the left four fingers to capture the left slap.
11. Once all fingerprints are captured, the operator performs any necessary re-captures and clicks ‘Save.’
13. The process is repeated for the second session of fingerprints. Collection with this device is now completed. If necessary, clean the platen of the device using spray cleaner and a lint-free cloth.

2.4.5d - TBS 3D-Enroll

1. Select ‘TBS 3D Capture Suite’ on the Desktop to initialize the collection interface shown in Fig. 12.

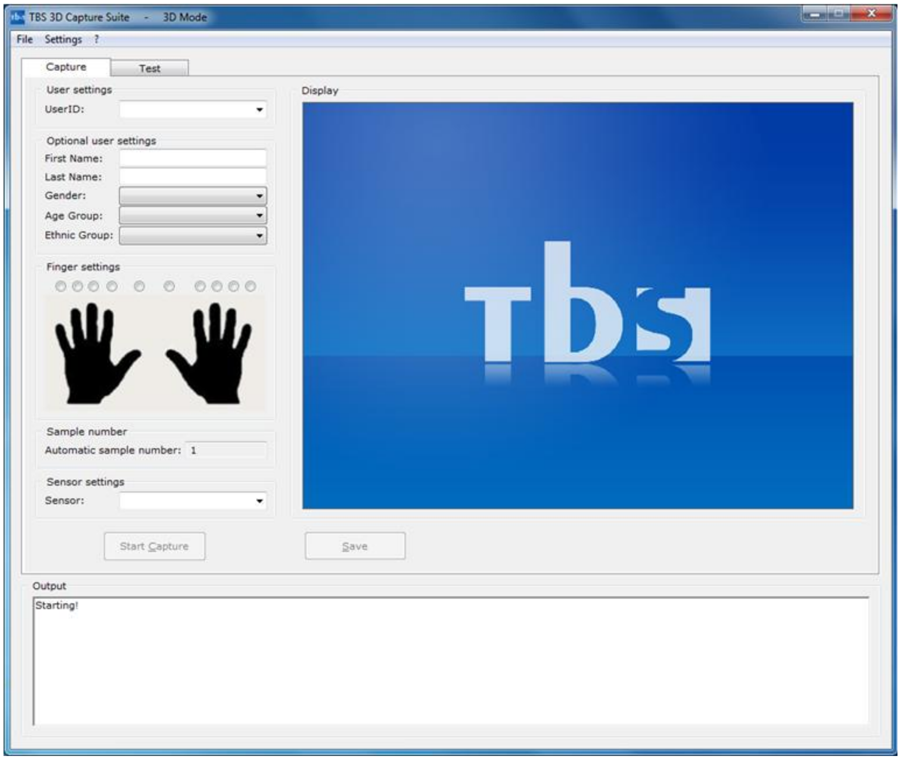


Figure 12: TBS fingerprint capture interface.

2. Place the cursor in the field labeled 'User ID' and scan the barcode to enter the RID number.
3. Select the radio button corresponding to the right thumb in the TBS interface.
4. Instruct the participant to insert their right thumb into the device. General finger placement is shown in Fig. 13. Ensure that the tip of the finger touches the guiding dot and aligns with the guiding line, both indicated on the interface.

Figure 13: Participant interaction with the TBS fingerprint device.

5. A green check mark will indicate when fingerprint capture is complete.
6. Select ‘Save.’
7. Repeat steps 3-6 for the remaining fingers on the right hand and all fingers on the left hand.
8. Select the shortcut to the TBS file storage location on the Desktop.
9. Select ‘Samples’ inside the folder identified in Step 8.
10. Select the folder corresponding to the RID number of current participant. This folder was automatically created in step 2.
11. Create a folder labeled ‘1’ inside of the RID folder.
12. Move all data in the root folder into folder ‘1.’
13. Repeat steps 3-12 using folder ‘2.’

2.4.6 Station 4: Collecting Fingerprints on Ten-Print Cards

This station should be completed last to prevent the fingerprint ink from interfering with the operation of the other livescan devices.

1. Label the ten-print card as shown in Fig 14, with the participant’s RID number written in the ‘Signature’ box and the date written in the box labeled ‘Leave Blank’.

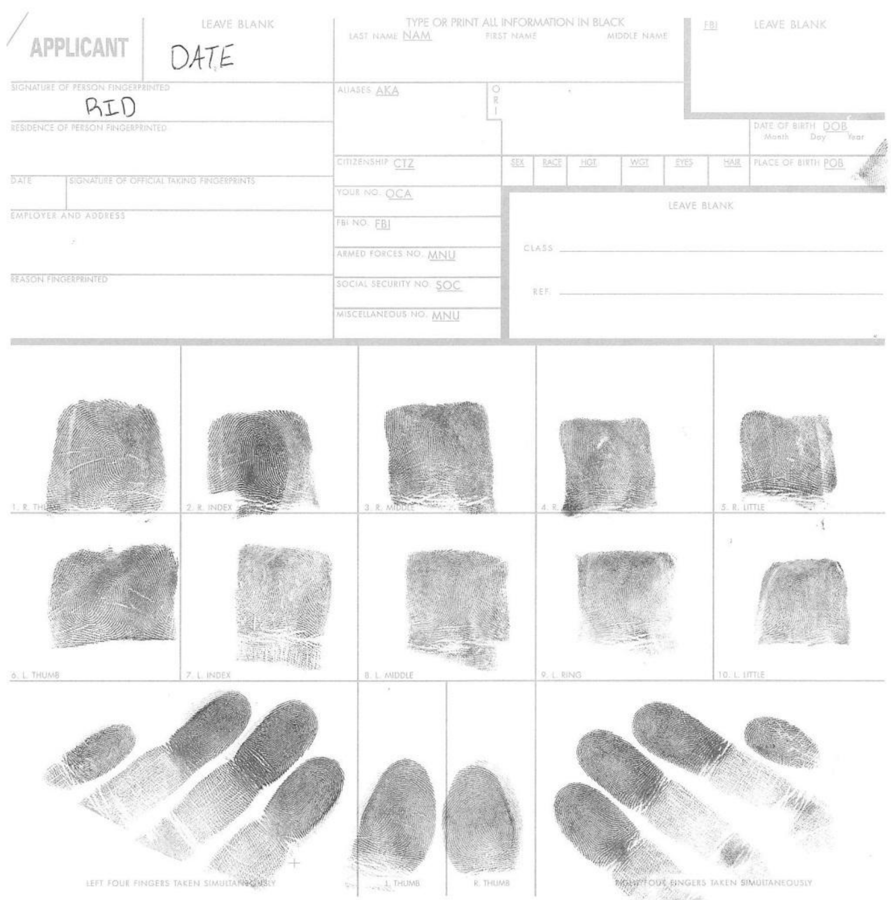


Figure 14: Sample 10-print card.

2. Beginning with the right thumb, roll the finger in the ink, going nail to nail.

3. Position the participant next to the ten-print card.
4. Place the side of the thumb in the specified box, and roll from nail to nail.
5. Repeat steps 2-4 with the remaining fingers on the right hand and all fingers on the left hand.
6. Check the amount of ink remaining on the right fingers and re-ink if needed. Applying even pressure, capture the left slap impression in the designated box.
7. Repeat step 6 for the right hand.
8. Check the amount of ink remaining on the thumbs and re-ink if needed. Applying even pressure, place the left and right thumb on the designated to capture the thumb slap impression.
9. If any mistakes are made in the inking of the fingerprints, place a white 're-tab' sticker over the bad print block then retake that impression.
10. Once satisfied with the completion of the ten-print card, give the participant an ink remover wipe and ask them to remove all residue from the fingers.
11. Write the participant's RID number on the top right-hand corner of an empty manila envelope.
12. Place the ten-print card in the manila folder, along with the print-out of the subject RID number with bar code.

2.4.7 Collection Completion

After the participant has provided fingerprints at all of the stations, provide directions to the bathroom (or lab sink) in case they wish to wash their hand more thoroughly, and instruct them to proceed to the remuneration office to receive their gift cards.

2.4.8 Post Processing

The data collected was stored in four different locations: 1) the laptop that served as the interface tot eh FlashScan D1 device, 2) the PC that served as the interface for the FlashScan D4 device, 3) the SEEK II device, and 4) the laptop that served as the interface to the Guardian, DigID Mini, Touchprint, and TBS devices. Each of these location provided adequate storage for day-to-day collection activities, but a backup of all data was performed on a weekly basis.

Data was delivered to ManTech in two releases. One took place after the collection of data from the first 200 participants, and the second after the final total of 500 was achieved. Prior to each of these data releases, the data was evaluated and a list of quality issues or missing data was compiled and supplied along with the release.

The ten-print cards could not be delivered due to IRB restrictions on data transfer. Because of this, ManTech supplied the WVU team with an FBI-certified flat-bed scanner (Epson Perfection V700) and Aware AccuScan card scanning software to create electronic records of the ten-print cards. Cards were scanned at both 500 and 100ppi, and a .eft record and individual .bmp images were created for each participant at both resolutions. Card scanning was performed on a daily basis using a computer located in guest office on the same floor as the collection lab. The card scanning procedure is as follows:

1. Open 'CSScanDemoEFT.exe' located on the computer's Desktop.

2. Once the GUI is loaded, the designated scanner should be changed to ‘Epson Perfection V700’ in the drop down selection list.
3. The layout file then needs to be chosen by following the following steps in the Windows 7 OS:
    a. Browse
    b. select C drive
    c. Choose ‘program files(x86’
    d. Choose ‘Aware’
    e. Choose ‘AccuScan’
    f. Choose ‘Samples’
    g. Choose ‘Samples’
    h. Choose ‘acuscan_fbi_criminal_alt2.xml’
4. Place ten print card in scanner.
5. Click ‘Scan’ in the scanning software interface (Fig.15). Note that the default resolution is 500ppi.

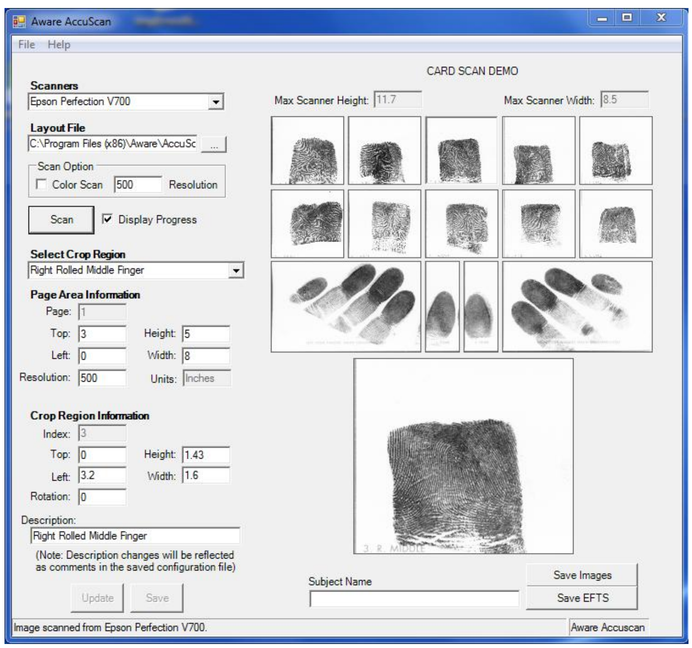


Figure 14: AccuScan scanning interface.

6. Click ‘Save Images.’
7. Save in ‘ManTech Ten Print Data’ in a folder named according to participant’s RID number located in the date collected. Use the barcode scanner to scan the barcode in the envelope along with the ten print card to avoid number entry errors.
8. Save files using the naming convention ‘RID_DATE_500.bmp.’ Again, the barcode scanner can be used to retrieve the RID and date.
9. In the same naming convention from step 8, put the file name in the Subject name area, click ‘Save EFTs,’ and save the data in the same folder as above.
10. Change the scanner resolution to 1000ppi in the ‘Scan Option’ field.
11. Under ‘Page Area Information,’ change the resolution to 1000.
12. Click ‘Update’ near the bottom of the window.

13. Repeat steps 5-8.
14. Save files the naming convention 'RID_DATE_1000.bmp.' Again, the barcode scanner can be used to retrieve the RID and date.
15. Repeat step 9 using the naming convention from step 14.

3. Collection Demographics

Figures 15-19 provide information on cumulative participation in the data collection and a breakdown of ethnicity, age and gender. Fig. 15 indicates that participation peaked after marketing events in mid May and late June. Collection activities were suspended twice during the project period due to DOJ review of the IRB documentation. The first suspension was in place from 5/24 to 5/30/2012 and the second was in place from 6/6 to 6/28/2012. Despite these suspensions, participation remained surprisingly high during the summer months. This is mainly due to non-student participation from the Morgantown community. The long suspension period in June is represented in the cumulative growth chart shown in Fig. 16, indicating otherwise steady participation. Fig. 17 indicates that Caucasians make up over half of the participants at 57%, followed by African Americans (11%) and Asian Indians (9%). This ethnicity distribution shows higher than normal African American participation, most likely due to higher participation from the community rather than student population. This shift in normal academic year demographics is seen in the age distribution in Fig. 18 as well, indicating that the majority of participants were in the 20-29 age range, making up 53% of the total, with the next highest groups in the 30-39 (16%) and 40-49 & 50-59 (both 11%) age ranges. Fig. 19 shows that male participation was greater than or equal to female for most ethnicities, with the exception of Caucasians and Asians, where female participation was greater than male.

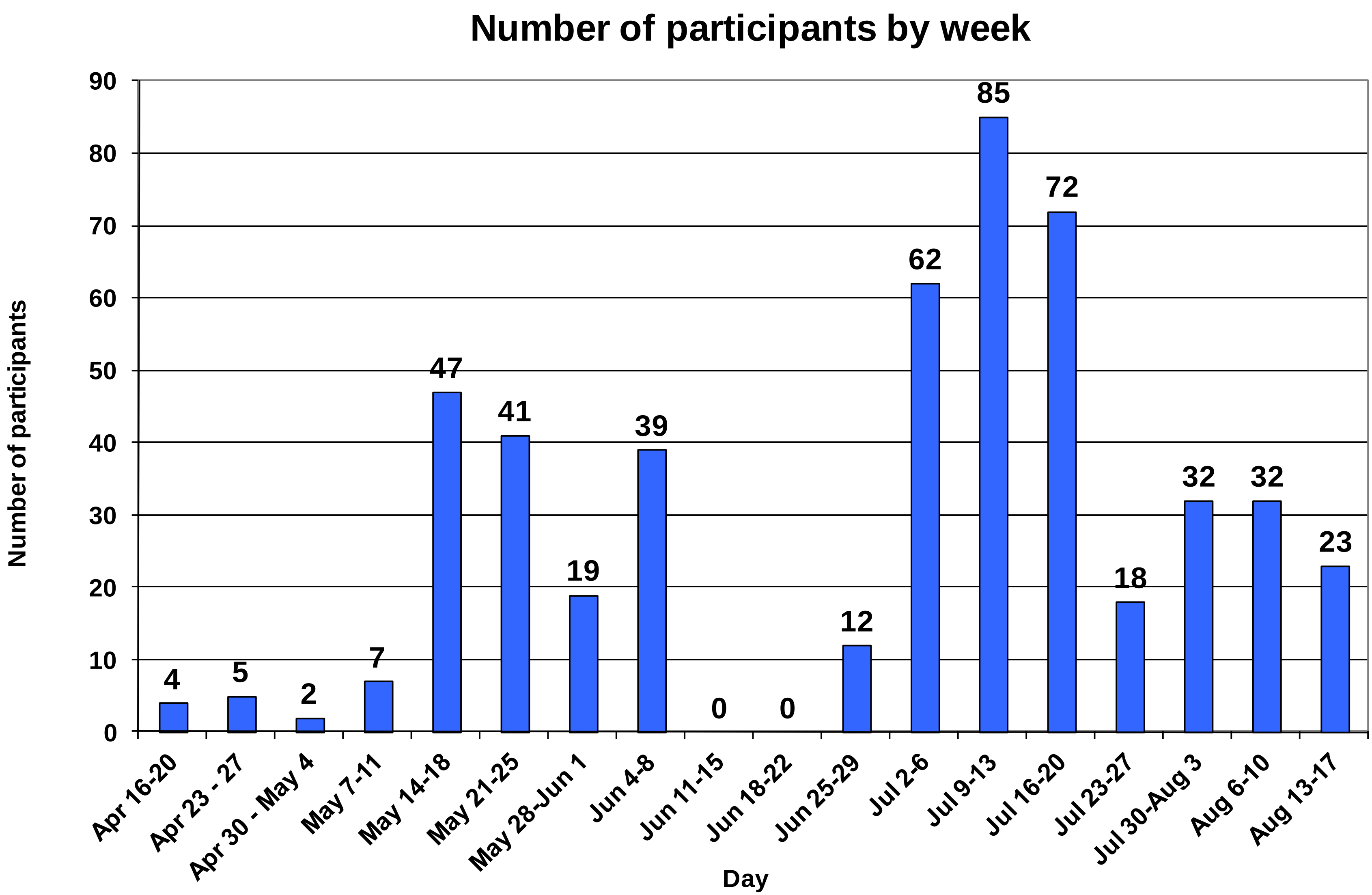


Figure 15: Number of participants by week.

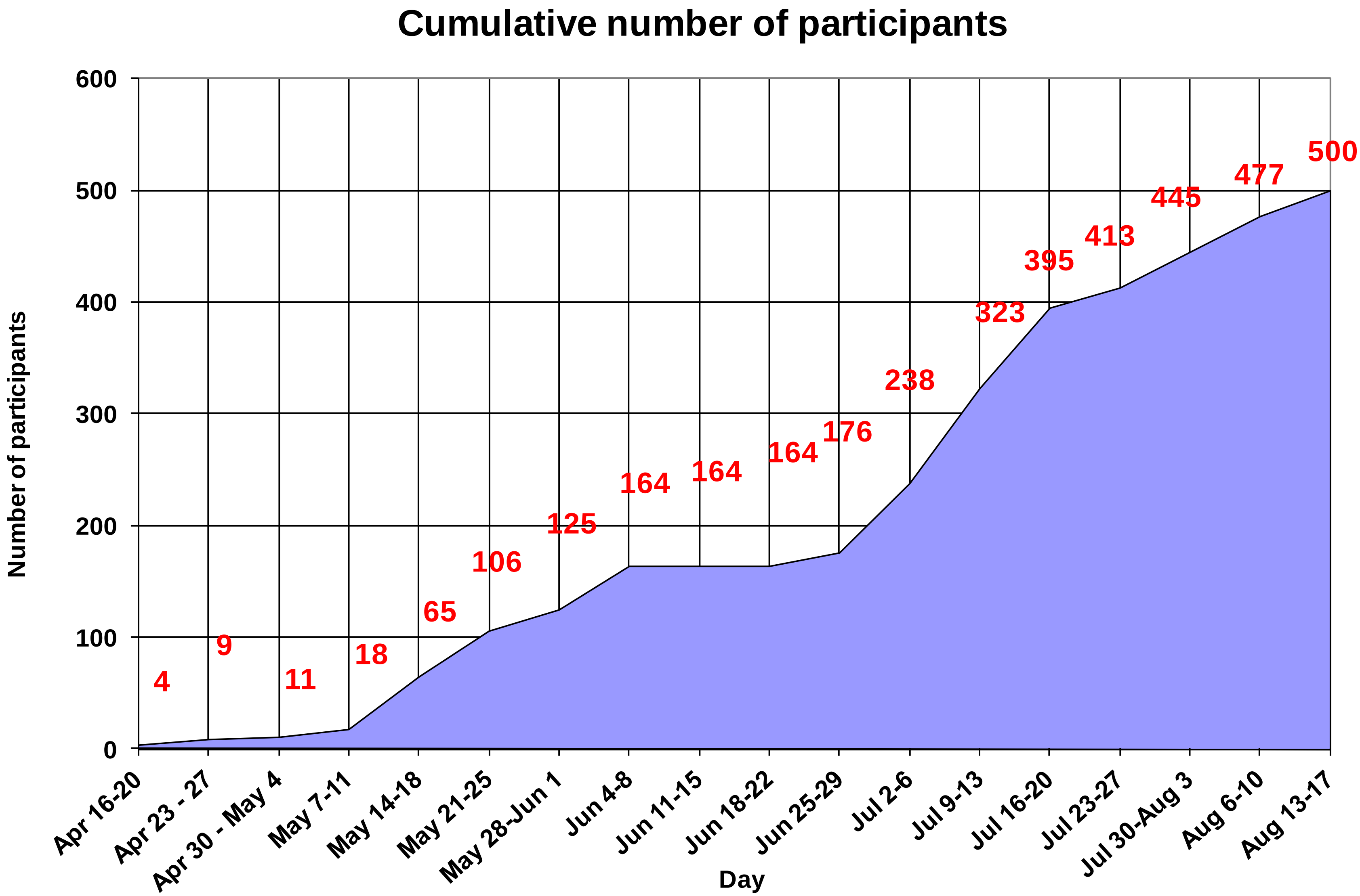


Figure16: Cumulative participation.

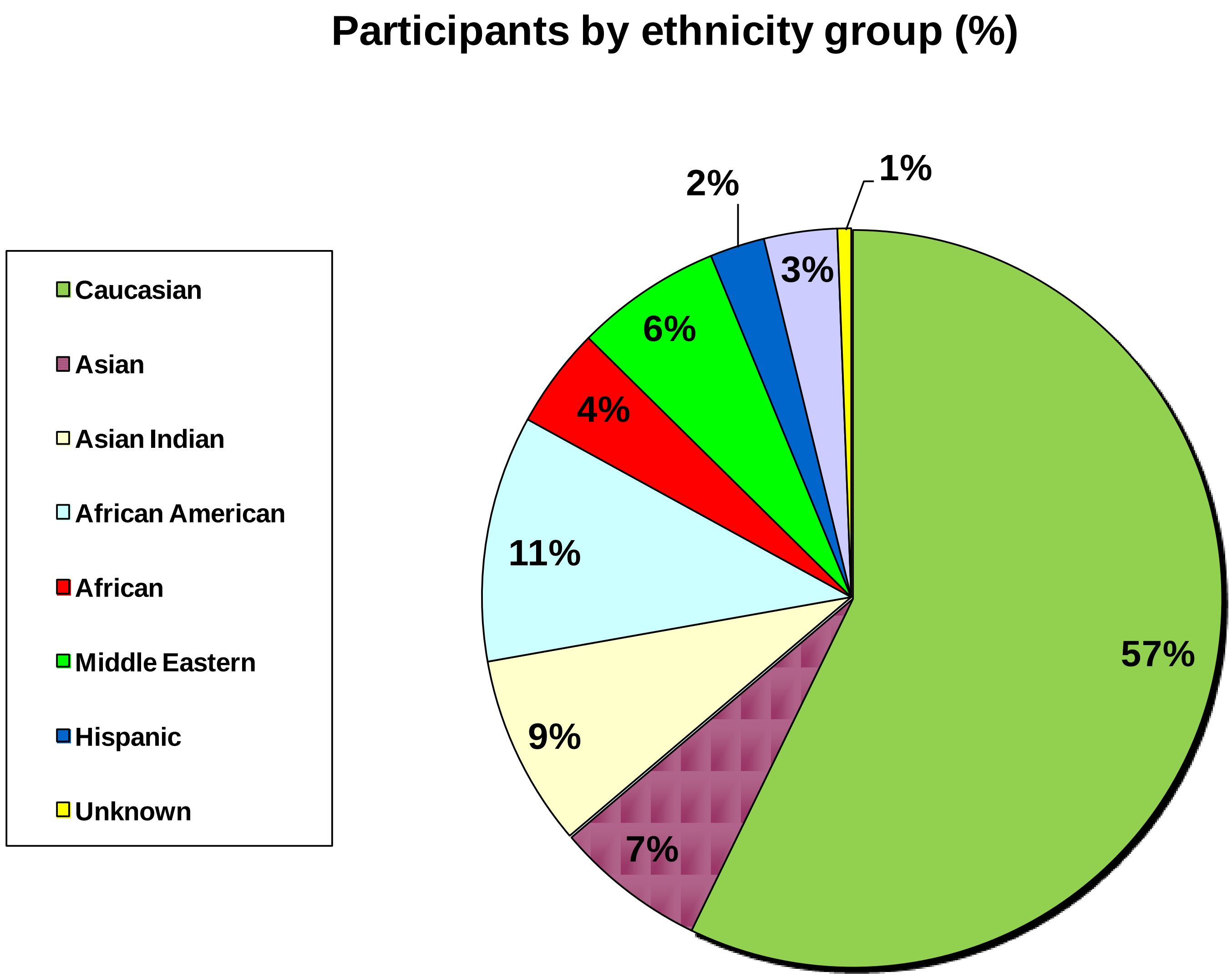


Figure 17: Participant ethnicity.

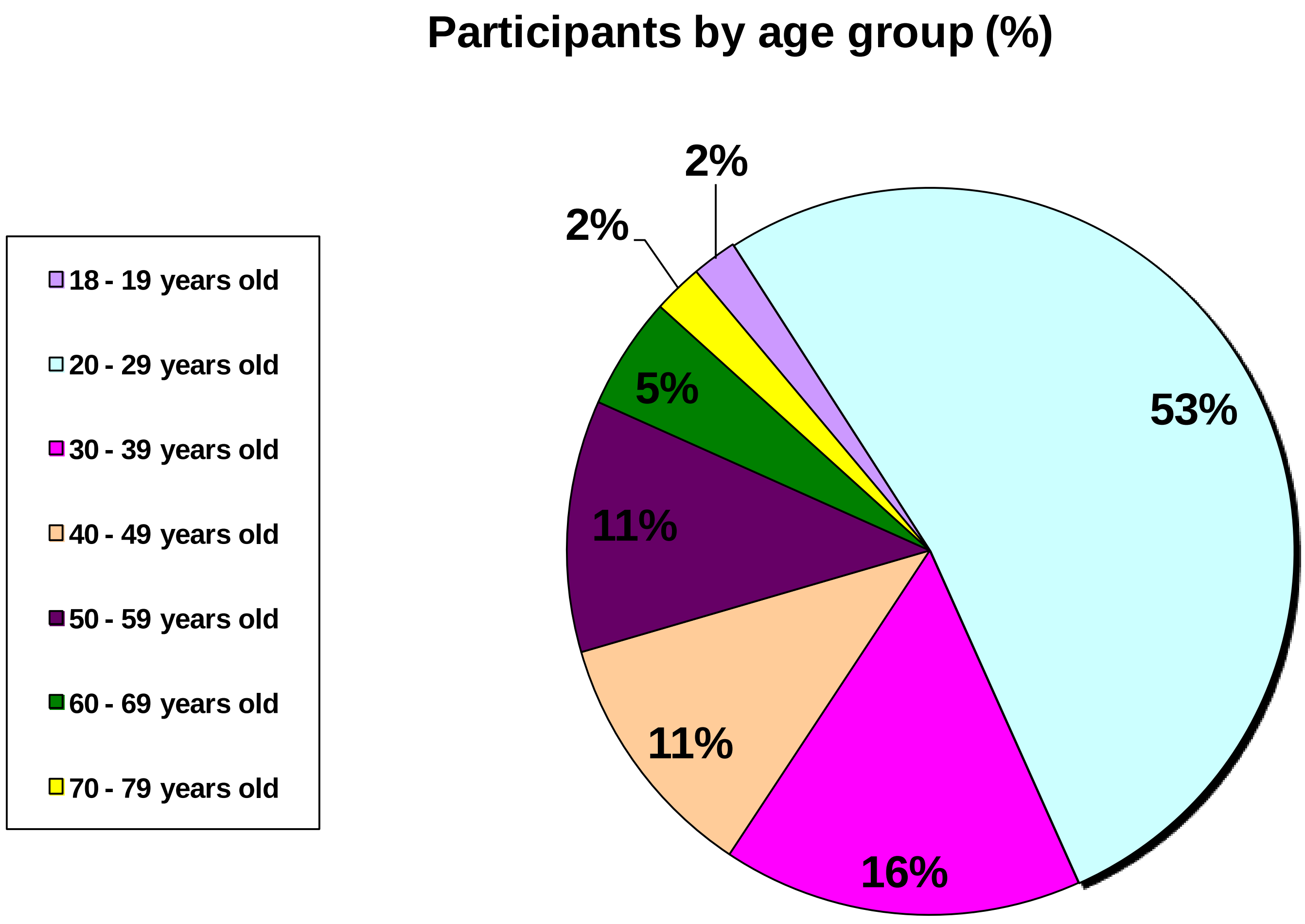


Figure 18: Participant age.

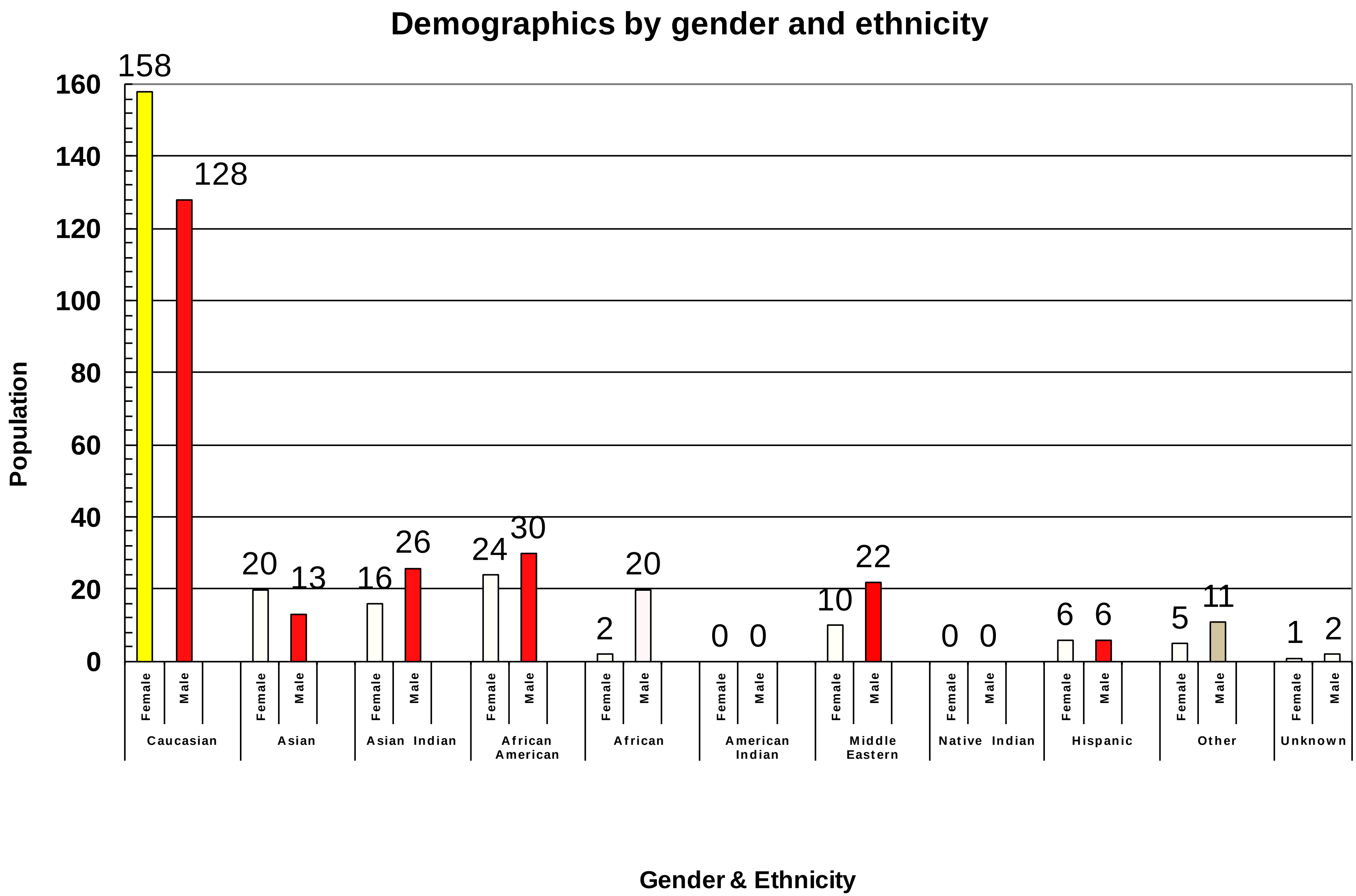


Figure 19: Breakdown of gender & ethnicity.

4. Prototype Issues and Operator Feedback

Overall, the prototype FlashScan3D devices performed considerably better than the previous hardware iterations of these devices that the WVU team has used in the past. The main operational issue that became apparent during this collection project involved the FlashScan3D D4 scanner. As mentioned in the error reporting documentation, this scanner would fail to capture slap prints from individuals with both dark skin and light palms. This was even more pronounced after the projector for the unit was replaced during a service performed toward the end of the collection (due to what seemed to be an overheating issue, but could not be replicated by FlashScan). WVU and ManTech staff discovered that this failure to capture may be a result of the brightness setting of the projector, which was varied to mitigate the problem, but did not eliminate it completely.

The four operators who performed the bulk of the data collection over the summer performance period were asked to provide feedback on their experience using the non-contact devices alongside other commercial fingerprint acquisition devices. They were to also comment on how the general public adapted to using the varying types of sensors included in the collection. They provided a written description of following aspects of their interaction with the various devices during the data collection process:

- How would you compare the use of the FlashScan3D non-contact systems with the more mature livescan device technologies?
- How would you compare the use of the FlashScan3D non-contact systems with the commercial non-contact TBS 3D-Enroll?
- How do you think the general public adapted to using the new fingerprint technologies?

Anonymized, unedited responses from these operators are provided below.

Operator 1

2D vs. 3D Scanners:

The 2D scanners used for the collection varied in captured data quality and ease of use. The glass surfaces on the i3 digID Mini and the L-1 Touch Print 5300 caused large variations in data quality which was mainly caused by the dryness or wetness of the participant’s fingertips. If the participant’s fingertips were very oily or sweaty, these two scanners would pick up dark smudges, and the participant’s prints would have to be recaptured after some of the excess oils or sweat were wiped off. If a participant’s fingerprints were too dry, these two scanners could barely pick up the prints at all; in this case participants were asked either to apply some hand lotion to their fingertips or rub their fingertips on the back of their ears or neck. Afterward the scanner could pick up the print much easier. It was a simple solution, but some participants had frustrations with the procedure.

The 3D scanners proved to be simpler to use than the 2D scanners. Some participants had difficulties, such as persons with crooked fingers and/or arthritis. However, many of the participants seemed more comfortable using the 3D scanners than they did with the 2D methods. Once the participant understood where to place his or her finger to retrieve a quality fingerprint capture, the process moved smoothly and efficiently. The recapture capabilities of the 3D scanners proved to be much easier to use, as well.

TBS vs. FlashScan:

The TBS scanner was generally a very quick and simple device to use. The quality of the prints varied slightly depending on the exact position and angle of the participant’s finger once the scanner began data capture. Occasionally data capture would result in blurry or warped images, but the recapture capabilities of the scanner were convenient and easy to use. However, some participants had troubles with the TBS.

There were some difficulties positioning their fingers correctly in the scanner, whether this was from small or short finger size, inflexibility, crooked and/or arthritic fingers, or the participant had issues due to hand-eye coordination.

The FlashScan devices were also simple to use, and many participants had an easier time using these two devices. The D4 scanner did have some trouble capturing fingerprints of participants with darker skin. There were also issues with initiating the machines. The single print FlashScan device occasionally had problems when starting up, but the D4 scanner was rather difficult to turn on properly. The issues with the D4 scanner appeared to be caused by loose video cables not connecting properly with the devices inside the machine.

Operator 2

The purpose of this project was to gather different sets of fingerprints in order to test two new scanners in their effectiveness and efficiency against other older models. The main differences between these two and the others is that these were touch-less scanners while most of the others involved a place to press your finger or hand on them. Based on the completion of the project, the researchers favored the newer prototypes.

The two prototypes were the FlashScan 3D and Flashscan3D D4. The 3D was a single finger while the D4 used four fingers at a time. To operate the 3D, one would start up the computer, then plug in the hdmi, usb, and power cables, in that order. Next, one would open up the program and a GUI would pop up. Also, a white light would appear from inside the machine. After camera toggling, the white light on the machine would change to green and then the GUI screen light would switch from white to black. The machine would be ready after that. A subject would then place their right thumb inside the machine underneath the lip and right above the hole. Clicking on the FlashScan button on the screen would then take a picture of the thumb and put it into a selected folder. After running through all ten fingers, the data was copied into the subject's own id folder. The D4 operated similarly, except both sets of four fingers and the two thumbs together were scanned instead of each finger individually. The difference between the 3D being great and the D4 being not so great is that the D4 continuously crashed as time went on. It would get almost finished and then randomly crash, with only a couple of prints left to go through. When working, it seemed like an upgrade to the touch scanners, but it crashed significantly throughout the course of the project, which was a serious problem.

These two machines seemed better than the 2D scanners. The 3D machine was by far the quickest to go through. The D4 machine took longer due to the software having to match the thumbs to the fingers. They seemed better because they got rid of misprints and smudges. There also was no need on either of them to stop to clean the fingerprint pad since there wasn't one. They had better quality pictures since there was no smudging or misprints.

For the TBS model, many subjects found it hard to position their finger inside the machine for a good quality picture. The fingers were either off center or too far inwards. Also, fingernails messed up the quality of the picture taken. The scanner would think that the nail was the start of the finger and then the scanner would prematurely scan the finger resulting in a bad picture. Because the prototypes weren't automated, the user could choose when to scan the finger(s), therefore resulting in a better image.

The majority of the participants preferred the single finger FlashScan 3D machine to all the rest, mostly because it was faster and there was less physical interaction between the researcher and the subject. Some participants didn't prefer other people controlling their hand and so it was difficult to roll their fingers on some of the machines or ten-print cards. Their fingers would become stiff and rigid or just wouldn't move, and so some prints weren't full or they were smudged over. Also, some who got bored with the project or didn't have a complete understanding would sort of become less cooperative as the time went on. The 3D scanners were better because they removed many of the physical problems that the 2D scanners had.

Operator 3

Throughout the fingerprinting process, a few issues and differences arose between the 3D and 2D fingerprint scanners. The best of the 2D scanners, in my opinion, was the Crossmatch Guardian. The GUI was fully functional for the Guardian. The Guardian also took the best full prints with a very small error rate. One did not have to worry about the participants hands being too dry as the Crossmatch would pick up the print quite well. The only issue with the Guardian was that there was no error checking for partial prints, i.e. when there was a partial print, one would have to start the collection process over from the beginning. The other 2D fingerprint scanners had an issue with picking up on fingerprints that were too dry. The L-1 would sometimes take about 15 minutes alone to capture all the prints because the scanner would not recognize that a finger was actually on the glass. Once it did begin the capture, the scanner would also sometimes take a partial print. The i3 also had these same issues. The i3 and L-1 GUI did have the option to recapture quite easily, so those prints that were partial could be fixed. The Seek was the best 2D machine on error correction. It took the slap shots first and then compared the individual prints to the slap shots. In doing so, it checked to see if the fingers on the machine were actually the correct one. It also corrected partial prints and gave you a rating on the quality of the print. The only issues with the Seek occurred when the scanner stated that the wrong fingers were used, when in fact the right ones were. There were also issues if people had wrinkles on their fingers. The scanner labeled these as low quality, but there was no way that the user could have fixed this.

The best of the 3D scanners was the FlashScan 3D. The FlashScan 3D was user-friendly and simple. The participants did not have trouble figuring out where to place their finger once it was explained to them. The error rate on this machine was also very low. It was almost impossible for the user to mess up the print unless the participant moved their finger. If it was moved, the file was just deleted and rescanned. The worst of the 3D scanners was the FlashScan D4. The D4 had a very low usage rating. The start-up of the machine could take up to an hour if it was not cooperating. Everything had to be done in a specific manner, and even then, it would rarely operate on the first boot-up. Once booted-up, the machine still would not take a lot of participant's fingerprint images. For instance, if a participant's skin was too dark, the projector would not illuminate the hand enough, so the scanner would not recognize that there were indeed fingers under the hood. Also, once the fingerprints were scanned and being analyzed by the program, the system would sometimes time-out, and the process would have to be repeated. There was also no way to redo a single image. If it timed out on the left hand image, the process would have to be repeated starting with the right hand. The processing time of the software was also very large, so there was a lot of downtime associated with this machine. The other 3D scanner was the TBS. The TBS was a decent scanner and had good image processing. The problem with the TBS was the interaction required with the participants. The participant had to place their finger in the scanner and align it symmetrically. The finger also had to touch a dot on the screen that determined that the finger was in the correct position. This was difficult for the fingers that had lesser control, such as the middle and ring finger. The prints would also get ruined if the participant moved at any point after the image was taken. Participants with crooked fingers also had trouble aligning their fingers symmetrically, so the process could take some quite time to complete.

The only other issue with this fingerprint collection was the participant's ability to cooperate. These machines required the participant's to understand and complete the process. For some of the machines, such as the TBS, this was a difficult task. Participants also had trouble relaxing and not allowing the research assistant to roll the fingers as needed. This would result in smudged prints or prints being rolled back which would have to be redone. This would sometimes happen because the research assistants did not have the ability to force the participants to roll the fingers how they should be rolled. Physical problems with the participants also became an issue at times. Participants with arthritis or broken fingers could not move their fingers the way they should be moved. This results in smudged prints as well. This was controlled to the best of the abilities of the research assistants, but was still an issue that could sometimes not be avoided. All-in-all, the participants did well when relaxed. The most user-friendly machines were the FlashScan 3D and the Guardian. Participants understood the process of both well and could complete what was required of them easily.

Operator 4

2D vs. 3D Scanners:

The best of the 2D scanners was the digi mini when the participant's hands were not dry. When their hands were dry the platen would not pick up the print and lotion would have to be applied to their hands or they had to rub their fingers behind their ears to get more oil on them. The L1 Touchprint was also uncooperative with dry hands but less so than the mini. With the finger started on the side the L1 wouldn't always read that a finger was on there and wouldn't beep for the process to begin. Also even if they did show up, it took a while for the machine to recognize and allow the process to begin. This machine would also take partial prints when their hands were dry and they would then have to be re-captured. The guardian worked very well but the program that was used to run it was not the greatest because it didn't allow the research assistant to go back and recapture the prints if wanted. The program chose which ones that needed re-captured but didn't catch all of them. This in turn made the research assistant delete the old data and restart the whole trial again which was very inefficient. All of the other programs had this feature and proved to be very helpful when the participants would not relax and cooperate with the assistant.

The 3D scanners were very different from the 2D. The only problem with the TBS scanner was that it was hard for some to extend their finger and get it in the particular spot for the cameras to take good pictures. When elderly participants came through and had arthritis, they couldn't get their finger in the correct place and after so long of working with them their fingers started hurting and such so the data was either not collected or had errors. The FlashScan 3D D4 worked fine with light skinned participants when it was working, however with darker skinned participants the scans would keep failing. This made many errors arise during the collection. The program was a little slow and the participants and researchers experienced "twiddle time" as in sitting and waiting which was not time efficient. Another flaw with the D4 was getting it working without errors coming up on the screen. When this happened the computer had to be restarted and everything unplugged from the computer and the device, then everything plugged back in after the computer had booted up. The single finger FlashScan 3D gave almost no trouble during the whole collection and provided good data. The program was very fast that ran it and the device could have a trial completed in under a minute unlike the D4.

TBS vs. FlashScan:

The single finger FlashScan 3D is the best out of any of these based off participant observation. It provided a comfortable place for the participant's finger and was completed in a matter of two minutes (both trials). The TBS was uncomfortable for many participants; however some participants had fun with it and treated it as if it was a game trying to get their finger in the right spot before the program started. The biggest problem with the TBS was the ring finger not working independently with most participants. Most of them had to either hold their finger straight or have an assistant maneuver their finger for them. It was easier to move the machine from left to right rather than move the participant's finger to the correct place. The FlashScan D4 worked well when it worked, however it only worked for a limited amount of time for a limited amount of participants. As stated above, the device would not cooperate with dark skinned participants and would only work sometimes near the end of the collection and even in the beginning it didn't work all the time and had to be unplugged and plugged back in after the computer restarted.

Public interaction:

As a whole the public interacted with the FlashScan 3D single finger scanner the best. There were many participants that said the machine was comfortable and were surprised when it was done so quickly. The fingerprints were easy to take when the participant was cooperative with the research assistant and relaxed instead of them trying to do it themselves. During the rolls on the 2D machines, some participants would try to do the rolls and would apply too much pressure or smudge the prints. The research assistant couldn't force the participant to cooperate other than asking them to relax and let them roll their fingers. The FlashScan D4 was slow and the participants did not enjoy sitting there waiting for the machine to be done processing the information. The participants had trouble with the TBS because some of them could not individually work their fingers. While older participants were doing the collection and had arthritis problems their hands would cramp up and it would be hard for them to complete the process. The research assistants had to help them keep their finger still and move the machine around while the finger didn't move. With the TBS raising the table to where the machine was about chest to neck level helped the participants keep their finger straight, also the participants tried using the bottom of the hole as a support. This in turn moved the machine when they tried to move their finger. It seemed as if the participants cooperated better on the machines where you started with the finger flat and then rolled to both sides instead of starting on the side (L-1).