Document Title: **SVI (Generation 2) 3DMobileID™ Face Recognition Binocular System: Test & Evaluation (Version 1.1)**

Author(s): **Lars Ericson, Ph.D., Jon Hayes, Steve Shine**

Document No.: **249537**

Date Received: **December 2015**

Award Number: **2010-IJ-CX-K024**

SVI (Generation 2) 3DMobileID™ Face Recognition Binocular System: Test & Evaluation

(Version 1.1)

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

April 24, 2014

Prepared by

ManTech Advanced Systems International
1000 Technology Drive, Suite 3310
Fairmont, West Virginia 26554
Telephone: (304) 368-4120
Fax: (304) 366-8096

Dr. Lars Ericson, Director

Jon Hayes, Principal Subject Matter Expert

Steve Shine (Azimuth, Inc.)

UNCLASSIFIED

This project was supported by Award No. 2010-IJ-CX-K024, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 EXECUTIVE SUMMARY

The National Institute of Justice (NIJ) Sensors, Surveillance, and Biometric Technologies (SSBT) Center of Excellence (CoE) has conducted test and evaluation (T&E) of a long-range facial recognition binocular system called 3DMobileID developed by StereoVision Imaging, Inc. (SVI) under NIJ research and development (R&D) funding.[1,2] The binoculars capture images of a subject using stereoscopic optics so as to remove the surrounding background through imaging processing for improved biometric identification. The SVI binoculars evaluated under this effort are the second generation (Gen2) of a system evaluated by the SSBT CoE in 2012.[3] The T&E in the current effort involved a technology assessment of device functionality, a data collection of face images from 100 subjects, and an evaluation of the match performance using two industry standard algorithms. The SVI Gen2 binoculars have been developed for use by law enforcement in under cover surveillance of non-cooperative subjects.

Data analysis was conducted using a face image dataset collected by West Virginia University (WVU). The dataset is available for use by third-party research organizations upon request. Face images were collected from 100 unique subjects in a structured manner during the time period of August – November 2013 on the following devices:

- Indoors (Controlled Lighting, Pose, Distance):
    a. Digital SLR camera
- Outdoor (Uncontrolled Lighting, Controlled Pose and Distances)
    a. SVI 3DMobileID Binocular Prototype
        i. Tripod Mode Distances: 35, 50, 65, 75, 90, 100, 125 m
        ii. Handheld Mode Distances: 50, 75, 100 m
    b. Digital SLR camera with Telephoto Lens
        i. Distances: 35, 50, 65, 75, 90, 100, 125 m

The collected face images were processed with SVI software to remove the background, resulting in sets of images for Left and Right camera, Occluded (i.e., background-removed, see Section 3.1 General Functionality), and Log Based. The log-based image set was a subset of images for each subject selected by the L1 ABIS matching algorithm based on high quality content.

The face image datasets were submitted as probe sets against the enrollment gallery using the L-1 Identity Solutions (L1) ABIS and Neurotechnology MegaMatcher (MM) matching algorithms to determine the matching performance of images captured by the 3DMobileID. The following matching runs were conducted, for a total of 96 runs:

- Gallery vs. Gallery (MM)
- Gallery Low vs. Gallery (L1)
  - Gallery Low is a Gallery vs. Gallery matching run where the probe images have been reduced in file and pixel size to accommodate ingestion by the matcher.
- Canon 800mm Outdoor vs. Gallery (MM, L1)
  - Distances: 35, 50, 65, 75, 90, 100, 125 m
- SVI Gen2 3DMobileID vs. Gallery (MM, L1)
  - Tripod Mode
    - Distances: 35, 50, 65, 75, 90, 100, 125 m
      - All the left camera images
      - All the right camera images
      - All the occluded images
      - All the images designated in the SVI Disparity Calculator log file
  - Handheld Mode
    - Distances: 50, 75, 100 m
      - All the left camera images
      - All the right camera images
      - All the occluded images
      - All the images designated in the SVI Disparity Calculator log file

To aid in the evaluation of the SVI Gen2 system, the following matching runs were performed using the older Gen1 data to provide a more direct comparison:

- SVI Gen1 FRT 3DVuCam vs. Gen1 Gallery (MM, L1)
  - Distances: 50, 75, 100 m
    - All the occluded images

The matching runs were analyzed with respect to device, capture mode, target distance, and matching algorithm by examining the True Match Rate at Rank 1 (TMR) and similarity score distributions. Based on extensive analysis, there were nine key conclusions:

1. **The Gen2 system demonstrates a dramatically improved performance over the Gen1 device.** The hardware and software changes to the Gen2 have made an apparent significant positive effect on the TMR performance under both L1 and MM for the Occluded and Log Based image sets. For example, the L1 Occluded matching runs improved the TMR from 12.8% to 64.0% at the 75 m distance, while the MM Occluded matching runs improved from 8.0% to 57.2% at 75 m (see Figure 71).

2. **The Gen2 binoculars are a significant improvement over Gen1 in terms of functionality, but there are still issues that need addressing before becoming an operational product.** As discussed in Section 3.0 3DMOBILEID TECHNOLOGY

ASSESSMENT, improvements are needed in image stabilization, lighting exposure, options for data transfer, ruggedization, and device housing.

3. **Based on the full system evaluation, the SVI Gen2 performs well and is on track to be a usable law enforcement device.** The full system evaluation is a more operationally-relevant evaluation method and better encapsulated the performance of the SVI binoculars. The SVI Gen2 system in Tripod Mode with the L1 matcher possessed a TMR of 59 – 68% for Log Based image sets in the optimal ranges of 50 – 100 m (see Figure 73). In the MM matching runs, the system produced a high TMR of 83% at 50 m with the Log Based image set (see Figure 74). The standard evaluation methods used in the majority of this report and in the Gen1 analysis likely underestimates the performance of the binoculars.

4. **The 3DMobileID may need to include more capabilities, such as video capture, before law enforcement is willing to adopt the system.** Based on practitioner engagement, and given constrained budget and operational requirements, agencies need systems that serve more than one role.

5. **Removing the background through the occlusion process improved the match performance of the SVI Gen2 system when using the L1 matcher.** The SVI Gen2 Tripod Mode L1 matching run using all the Left or Right image set had a TMR < 2%, while the same images after undergoing occlusion processing resulted in a high TMR of 64.6% at 65 m (see Figure 61). In Handheld Mode, the Occluded matching run resulted in a peak TMR of 55.8% at 75 m, with Left and Right matching runs producing a TMR < 2% (see Figure 66).

6. **Occluded images do not improve the performance of MM matching runs, and can sometimes hinder the performance of the system.** In Tripod Mode with the MM matcher, the TMRs of Log Based matching runs parallel those of the Left and Right matching runs. The Occluded matching runs perform worse than all others at target distances of 35 – 75 m and comparable at the longer ranges (see Figure 63). These results emphasize the fact that not all algorithms work the same and suggest that a background removal process may be algorithm dependent in its added benefits.

7. **Integration of the L1 matcher with the Disparity Calculator is incorrectly or suboptimally setup.** The Log Based matching runs should perform as well, if not better, than the Occluded matching runs. It should select the best images for submission as probes for a given subject. However, Figure 70 shows that the Tripod Mode L1 Occluded matching runs perform better than the L1 Log Based runs, as high as 30% better at some distances. Similarly, the Handheld L1 Occluded matching runs resulted in a peak TMR of 55.8% at 75 m, while the Log Based matching run resulted in a peak TMR of 29.7% at 75 m (see Figure 66).

8. **When braced on a tripod, the Tripod and Handheld Modes perform comparably.** This was true for both L1 and MM matchers, as depicted in Figure 68 and Figure 69, respectively. The faster shutter speed and shorter exposure time of the Handheld Mode

did not affect the match performance at any distance. Note that the handheld images were taken with the device mounted on a tripod and not freely held by an operator, which could reduce match performances.

9. **SVI and future T&E efforts should conduct a parametric study of the effect of Disparity Calculator occlusion parameters on matching performance.** Further improvements to the occlusion image process and subsequent match performance may be realized by thoroughly exploring this parameter space.

2.0 INTRODUCTION

The NIJ SSBT CoE has conducted T&E of a long-range facial recognition binocular system called 3DMobileID developed by SVI under NIJ R&D funding.[1,2] The binoculars capture images of a subject using stereoscopic optics so as to remove the surrounding background through imaging processing for improved biometric identification. The SVI binoculars evaluated under this effort are the Gen2 of a system evaluated by the SSBT CoE in 2012.[3] The T&E in the current effort involved a technology assessment of device functionality, a data collection of face images from 100 subjects, and an evaluation of the match performance using two industry standard algorithms. The SVI Gen2 binoculars have been developed for use by law enforcement in under cover surveillance of non-cooperative subjects.

Figure 1: SVI 3DMobielID (Gen2) Binoculars
Photo by NLECTC SSBT CoE

2.1 Facial Recognition at a Distance in Criminal Justice

Facial recognition has always been important to criminal justice for gathering information and evidence on suspects during criminal investigations and security operations. Face biometrics is a logical tool to enhance criminal justice activities because of the increasing presence of video technology and its connection to existing law enforcement practices (e.g., mugshots, suspect sketches, witness identification, and patrol stops). However, until recently facial recognition was limited to controlled collections at booking stations or in the field with cooperative subjects at short distances. Advances in video hardware and facial recognition biometric software is advancing this field and increasing its value to criminal justice. With the upcoming implementation of an IT upgrade to the FBI's Next Generation Identification (NGI) system that incorporates facial biometric searches,[4] agencies will start looking towards facial recognition at a distance (FRD) to augment existing tools and practices.

NIJ has been developing guidance to be published at a later date (with the assistance of the SSBT CoE) that codifies biometric use-case scenarios in criminal justice in a standardized manner to facilitate common discussions and T&E frameworks. In general, FRD scenarios involve the following subset of parameter restrictions:

1. The interaction with the subject is an **Encounter** and not a forensic examination.
2. The biometric objective is **Identification** of the unknown subject and not verification.
3. The modality is **Face**.
4. The sensor distance is **Noncontact Medium** or **Noncontact Long Range**.
5. The environment is **Outdoor**.
6. The time of day is **Day**.

Based on those conditions, and discussions with the practitioner community, there are four general scenarios in which criminal justice agencies (i.e., law enforcement, corrections, and courts) might employ FRD – Investigative Surveillance, Tactical Operations, Public Surveillance, and Facility Surveillance.

Investigative Surveillance scenarios are the primary concept of operations for which the SVI 3DMobileID has been developed. In these scenarios, the operator is monitoring a subject or location to gathering information that might aid in an ongoing investigation. FRD can be used to inconspicuously capture face images of subjects of interest and use that data to obtain a person's identity, and therefore expand the breadth or depth of the investigation. In these scenarios, the subjects are uncooperative or non-cooperative towards the collection, requiring the FRD system to have more latitude with respect to face pose and angle. In addition, the surveillance will usually take place in uncontrolled environments, necessitating flexibility in lighting requirements for a successful capture. Finally, the longer the range of capture available to the operator, the better the chances of remaining undetected and obtaining valuable or unbiased subject data.

Tactical Operations scenarios share many of the same requirements as Investigative Surveillance. In these scenarios, practitioners are utilizing FRD to obtain information on suspects, criminals, and bystanders in high threat stressful situations. Uncontrolled environmental and subject factors are important, even more so than in investigative situations since there may not be a second opportunity to capture face images. Speed and ease of use are important in these scenarios because of the high pressure and rapid response of activities.

Public Surveillance involves collection and analysis in real-time of data from cameras and other sensors deployed in a fixed configuration. Examples include cameras arrays capturing video of a high crime city area, special security events (e.g., presidential speeches), or a transportation hub. Although the SSBT CoE is not aware of any active real-time FRD being utilized in any domestic criminal justice venues at the moment, the technology and operational need is evolving in that direction. These scenarios require systems that can handle multiple subjects at once with varying facial pose and angle. Some technical operating parameters will be dependent on whether FRD is being performed to actively locate a known individual(s) or matching against a watchlist of priority suspects.

Facility Surveillance scenarios are similar to the previous public surveillance ones, but are focused on monitoring the perimeter or grounds of a specific facility. FRD can be deployed as a non-intrusive access control/monitoring application to scan persons as they approach a building or entrance, or it can be used to identify subjects in restricted areas or exhibiting suspicious behaviors. Because the deployment has fixed environmental conditions, known surroundings, and some control over the FRD implementation, this scenario will tend to be the least difficult to accomplish and have the least demanding technical requirements. Example facilities include correctional institutions, government buildings, and secure sites (e.g., power plants).

2.2 WVU Face Collection

Data analysis was conducted using a face image dataset collected by WVU. For WVU Institutional Review Board and data request purposes, the collection, protocol, and dataset are formally titled "Long-Range Facial Recognition Collection, Dataset 2." The dataset is available for use by third-party research organizations upon request by submitting an email request to wvubiometricdata@mail.wvu.edu. The full report detailing the WVU face collection is included in Appendix B for reference. Face images were collected from 100 unique subjects in a structured manner during the time period of August – November 2013 on the following devices:

- Indoors (Controlled Lighting, Pose, Distance):
  a. Canon 5D Mk II digital SLR camera with a Canon EF 70-200mm (f/2.8L, image stabilized) lens, mounted on a tripod
     i. Followed "ANSI/NIST–ITL 1-2007 Best Practice Recommendation for the Capture of Mugshots"[5]
- Outdoor (Uncontrolled Lighting, Controlled Pose and Distances)
  a. SVI 3DMobileID Binocular Prototype, mounted on a tripod (for both modes)
     i. Tripod Mode Distances: 35, 50, 65, 75, 90, 100, 125 m
     ii. Handheld Mode Distances: 50, 75, 100 m
        1. *The SVI system was more sensitive to cloudy outdoor lighting conditions resulting in failed captures for 11 subjects. Schedule limitations did not allow for rescheduled sessions with those subjects. As a result, only 89 subjects had handheld face images collected.*
  b. Canon 6D digital SLR camera with a Sigma Zoom Super Telephoto 300-800mm f/5.6 EX DG APO IF HSM Autofocus Lens, mounted on a tripod
     i. Distances: 35, 50, 65, 75, 90, 100, 125 m

Figure 2: Digital SLR Camera with Telephoto Lens
The Canon 6D digital SLR camera with a Sigma Zoom Super Telephoto used as a comparison face image capture system. The camera and lens are approximately 2.5 ft. in length and weighs ~14.5 lbs.

2.3 About the SSBT CoE

The NIJ SSBT CoE is a center within the National Law Enforcement and Corrections Technology Center (NLECTC) System.[6] The Center provides scientific and technical support to NIJ's R&D efforts. The Center also provides technology assistance, information, and support to criminal justice agencies. The Center supports the sensor and surveillance portfolio and biometrics portfolio. The CoEs are the authoritative resource within the NLECTC System for both practitioners and developers in their technology area(s) of focus. The primary role of the CoEs is to assist in the transition of law enforcement technology from the laboratory into practice by first adopters.

3.0 3DMOBILEID TECHNOLOGY ASSESSMENT

3.1 General Functionality

To use the SVI Gen2 binoculars, an operator powers up the binoculars and associated laptop software. The software is used to connect wirelessly to the binoculars. The user lines up the target in a visual reticle, followed by capturing by either pressing a button on the binoculars or activating from the laptop software. The binoculars capture a short video clip from each of the left and right optical cameras and transmit the images to the software.

In the Gen2 system delivered to NIJ, the binoculars transmitted the subject image pair to the laptop software, which then saved it to the computer for later processing. A full system has also been developed by SVI wherein the image pair is transmitted to the laptop running SVI's background removal software and an Automated Biometric Identification System (ABIS). In this use case, the image pair is accepted by the background removal software, which processes the images into left, right, occluded (i.e., background-removed images). In this context the "occluded" images are those that have had the background surrounding a subject blocked-off and removed. A subset of these images is then submitted to the ABIS and a rank match result is returned to the operator.

The concept behind the SVI binoculars is the use of image triangulation to facilitate background removal. There are other camera systems currently on the market that also use the image triangulation (i.e., stereoscopic optics) to produce a 3D image, including digital camcorder binoculars.[7,8] SVI should consider teaming with a company that is already working on similar optics devices so as to focus on the software-based background removal. This approach could improve the overall product offering and reduce the time to market.

Interactions with law enforcement practitioners have raised a practical issue – most departments are unable to allocate budget to purchase a single-capability device rather than one with multi-functional or robust capabilities. Expanding the system capabilities to include video recording to capture an act in progress would be beneficial. SVI has stated that the binoculars are capable of video capture, but that the capability has not yet been implemented.

In assessing the evolution of the Gen1 to the Gen2 binoculars there are substantial improvements as well several backward steps. Most of the backward steps can likely be attributed to a lack of time; there are many items that SVI appears to have thoroughly researched (based on discussions with the SSBT CoE), but did not have the time or the monetary resources to fully implement before a delivery to NIJ was required.

3.2 Assessment Positives

User Manual: SVI developed a much more useful targeted user manual for the Gen2 system.[9] This manual defines the system to a good level of detail. It steps a user through the execution of the software and potential issues that may occur with the software as well as hardware operation error codes. During operation of the device the team has seen all of the various error codes that the system produces including communication errors that occur due to the wireless connection between the binoculars and the computer as well the auto-focus and auto-exposure errors. The auto-focus error is the least likely error to occur, with the auto-exposure being the more likely happen.

Lighting: The Gen1 system required heavy operator interaction to calibrate exposure settings for various lighting conditions. The Gen2 system works in much lower lighting environments and without the need for the operator to measure and adjust the system settings. However, operating the device in handheld mode in cloudy environmental conditions often results in insufficient lighting for a capture; a user is then required to switch to tripod mode. Tripod mode does not require as much light to operate. The SSBT CoE team was able to use the system, while in tripod mode, with as low an illumination of 176 lux (although this is likely not the lowest viable level of exposure). For comparison, a very dark overcast day is ~100 lux, an average overcast day is ~1,000 lux, and full daylight is ~20,000 lux.[10] The user manual breaks down the difference in lighting condition requirements from the Gen1 system with respect to Gen2; however the SSBT CoE team believes the added breakdown of Handheld versus Tripod mode lighting would be beneficial.

Disparity Calculator: There are clear improvements in the Disparity Calculator, the software that removes the background behind a photographed person. Currently it must be manually operated to ingest data files. This is the process to retrieve the files stored by the 3D capture video application for further processing and, if interfaced to the server facial recognition engine, for identification. The software executes quickly and has a simple interface to allow saving of files, operation in either handheld or tripod mode, and lastly the ability to quickly see the most recent captured left and right images.

Auto-Focus: One of the greatest feature enhancements is the auto-focus capability of the Gen2 binoculars, where any point in the 50 to 125 m range can be targeted. The Gen1 system required people to be at fixed distances of 50, 75, or 100 m with little tolerance for distance from the stated ranges.

Auto-Exposure: The image quality of the Gen2 system is much better than Gen1. This was improved mostly by the addition of auto-exposure. While in tripod mode, the system is noticeably better than the Gen1; however is it not nearly as good as comparable commercial systems.

Handheld: The inclusion of a handheld mode is a notable improvement in functionality. Section 4.0 of the SVI Final Report to NIJ notes, "[Re-designed] the binocular and receiver optics to increase the speed of the optics and the integration of discrete auto-focus modules. This allowed for a truly handheld device without the need for a tripod."[2] Handheld mode would likely be the primary mode used by law enforcement practitioners in the field. Although in theory the handheld mode is an improvement, the SSBT CoE team had substantial issues when operating the system in handheld mode (see Section 3.3 Assessment Negatives).

Wireless: One of the primary functionality changes in the Gen2 system is that it connects and transmits capture images to a computer via wireless communications. The Gen1 system required a tethered cable between the binocular unit and the computer, which made the overall system cumbersome and unrealistic for many surveillance situations. The addition of wireless communications is a positive improvement towards an operationally useful device. However, the option to connect via cable should be available to users in departments with policies restricting the use of wireless devices or in operations that require broadcast silence for covert reasons.

3.3 Assessment Negatives

Image Stabilization: The Gen2 system does not include any hardware or software image stabilization. SVI researched the inclusion of image stabilization into the Gen2 system, but were unable to include it in the system before delivery. It appears it was a multilevel approach that the primary part included changing a lens coating from a 50/50 to an 80/20, which would have worked a majority of the issues, but due to the complexity it was not integrated into Gen2. SVI is currently working on the 3rd generation system (Gen3) and will likely include this upgrade there. From the SVI Final Report, the 80/20 coating would have "over a 2x increase in light, that effectively overall increased the signal-to-noise by a factor of 2 and thus allowing for faster optics and a more stable image capture due to shorter integration times for proper "exposure" required under identical times as compared to the previous 50/50 coating."[2]

Handheld: As mentioned previously, the addition of a handheld mode functionality is an improvement. However its execution in the Gen2 system has flaws that need to be addressed. The SSBT CoE team had substantial issues when operating the system in handheld mode. These included the inability to hold the unit steady during capture, which was a function of both the size, weight, and attached battery pack to the unit. This did not allow for a person to easily target a person of interest into the reticle. There was also a noticeable difference in lighting sensitivity when operating in handheld mode, with the handheld mode required greater ambient lighting to function. These are notable operational issues since handheld mode would likely be the primary mode used by future law enforcement practitioners in the field.

Auto-focus: The team has noticed a fairly large difference in the left and right images with respect to focus. This is readily visible to the human eye. It should be noted that SVI discussed said issues in their final report to NIJ.[2] It should also be noted that the system will often focus on objects over a targeted person. This issue was known to SVI during the Gen2 delivery.

Lighting: While the Gen2 system functions adequately in most ambient environmental lighting, there are other operational factors that have been found to affect the ability to capture usable images. The SSBT CoE found that capturing images through building or car windows can be difficult. Transmission through any window will result in a loss of light, but some buildings have exterior tinting and many cars have tinted windows. Given the concept of operations for the SVI binoculars (undercover law enforcement surveillance), this could be a significant limitation in the field. From the SVI Final Report: "if the device is used indoors through glass to ID test subjects outdoors the transmission properties of the glass must be considered. In this case analog gain may be higher than outdoor use and automatically applied depending on the glass properties and outdoor conditions and higher noise will be introduced into the system; thus performance may be degraded."[2]

Background: It was found that shade in the immediate environment of the target subject would have a great effect on the contrast of the capture images. The only viable method of mitigating this would to improve the capture ability of the binoculars at low light exposure. However, it is an operational factor that many operators may not consider and one that is not emphasized in the Gen2 user manual.

Software: The current version of the SVI software has some improvements, but overall is cumbersome when compared to the prior version. The new software version does not directly link to the Disparity Calculator nor does the software link to the matching capability the system should provide (i.e., no end-to-end functionality). In addition, a unique error was discovered that SVI had not previously seen that caused the system to only capture a hybrid of images from a past and current collection merged into one VUR set (VUR is a proprietary video file format). To be clear, this includes images from the just prior capture mixed with the current capture. This was easily discerned as we had a target that was wearing glasses in one capture and not the next. SVI quickly worked a short-term operational solution and was able to provide a software update. However the root problem has not been determined and the update cannot catch the issue until after it has occurred. The update requires a system restart when it occurs. During the technology assessment, this error occurred approximately every 1 in 15 captures. Beyond that issue, it is necessary to restart the software when changing from Handheld to Tripod mode or when changing from saving VUR or images is desired.

It is the team's understanding that the T&E version of the Gen2 system delivered to NIJ has focused on facilitating the SSBT CoE's evaluation, which would focus on the standalone Disparity Calculator for processing images. It is expect that this integration exists at SVI and is easily provided to a customer. A full capture to match result integrated product using the Gen2 software was not part of the delivery.

Data Transfer: The Gen1 system provided for more useful options to capture, transfer, and matching images. The binoculars could work in a tethered mode or store the images on a compact flash card for transfer later. The Gen2 system requires a wireless connection between the binoculars and a laptop computer before capture can occur. This is a big reduction in usefulness of the system since it requires an operator in the field to have a running computer nearby before using the binoculars.

Hardware: Although it appears from reading the SVI Final Report that SVI planned to completely re-house the system, the Gen2 delivered to NIJ used the same housing and included buttons and functions that were left over from Gen1 and now obsolete. In addition, the operational battery is still external to the system and tethered via a cable. The binoculars are also not in a ruggedized form and have many open ports where dirt or rain could easily cause a system malfunction. The SVI Final Report that states the system operates "under uncontrolled lighting and environmental conditions," which is not entirely true given the vulnerability of the binoculars to rain and dusty weather.

Form Factor: The Gen2 binoculars appear to have taken a step backward with respect to form factor. There is only one operational button on the unit, the "Shutter" button for capture although there are still several buttons a person could depress. This could be confusing. The binoculars do not have a power button (On/Off). A user is required to remove the power plug each time. This leads to unnecessary wear and tear on the device. The battery pack is still external, large, and cumbersome.

3.4 Miscellaneous Comments

SVI's Final Report states the system captures "noncooperative persons of interest at ranges of up to 100 meters".[2] A Noncooperative Person is defined as a subject who is unaware of the biometric collection. This does not seem correct due to the need for a person to be at rest and facing the system for capture, as well as the need for good lighting and clear weather to capture. The goal of this may exist, but the system is far from meeting that objective.

SVI also noted adjusting the contrast of the images to meet the 18% grayscale requirement (referenced in AE section of the Final Report).[2] This statement is likely referring to the NIST standards associated with certain types of enrollment images (i.e., ANSI/NIST–ITL 1-2007 "Best Practice Recommendation for the Capture of Mugshots"),[5] but its context leads the team to believe SVI may misunderstand the requirement's purpose. In the NIST standard, an 18% gray backdrop is placed behind a subject and then used as an absolute reference for calibrating the exposure settings of a mugshot collection setup.

Although SVI has stated that they know that the system has focus issues between a target and background, it could be studied further to determine the extent of this issue.

It should be noted that many of the issues detailed here are already known by SVI. It is also clear from the plans and research noted in the Final Report that decisions on form factor, system specification, and software were not the optimal decisions or desire of SVI, but a consequence of delivering a product to NIJ on time and within contract.

4.0 TEST ENVIRONMENT & APPROACH

4.1 System Test Environment

The lab evaluation environment consisted of the resources needed to evaluate the face images collected from the devices in the WVU dataset. The hardware environment for the evaluation consisted 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. It was determined during a previous biometric T&E tasking that the computer hosting the L1 ABIS license possessed an intermittent RAID Controller error that could disrupt lengthy processing activities. Because of difficulties in setting up the L1 ABIS, and its license being associated with this computer, the team opted to work around this issue rather than try to transition to the other computer. The minor effects of this error are detailed in later sections. The image datasets were temporarily hosted on the computers during matching run processing, but are permanently stored on an encrypted external hard drive for archival and security purposes. These computers hosted the Neurotechnology's MegaMatcher and L1 algorithms and gallery managers.

The algorithms were selected to verify and evaluate the performance of the matching built into the SVI Gen2 binoculars and to provide an alternative performance comparison. The two software suites used in this evaluation were L-1 Identity Solution ABIS version 6.5.2 (L1) and Neurotechnology MegaMatcher version 4.2 (MM). The L1 algorithm is utilized in the SVI 3DMobileID binocular system as a gatekeeper of collected images to determine the best subset of images to submit to the L1 backend matcher during binocular usage. The MM was utilized in the Gen1 evaluations previously conducted; it was also selected based on its low cost, product maturity, performance, and experience integrating it into many products.

4.2 Face Image Datasets for Evaluation

The images used in this evaluation were captured from three devices, as detailed previously (see Section 2.2 WVU Face Collection). The first step in preparing the data for matching and analysis was to review all file names and ensure that they followed a standard naming format. If the files could not be readily identified as to their parameters due to filename errors or duplications, then the files were discarded for data integrity purposes. This was only necessary on one or two instances. This was important because the biometric test environment developed to executing matching runs used the filename to extra matching run parameters, such as distance and subject number. The second step was to review the WVU collection logs and remove any duplicate or extraneous data files. It was during this step that it was confirmed that eleven subjects did not have images captured with the SVI binoculars in handheld mode.

The indoor digital camera images served as enrollment images for the galleries during matching runs. Only the images at 0° pose, cropped to SAP 50 Standard 3300 x 4400 pixel dimensions were utilized during the matching runs. Additional angles were captured for completeness and for future dataset use.

Figure 3: Example Indoor Enrollment Images
Note that the subject provided permission to reproduce his face image for research reporting purposes in accordance with IRB-approved protocols.

The outdoor digital camera images (i.e. Canon 800mm) were cropped using an auto-cropping tool to a standard size of 1024 x 1365 pixels. This step was found to be necessary during the Gen1 evaluations because of difficulties submitting large images to the L1 matcher.[3] This image processing was repeated here to address the same issue and to be consistent with Gen1 evaluations.

35 m **50 m** **65 m** **75 m** **90 m** **100 m** **125 m**

Figure 4: Example Canon 800mm Outdoor Images
Note that the subject provided permission to reproduce his face images for research reporting purposes in accordance with IRB-approved protocols.

The SVI Gen2 images consisted of two .VUR video clips from the left and right binocular camera captured during data collection at each device mode and range. The VUR videos are an SVI proprietary file format. The WVU dataset was initially processed to bin the images by range rather than the default subject number. Then each subset was processed by hand through SVI's Disparity Calculator software program (i.e., SVI 3DMobileID Processor). Similar to the Gen1 system, the pair of short video clips is submitted as inputs to the SVI Disparity Calculator program wherein the frames are matched up and the background subtracted. The resulting outputs are six (6) TIFF images created from the left camera, six (6) images from the right camera, and six (6) occluded images from processing the combined image streams. In addition, the system utilizes the L1 algorithm to perform a quality assessment to identify a subset of images to be submitted as probes for matching. These image selections are reported in a log that can be accessed and copied by the user. The log of L1 selected images was copied into a standalone text file to be used later during matching runs. The SSBT CoE was sensitive to fact that settings used in the Disparity Calculator to generate occluded images can have an effect on the resulting matching runs. As a result, the settings were checked regularly to confirm that they followed those outlined in the 3DMobileIF instruction manual:[9]

- Level Adjustment: CDF
  - CDF Black Level (percent): 0.01
- Mean Computation: Gaussian
  - Mean Mask Size (odd): 9
  - Sigma: 7
- Dynamic Range Compression: 400
- Contrast Enhancement: OFF
- Min/Max setting for inter-eye distances in terms of pixels: 25 / 130

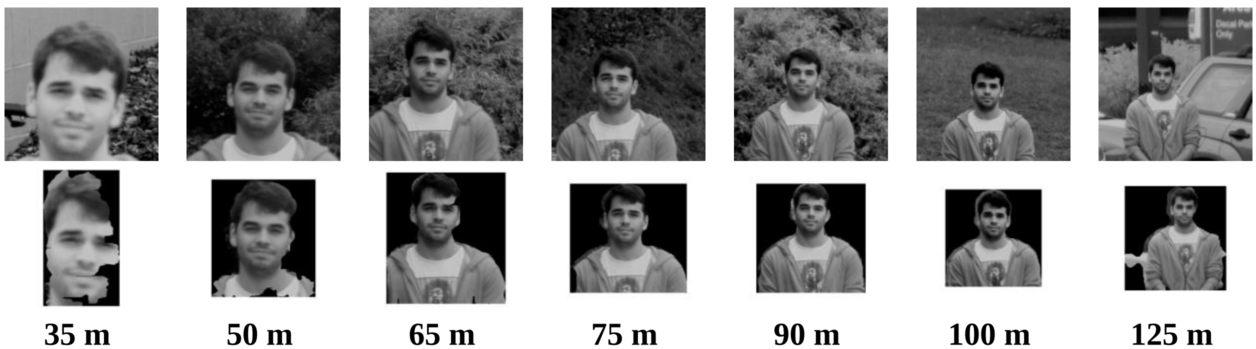


Figure 5: Example SVI Gen2 Images
Top Row: Left Images, Bottom Row: Occluded Images. Note that the subject provided permission to reproduce his face images for research reporting purposes in accordance with IRB-approved protocols.

For some VUR pairs, no images were identified by the L1 matcher of sufficient quality to be considered probe candidates. In these instances, the log file was left blank and a filler file was placed in the folder "000 NO LOG RESULTS.log" as a record for the SSBT CoE team. As a result, when an image set was created for a given range and device mode that contained all images from the logs, these subjects would not contribute any images. These subjects are therefore excluded from any analysis involving Log Based image sets and are not factored in when calculating True Match Rates.

Table 1: Number of Subjects without Log Files

Range (meters)	Tripod Mode	Handheld Mode
35	24	
50	10	7
65	6	
75	7	7
90	9	
100	13	11
125	13	

Once the SVI images at a given range were processed, a batch file executable was used to pull out all the images of a given type from each subject folder and place them in separate folders. This step also used the log files to copy those images identified by the L1 quality algorithm and create another folder of just those images. From one range folder of images would be produced folders of All Left images, All Right images, All Occluded images, and Log Based images for each device mode.

Table 2: Example of Image Sets from a Subject Collection

The Disparity Calculator processes a VUR pair to produce six Left, six Right, six Occluded images, and a log file of images selected by the L1 matcher to be used as probes. Note that the subject provided permission to reproduce his face images for research reporting purposes in accordance with IRB-approved protocols.

Image Set	Images
Left	
Right	
Occluded	
Log Based (from Left)	
(from Right)	
(from Occluded)	

The matching performance of either the L1 or MM face algorithms is dependent on the quality of the probe and enrollment images. The probe images were captured outdoor and in less than ideal conditions. The enrollment images are of excellent studio quality and are captured in accordance with the ANSI/NIST–ITL 1-2007.[5] The Intra-Ocular Distance (IOD), quantified by the number of pixels, was recorded for each capture camera device and distance. In general, the IOD pixel count is useful metric of image quality, which is correlated to matching performance in facial recognition systems. The following measurements (pixel counts) were taken from the devices (Canon enrollments, Canon 800mm outdoor, and SVI) and distances (35, 50, 65, 75, 90, 100, and 125 m) in the WVU SVI dataset. For each device and distance, the IOD pixel count for three random images was measured and the average pixel count is recorded below.

Table 3: Average IOD for Image Sets

	Average IOD (pixels)			
Range (meters)	**Enrollment**	**Canon 800mm**	**SVI Gen2**	**SVI Gen1**
2	736			
35		191	133	
50		152	88	101
65		105	71	
75		107	62	66
90		90	51	
100		78	47	46
125		63	35	

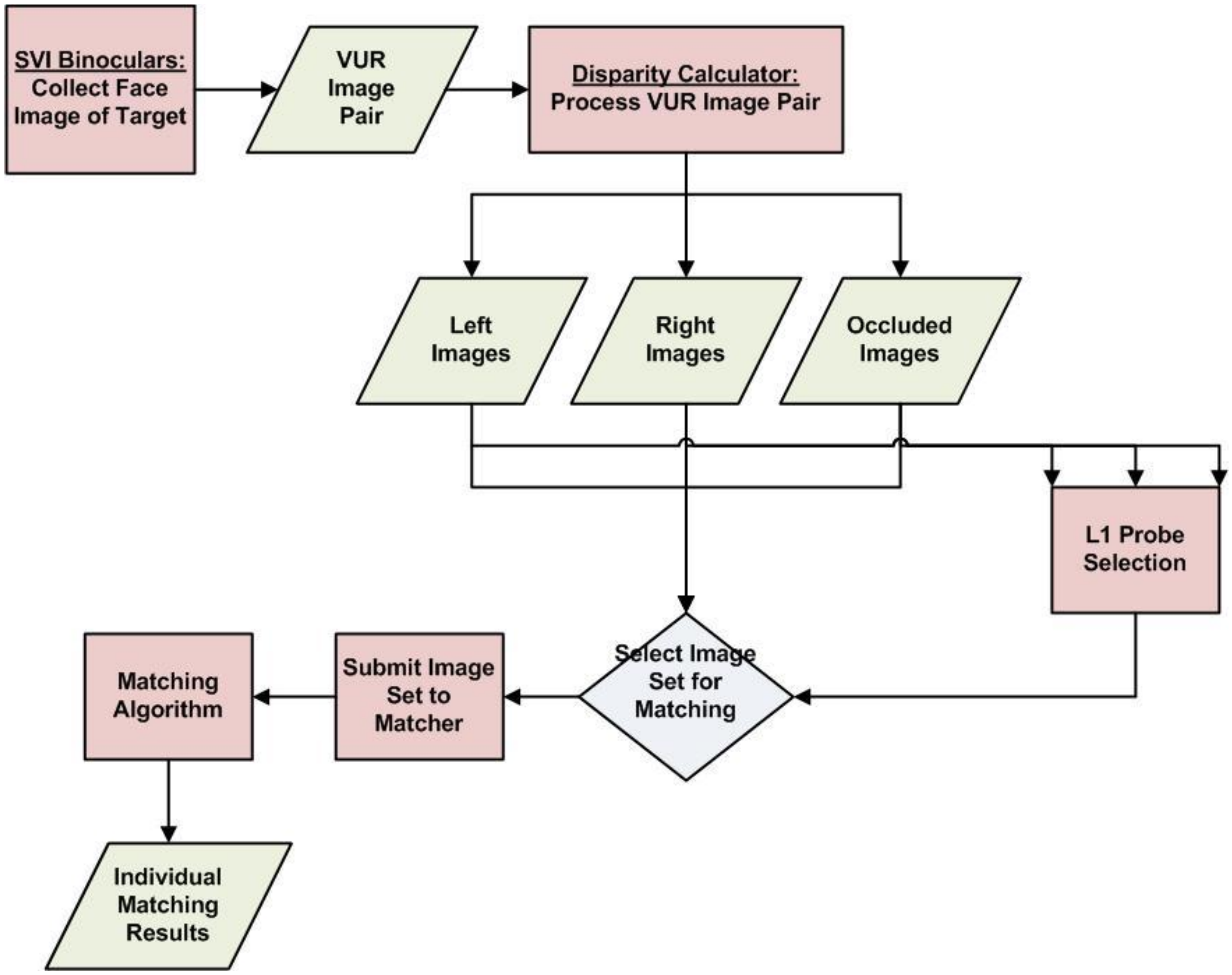


Figure 6: SVI Gen2 Basic System Process

4.3 Evaluation Methodology

The L1 and MM algorithms were utilized to evaluate the performance of the SVI Gen2 binoculars in its role as a biometric capture device. The focus of the evaluation was on the performance of the device and its integrated backend software system and not the performance of the well-established biometric matching algorithms. A custom-made biometric test environment was utilized that incorporated the matcher software development kits (SDKs) with an SQL database for storing matching run results.

For a given matching run, the gallery was created by enrolling the Canon Indoor images. MM had no issues with enrolling the pre-determined images and was a relatively straightforward process. The L1 ABIS is a more robust system and required steps to ensure the database was cleared from any previous run, reset to accept new submissions, and then sent the enrollment images to be loaded in the gallery database. On occasion, an enrollment run would fail to enroll a handful of images. The error messages indicated that the cause was likely due to a RAID Controller failure (see Section 4.1 System Test Environment). Those same failed images could be submitted a second time as a limited image set and would be enrolled successfully. The SQL gallery database was double checked to confirm that there were no duplicate enrollments.

The probe datasets were submitted using the same biometric test environments against the previously loaded gallery. A new gallery was created for each probe set to ensure a blank slate for matching activities. MM did not accept probe submissions that did not possess a face, as determined by its own internal face quality checks. No error was returned, but the resulting matching run log tracked a lack of matching activity for a disqualified probe image. L1 ABIS had issues with probe images that were large in size and pixel dimensions. This was attributed to the hardware problems described previously (see Section 4.1 System Test Environment). The only image set where this occurred was in the gallery versus gallery matching run. All Canon Outdoor and SVI Gen 2 image sets had no matching errors with L1 ABIS.

The output of a matching run was an SQL database populated with matching results and data parameters. The database was used to generate matching run reports that were used as inputs to a robust excel spreadsheet used to generate matching run statistics and analyses. Data integrity checks were used in all matching runs to ensure that the results were consistent with the known probe and gallery image set inputs and that all subjects present in the probe set also existed in the gallery set. The primary matching run metrics used in subsequent analyses were the True Match Rate at Rank 1 (TMR), False Match Rate at Rank 1 (FMR), Non-Match Rate (NMR), Similarity Score Mean, Similarity Score Standard Deviation, and True Match (TM) rate at ranks 1 – 10.

The number of True Matches was calculated as the number of matches at rank 1 returned by the algorithm where the probe ID number was equal to the gallery ID number. Similarly the number of False Matches was the number of matches at rank 1 where the ID numbers were not equal. The TMR and FMR were determined by dividing the number of matches in each case by the total number of probe submissions. Note that in the case of MM accepting occluded images, this is different than the number of probes processed by the algorithm due to non-face images being disqualified. This decision was made because the device performance and not algorithm performance is the primary focus of this evaluation.

The similarity score is a metric for the probability that a matched pair of biometrics originated from the same person. Each algorithm utilizes its own (proprietary) method to arrive at a similarity score, thus resulting in different scales and common values. Based on the Gallery vs. Gallery matches (see Section 5.1 Gallery Matching Runs), the scores range from 0 – 32 for L1 and 0 – 10,080 for MM, with a higher score indicating a higher confidence of the match being a True Match. For each matching run, the mean similarity score and its standard deviation were calculated for comparison purposes. 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 this analysis.

To aid in visualization, the scores were binned across the range of common values as determined by the maximum scores observed in the various matching runs. In this evaluation the Canon 800mm matching results produced the largest similarity scores for both L1 and MM and thus provided a guideline for the axis settings and bin values for created the graphs. According to

MM 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 software development kit documentation.[11]

Table 4: MegaMatcher False Accept Rate vs. Similarity Score

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

5.0 EVALUTION RESULTS

The face image datasets were submitted as probe sets against the enrollment gallery using the L1 ABIS and MM matching algorithms to determine the matching performance of images captured by the 3DMobileID. The details of the evaluation methodology are provided in Section 4.3 Evaluation Methodology. The following matching runs were conducted, for a total of 96 runs:

- Gallery vs. Gallery (MM)
- Gallery Low vs. Gallery (L1)
    - Gallery Low is a Gallery vs. Gallery matching run where the probe images have been reduced in file and pixel size to accommodate ingestion by the matcher.
- Canon 800mm Outdoor vs. Gallery (MM, L1)
    - Distances: 35, 50, 65, 75, 90, 100, 125 m
- SVI Gen2 3DMobileID vs. Gallery (MM, L1)
    - Tripod Mode
        - Distances: 35, 50, 65, 75, 90, 100, 125 m
            - All the left camera images
            - All the right camera images
            - All the occluded images
            - All the images designated in the SVI Disparity Calculator log file
    - Handheld Mode
        - Distances: 50, 75, 100 m
            - All the left camera images
            - All the right camera images
            - All the occluded images
            - All the images designated in the SVI Disparity Calculator log file

To aid in the evaluation of the SVI Gen2 system, the following matching runs were performed using the older Gen1 data to provide a more direct comparison:

- SVI Gen1 FRT 3DVuCam vs. Gen1 Gallery (MM, L1)
    - Distances: 50, 75, 100 m
        - All the occluded images

Results from each of the matching runs were used to calculate the following metrics and matching run statistics. To simplify results reporting, a description of these items is provided here, but not repeated in each of the individual matching runs.

- **Total Enrollments** – Number of images enrolled in the gallery
- **Unique Subjects** – Number of unique subjects represented in the gallery
- **Probe Submissions** – Number of probe images submitted to the matcher
- **Probes Accepted** – Number of probe images processed by the matcher and subsequently matched against the enrollment gallery
- **Unique Subjects** – Number of unique subjects represented in the Probes Accepted data set

- **True Matches** – Number of rank 1 match results returned by the matcher where the probe ID is the same as the gallery ID
- **False Matches** – Number of rank 1 match results returned by the matcher where the probe ID is NOT the same as the gallery ID
- **Total Matches** – Total number of matches performed by the algorithm with a given probe set and gallery set in which all probes are matched against all gallery images
- **Percent** – TMR or FMR for a given matching run; the fraction of probe submissions returned as True Matches or False Matches
- **Score, Mean** – The mean average similarity score for either the set of True Matches or False Matches
- **Score, Std Dev** – The standard deviation of the similarity scores for either the set of True Matches or False Matches
- **Non-Match Rate** – The fraction of probe submissions that are NOT accepted by the matcher and therefore not pitted against the enrollment gallery

In addition to the matching run statistics, a graphical plot is provided for each matching run that depicts the True Match Rank vs. Frequency for a given matching run. This graph depicts how often the true match was returned at a given rank for an entire probe submission set. Note that this TMR is calculated based on initial number of probe submissions and not total number of accepted probes.

The second graphic for each matching run (except for gallery vs. gallery runs) is the frequency distribution of similarity scores for the True Matches and False Matches returned in the rank 1 position. To aid in visualization, the L1 matcher scores have been sorted using a bin size of 0.1 and the MM matcher scores sorted with a bin size of 10. This was chosen simply based on the range of scores returned for the non-gallery matching runs.

Finally, each section for a subset of matching runs (e.g., Canon 800 mm Matching Runs or SVI Tripod Mode All Left) starts with a table summarizing and aggregating the matching run statistics and results for the various relevant matching runs. The True Score and False Score are the mean similarity score with plus or minus the score standard deviation. Given the size and number of the data results presented in this report, efforts were made to capture an individual matching run's results onto a single document page. Including a matching run results table and explanation for every matching run would be cumbersome and lengthy for a reader.

5.1 Gallery Matching Runs

5.1.1 MegaMatcher Gallery vs. Gallery Matching Results

The studio enrollment images were submitted as a probe dataset against itself to baseline the performance of the MM algorithm.

Table 5: MM Gallery vs. Gallery Matching Results

MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total Enrollments**	100			
Enrollment	**Unique Subjects**	100			
Probe	**Probe Submissions**	100			
Enrollment	**Probes Accepted**	100			
	Unique Subjects	100			
Matches	**True Matches**	100	**100%**	10080	0
	False Matches	0	**0%**	N/A	N/A
	Total Matches	10000			

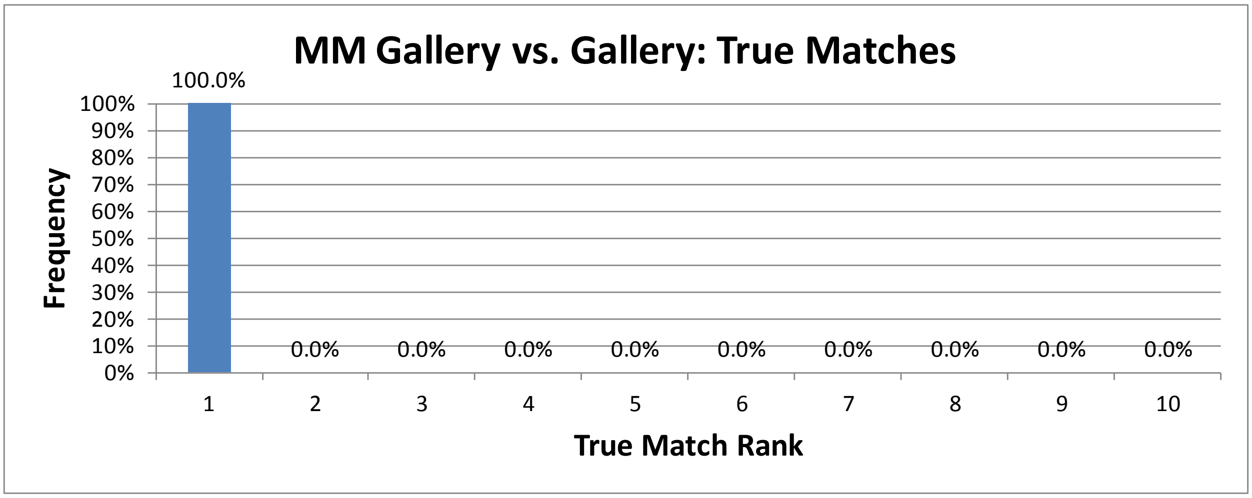


Figure 7: MM Gallery vs. Gallery Matching Results

5.1.2 L1 Gallery Low vs. Gallery Matching Results

Modified versions of the studio enrollment images were submitted as a probe dataset against the enrollment gallery to baseline the performance of the L1 ABIS algorithm. The original enrollment images were unable to be processed as probe submissions, resulting in errors. This is attributed to either hardware problems with the computer's RAID controller (a known issue identified during analysis efforts, see Section 4.1 System Test Environment) or the size of the probe images. To establish a lower bound on the gallery baseline, the enrollment images were reduced in pixel size to 910 x 1365 and processed through Adobe Photoshop at High (60) JPEG Quality setting. The resulting images possessed comparable pixels and file sizes to the Canon 800 mm images. The resulting match run would determine a minimum performance for gallery versus gallery using the L1 algorithm.

Table 6: L1 Gallery Low vs. Gallery Matching Results

L1		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	100			
Enrollment	**Unique Subjects**	100			
Probe	**Probe Submissions**	100			
Enrollment (Low)	**Probes Accepted**	100			
	Unique Subjects	100			
Matches	**True Matches**	100	**100.0%**	32	4
	False Matches	0	**0.0%**	N/A	N/A
	Total Matches	10000			

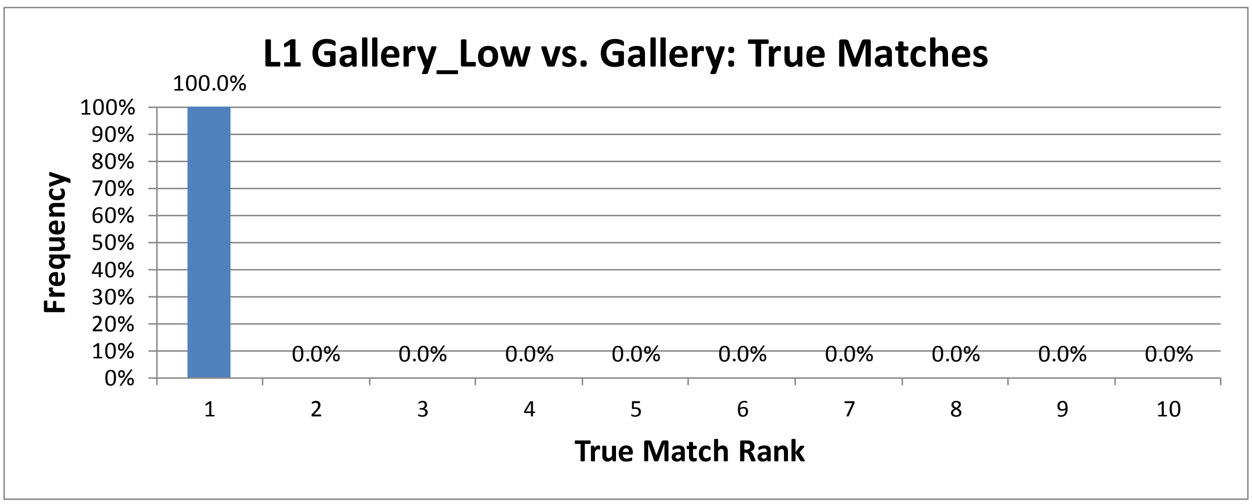


Figure 8: L1 Gallery Low vs. Gallery Matching Results

5.2 Canon 800 mm Matching Runs

Table 7: Canon 800mm vs. Gallery Matching Results

	L1		MM		L1		MM	
Range	TMR	FMR	TMR	FMR	True Score	False Score	True Score	False Score
35m	88%	12%	95%	5%	2.6 ± 1.6	0.7 ± 0.2	108 ± 90	9 ± 3
50m	87%	13%	91%	9%	2.7 ± 1.6	0.7 ± 0.2	108 ± 70	14 ± 4
65m	85%	15%	95%	5%	2.7 ± 1.7	0.7 ± 0.2	85 ± 60	15 ± 8
75m	82%	18%	94%	6%	2.4 ± 1.4	0.6 ± 0.2	73 ± 49	13 ± 5
90m	49%	51%	85%	15%	2.5 ± 1.5	0.5 ± 0.1	65 ± 40	15 ± 6
100m	71%	29%	86%	14%	2.1 ± 1.3	0.7 ± 0.3	52 ± 34	11 ± 4
125m	58%	42%	69%	31%	2.6 ± 1.6	0.6 ± 0.1	46 ± 28	13 ± 5

Table 8: Canon 800mm vs. Gallery, L1 Matching Run Statistics

L1	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
35m	100	100	100	100	100	88	12	10000
50m	100	100	100	100	100	87	13	10000
65m	100	100	100	100	100	85	15	10000
75m	100	100	100	100	100	82	18	10000
90m	100	100	100	100	100	49	51	10000
100m	100	100	100	100	100	71	29	10000
125m	100	100	100	100	100	58	42	10000

Table 9: Canon 800mm vs. Gallery, MM Matching Run Statistics

MM	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
35m	100	100	100	100	100	95	5	10000
50m	100	100	100	100	100	91	9	10000
65m	100	100	100	100	100	95	5	10000
75m	100	100	100	100	100	94	6	10000
90m	100	100	100	100	100	85	15	10000
100m	100	100	100	100	100	86	14	10000
125m	100	100	100	100	100	69	31	10000

5.2.1 Canon, 35 m

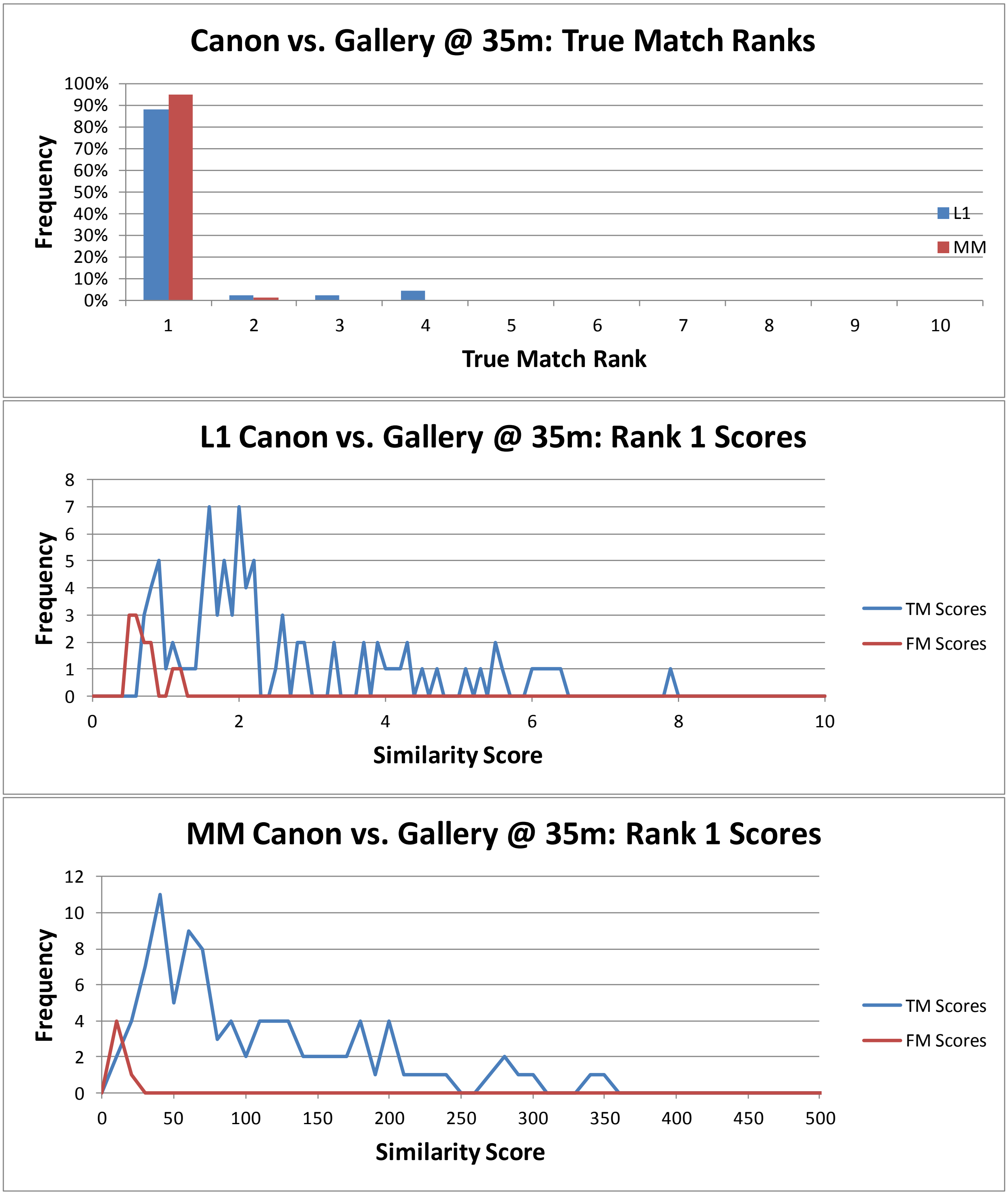


Figure 9: Canon 800mm vs. Gallery @ 35m Matching Results

5.2.2 Canon, 50 m

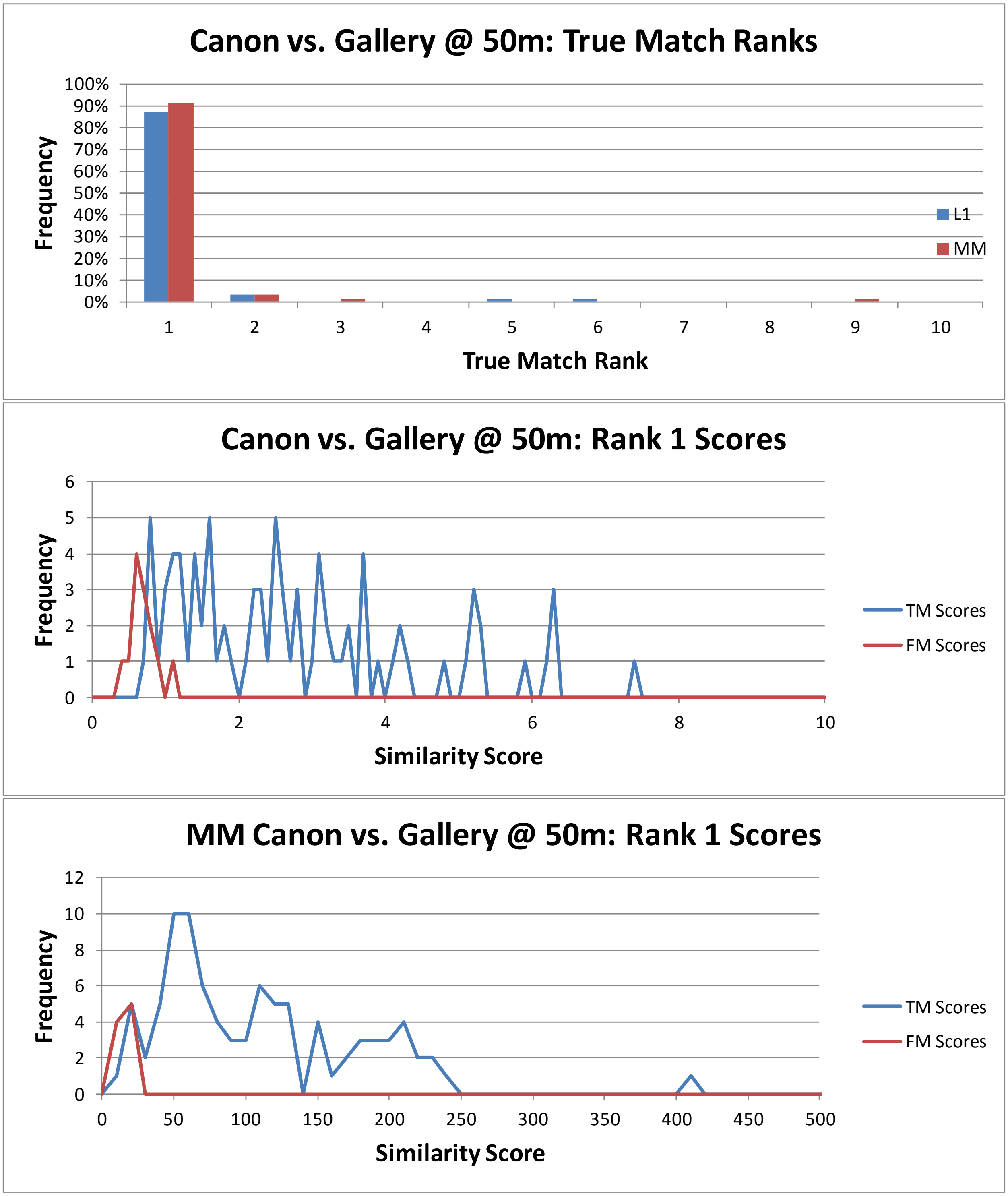


Figure 10: Canon 800mm vs. Gallery @ 50m Matching Results

5.2.3 Canon, 65 m

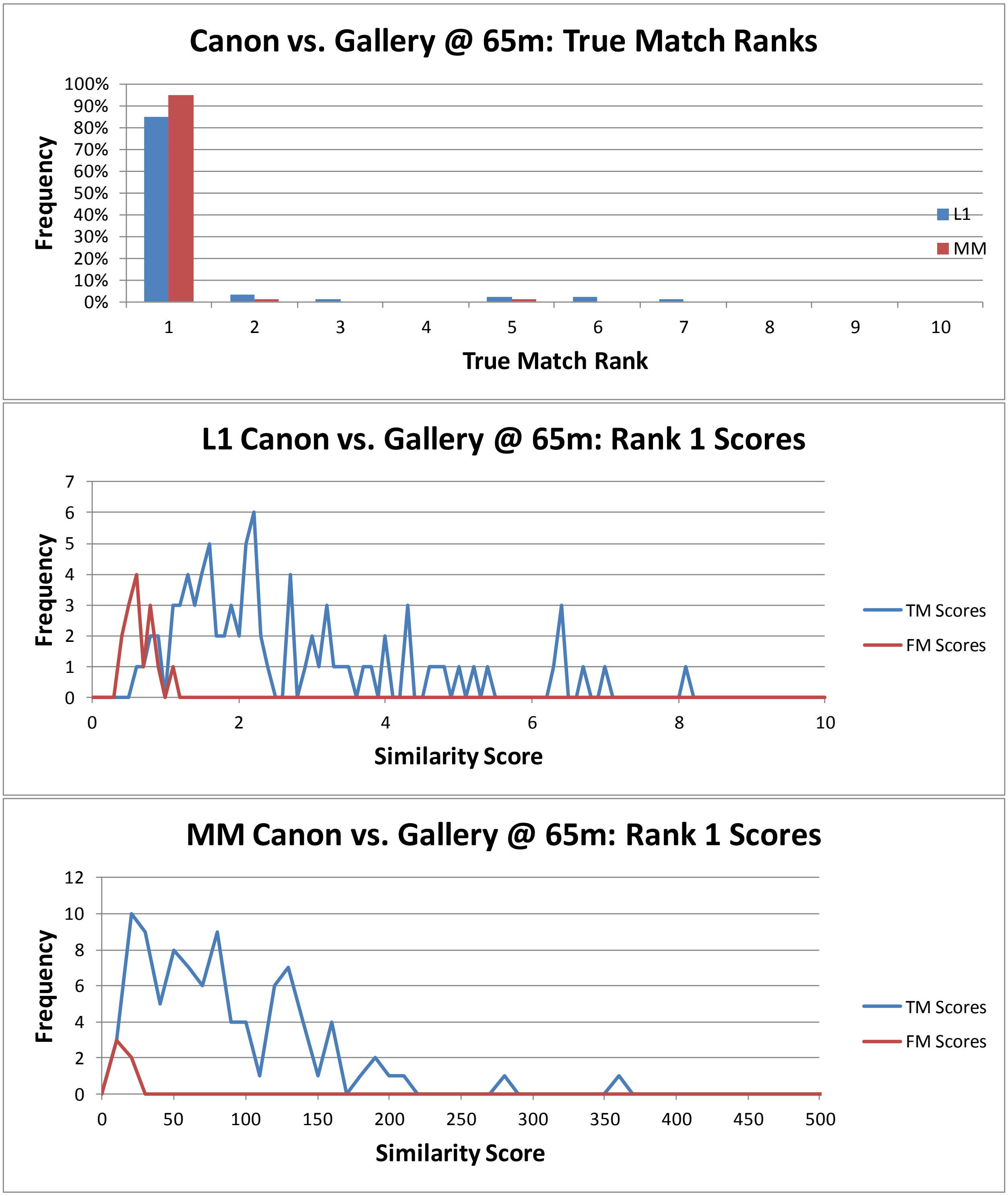


Figure 11: Canon 800mm vs. Gallery @ 65m Matching Results

5.2.4 Canon, 75 m

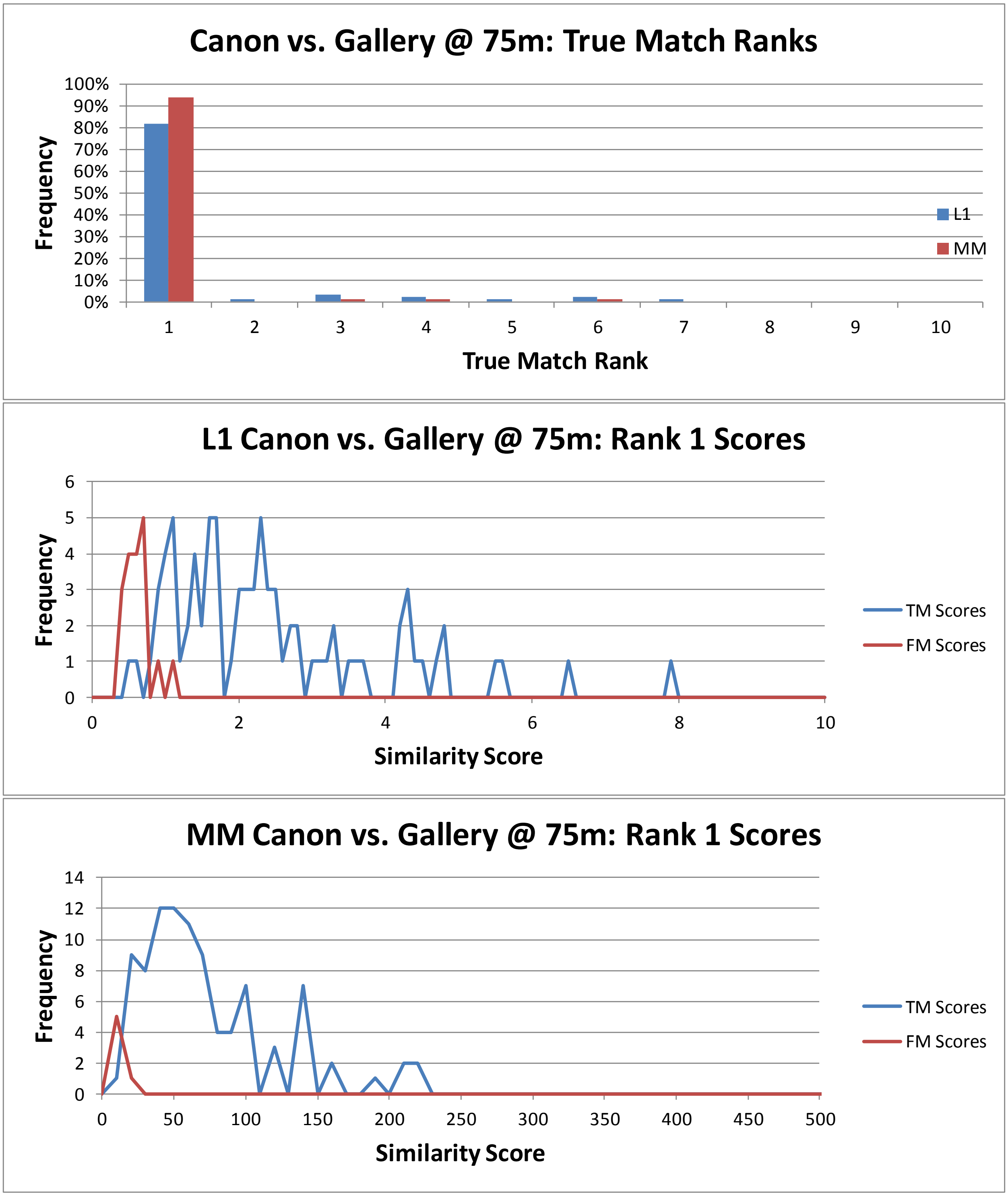
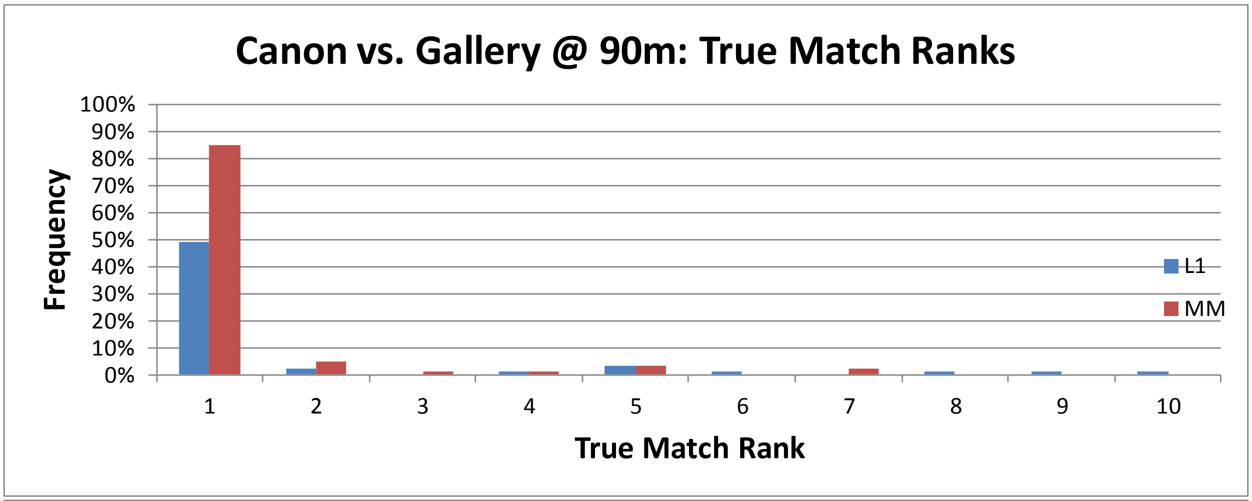
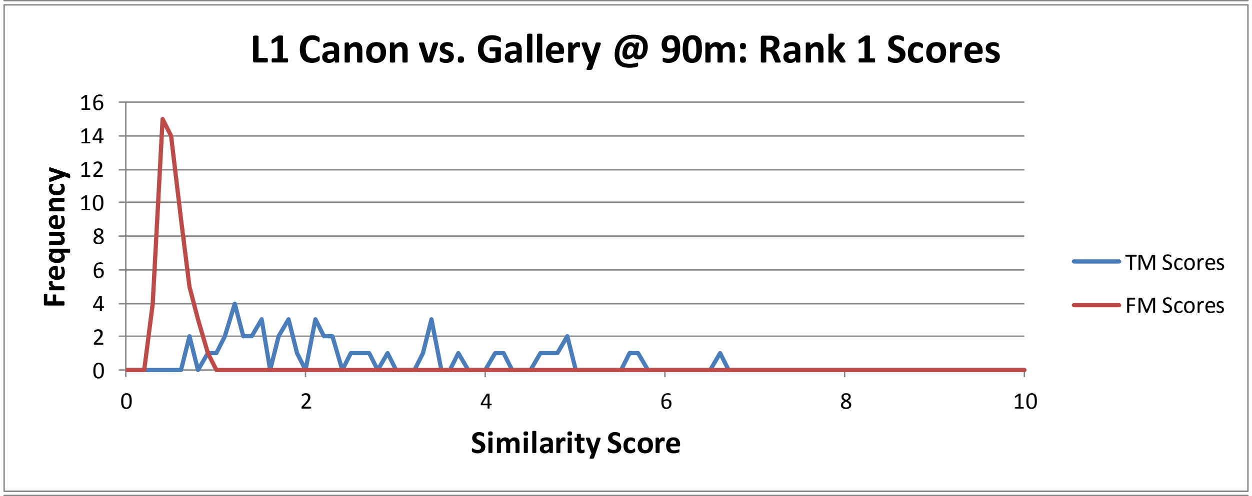


Figure 12: Canon 800mm vs. Gallery @ 75m Matching Results

5.2.5 Canon, 90 m





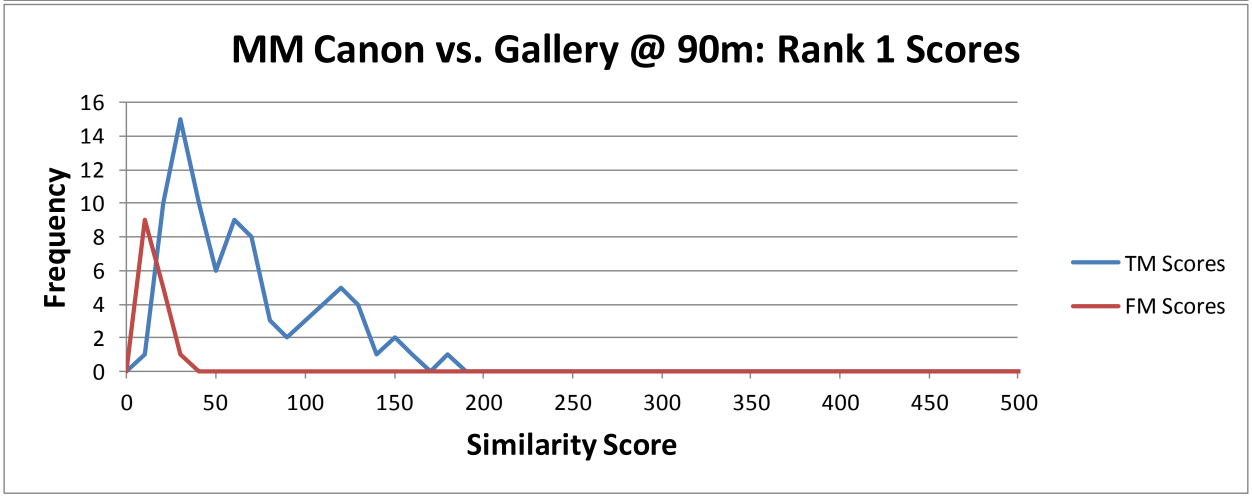


Figure 13: Canon 800mm vs. Gallery @ 90m Matching Results

5.2.6 Canon, 100 m

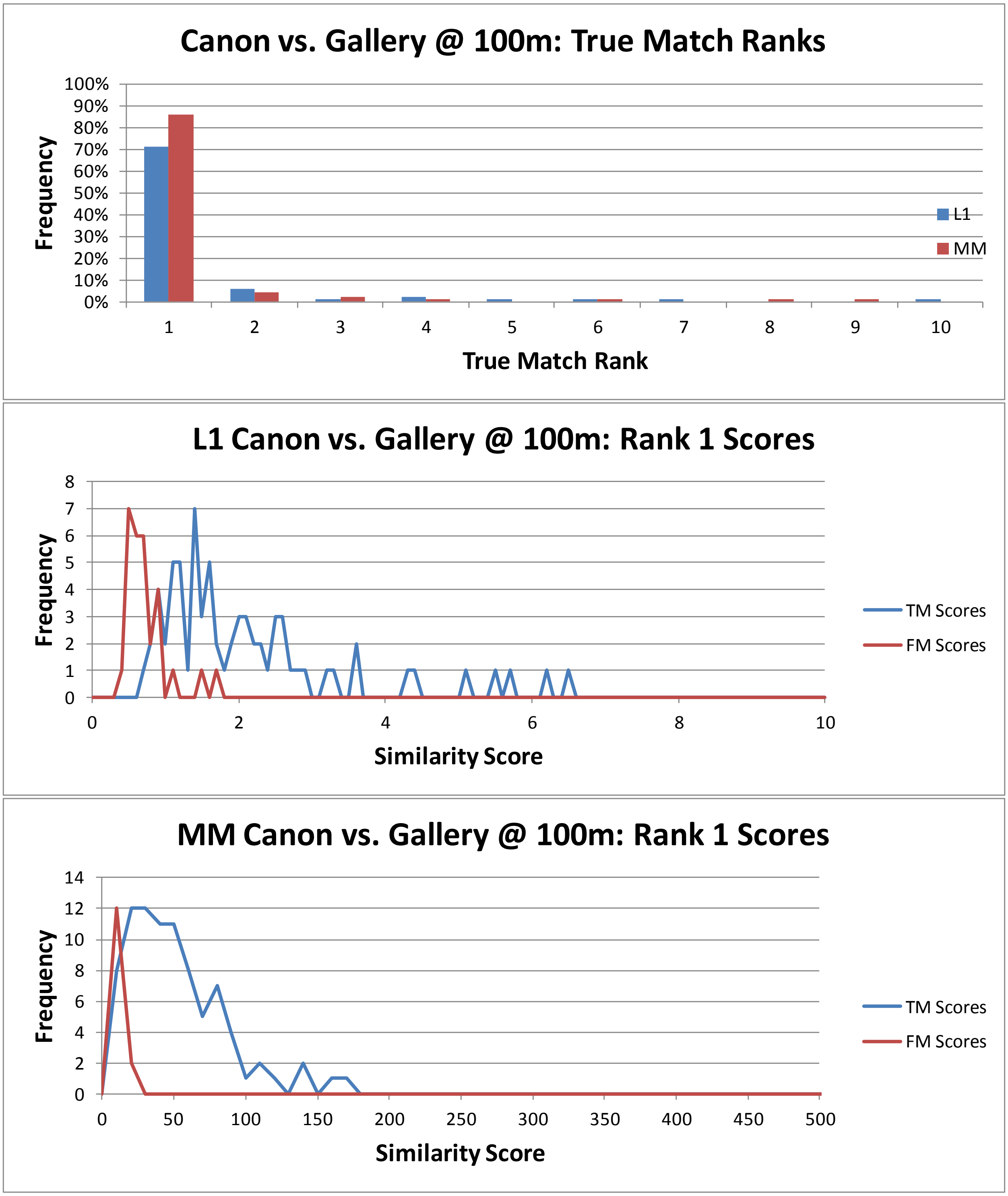


Figure 14: Canon 800mm vs. Gallery @ 100m Matching Results

5.2.7 Canon, 125 m

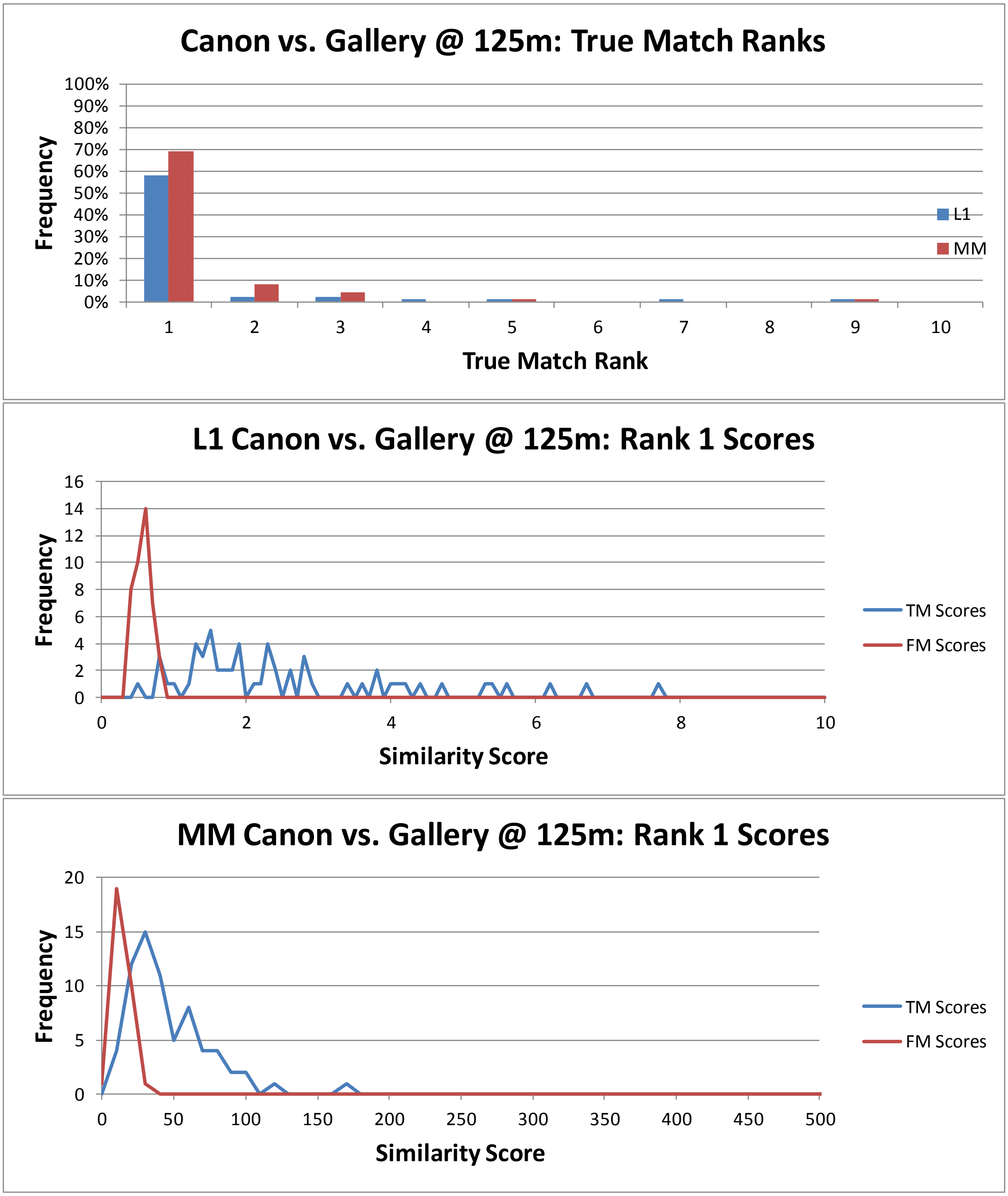


Figure 15: Canon 800mm vs. Gallery @ 125m Matching Results

5.3 SVI 3DMobileID Matching Runs

5.3.1 Tripod Mode

5.3.1.1 Tripod Mode, All Left Images

Table 10: SVI Gen2 Tripod Mode All Left vs. Gallery Matching Results

	L1		MM		L1		MM	
Range	**TMR**	**FMR**	**TMR**	**FMR**	**True Score**	**False Score**	**True Score**	**False Score**
35m	0.7%	99.3%	48.3%	51.7%	0.8 ± 0.2	0.8 ± 0.2	32 ± 17	14 ± 5
50m	0.7%	99.3%	79.0%	21.0%	0.8 ± 0.1	0.7 ± 0.2	49 ± 31	12 ± 4
65m	0.5%	99.5%	71.2%	28.8%	0.61 ± 0.06	0.6 ± 0.1	38 ± 24	13 ± 4
75m	1.7%	98.3%	66.2%	33.8%	0.6 ± 0.2	0.6 ± 0.1	33 ± 22	13 ± 4
90m	0.7%	99.3%	50.7%	49.3%	0.5 ± 0.1	0.6 ± 0.1	27 ± 15	13 ± 4
100m	0.8%	99.2%	35.7%	64.3%	0.6 ± 0.1	0.7 ± 0.2	21 ± 9	13 ± 4
125m	1.2%	98.8%	9.5%	90.5%	0.8 ± 0.3	0.7 ± 0.2	18 ± 5	13 ± 4

Table 11: SVI Gen2 Tripod All Left vs. Gallery, L1 Matching Run Statistics

L1	Gallery		Probe			Matches		
Range	**Total**	**Unique Subjects**	**Submit**	**Accepted**	**Unique Subjects**	**True Matches**	**False Matches**	**Total Matches**
35m	100	100	588	588	98	4	584	58800
50m	100	100	600	600	100	4	596	60000
65m	100	100	594	594	99	3	591	59400
75m	100	100	600	600	100	10	590	60000
90m	100	100	594	594	99	4	590	59400
100m	100	100	594	594	99	5	589	59400
125m	100	100	600	600	100	7	593	60000

Table 12: SVI Gen2 Tripod All Left vs. Gallery, MM Matching Run Statistics

MM	Gallery		Probe			Matches		
Range	**Total**	**Unique Subjects**	**Submit**	**Accepted**	**Unique Subjects**	**True Matches**	**False Matches**	**Total Matches**
35m	100	100	588	588	98	284	304	58800
50m	100	100	600	600	100	474	126	60000
65m	100	100	594	594	99	423	171	59400
75m	100	100	600	600	100	397	203	60000
90m	100	100	594	594	99	301	293	59400
100m	100	100	594	594	99	212	382	59400
125m	100	100	600	600	100	57	543	60000

5.3.1.1.1 SVI, Tripod, All Left, 35 m

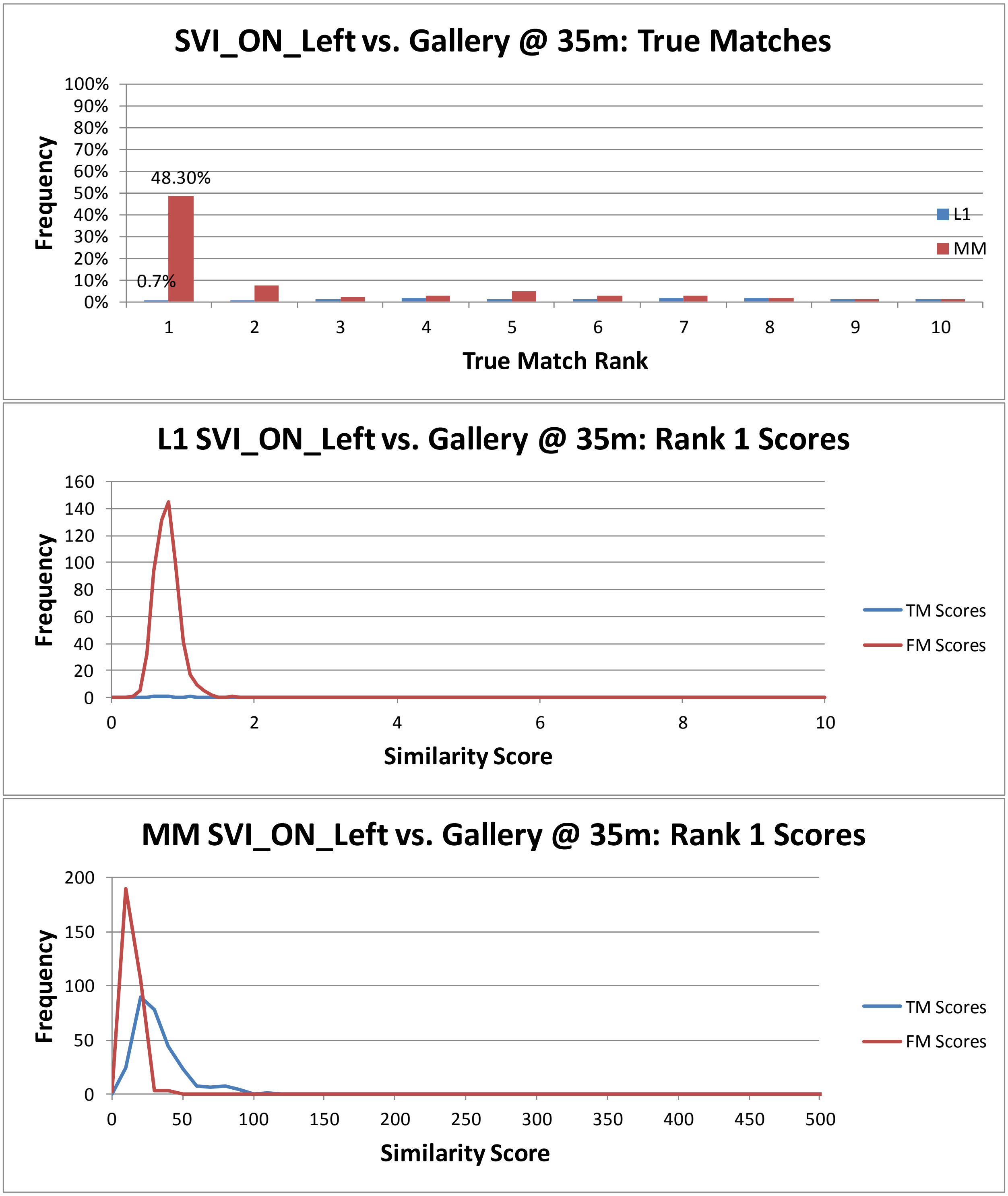


Figure 16: SVI Gen2 Tripod Left vs. Gallery @ 35m Matching Results

5.3.1.1.2 SVI, Tripod, All Left, 50 m

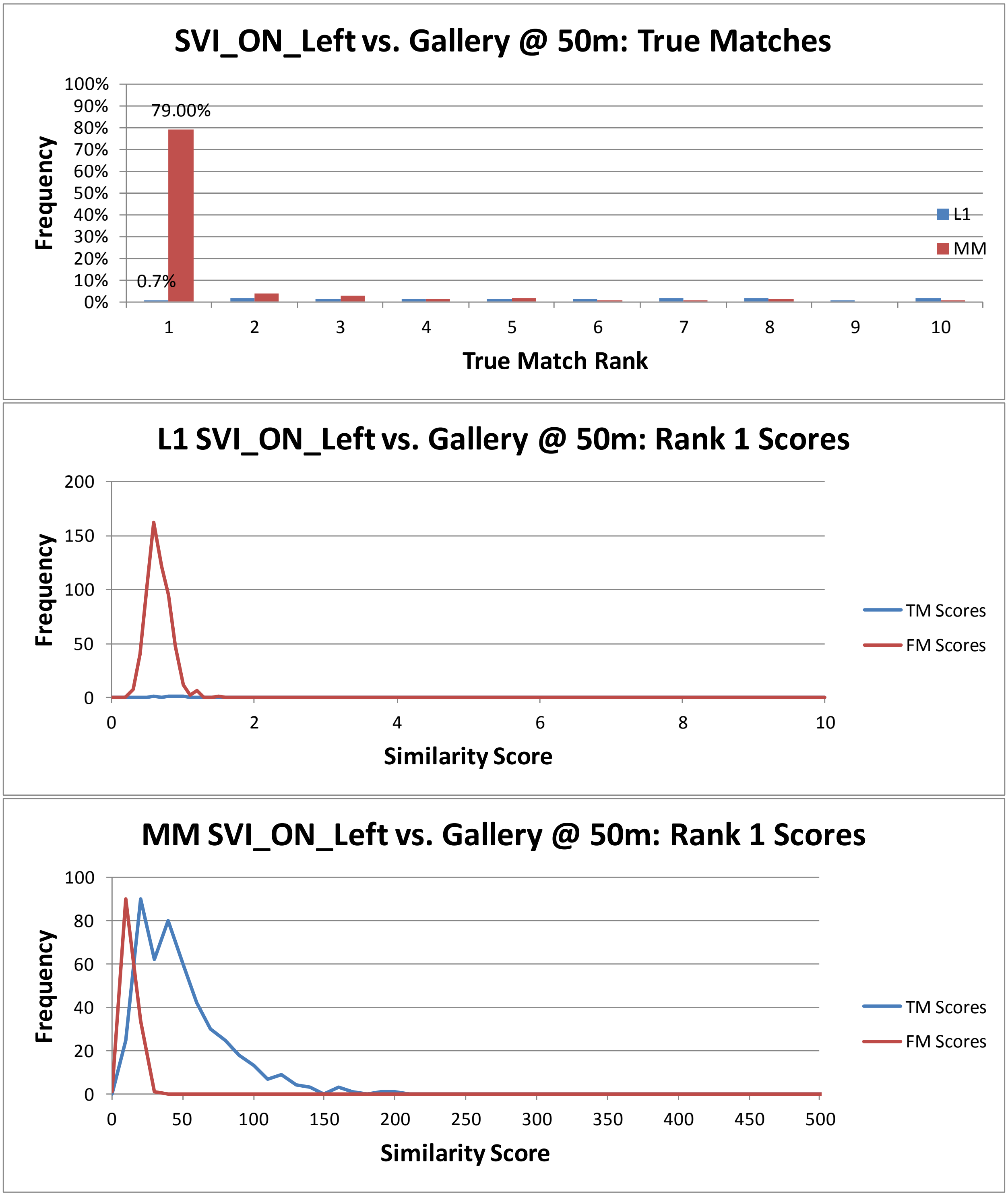


Figure 17: SVI Gen2 Tripod Left vs. Gallery @ 50m Matching Results

5.3.1.1.3 SVI, Tripod, All Left, 65 m

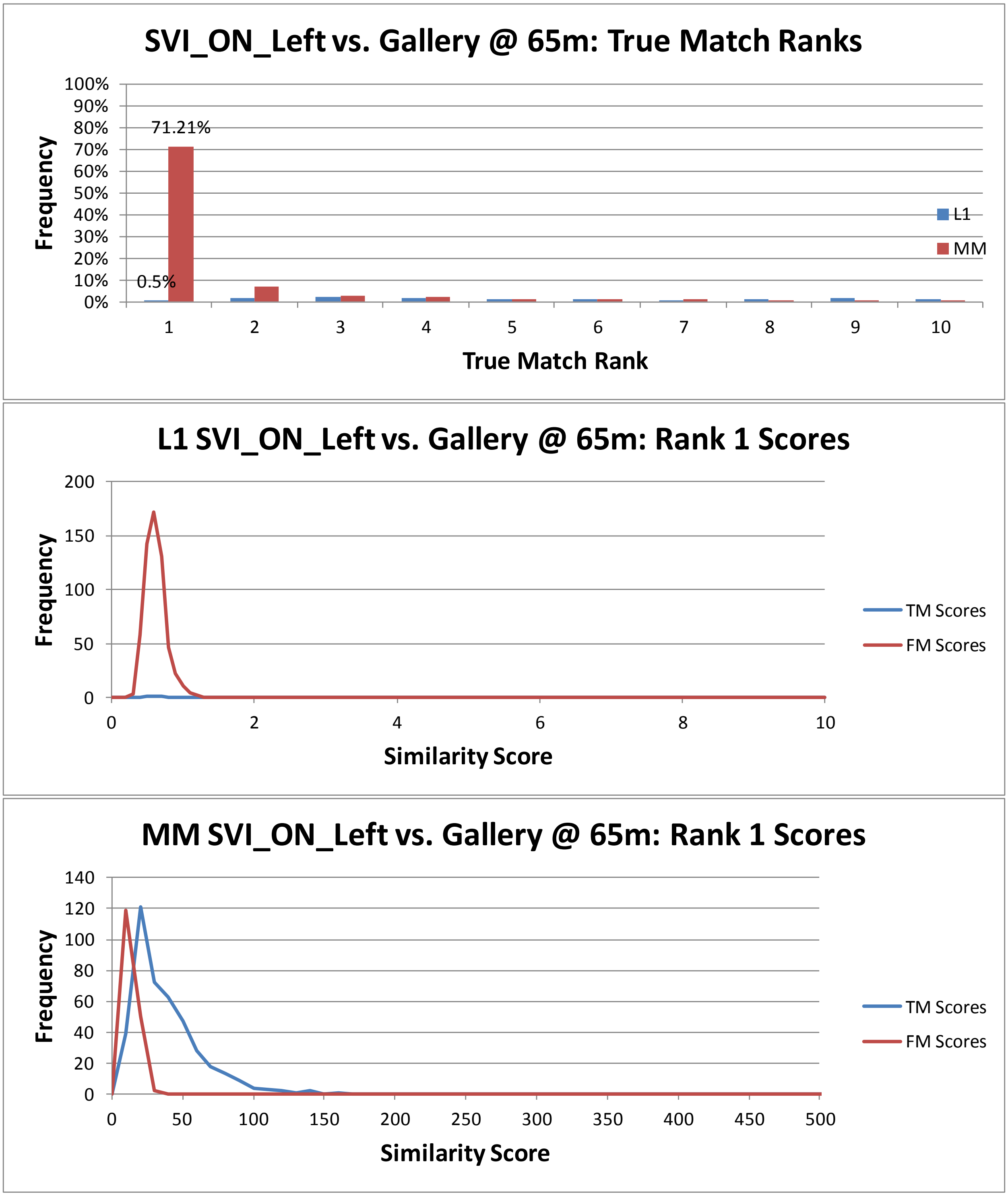


Figure 18: SVI Gen2 Tripod Left vs. Gallery @ 65m Matching Results

5.3.1.1.4 SVI, Tripod, All Left, 75 m

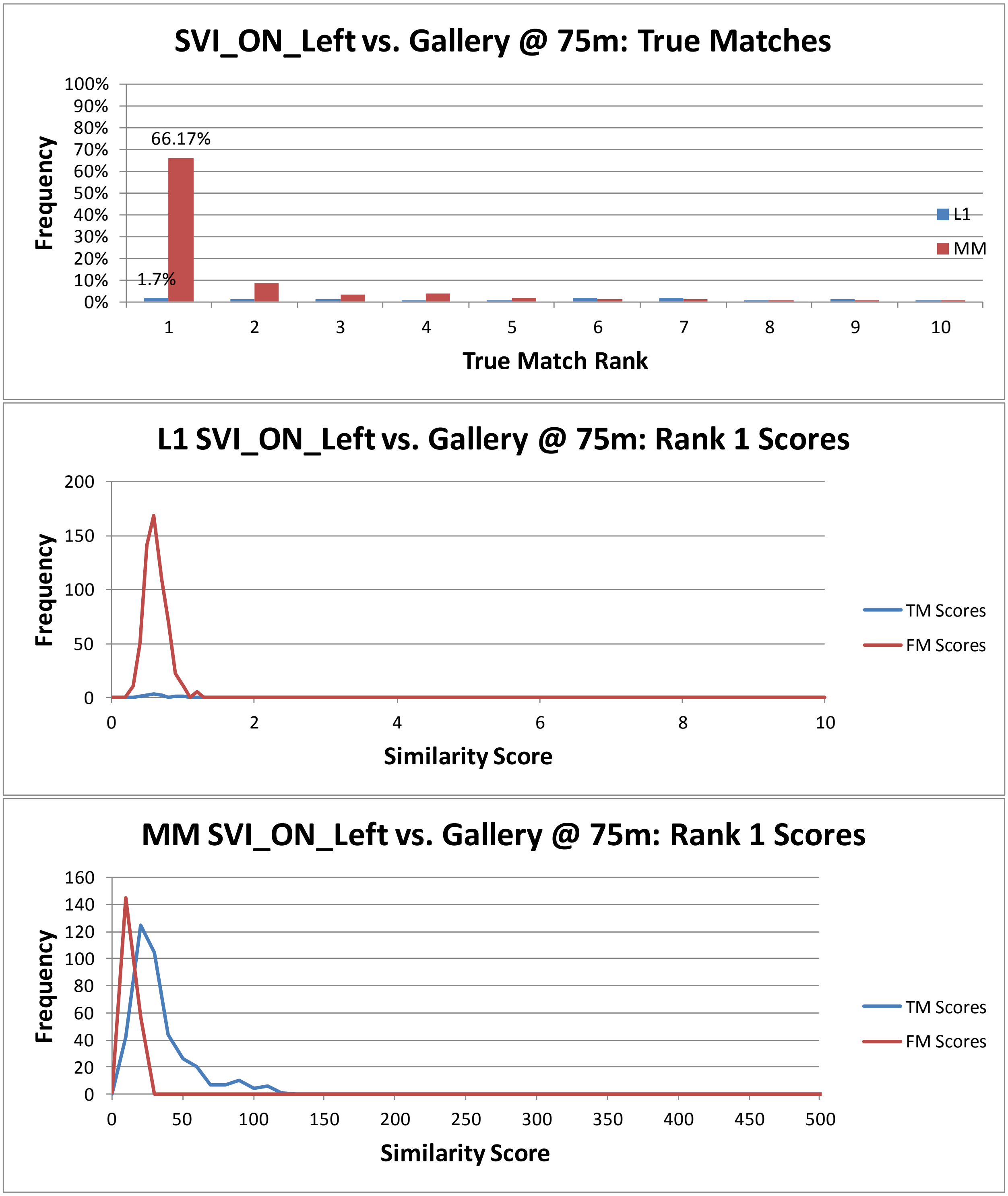


Figure 19: SVI Gen2 Tripod Left vs. Gallery @ 75m Matching Results

5.3.1.1.5 SVI, Tripod, All Left, 90 m

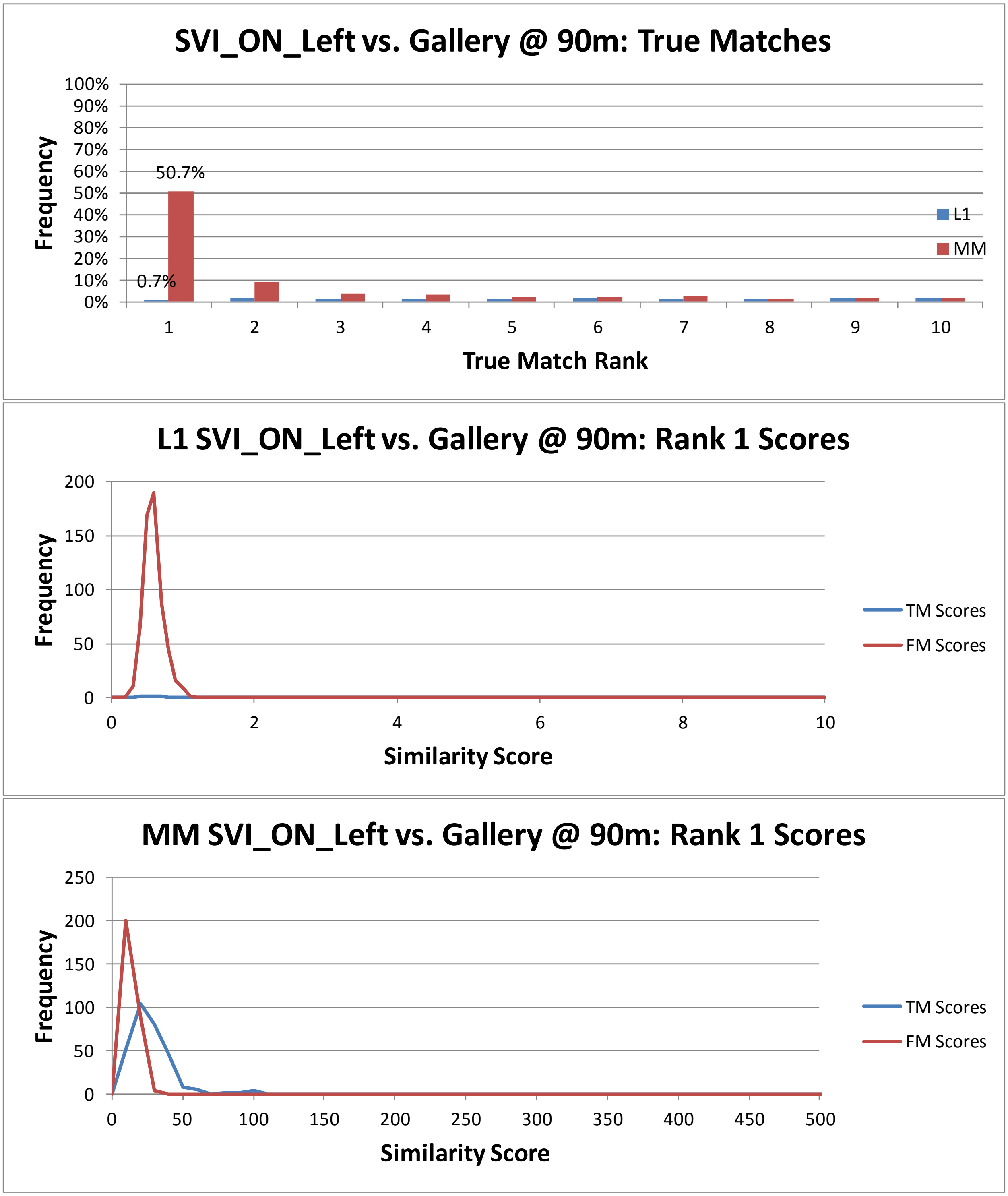


Figure 20: SVI Gen2 Tripod Left vs. Gallery @ 90m Matching Results

5.3.1.1.6 SVI, Tripod, All Left, 100 m

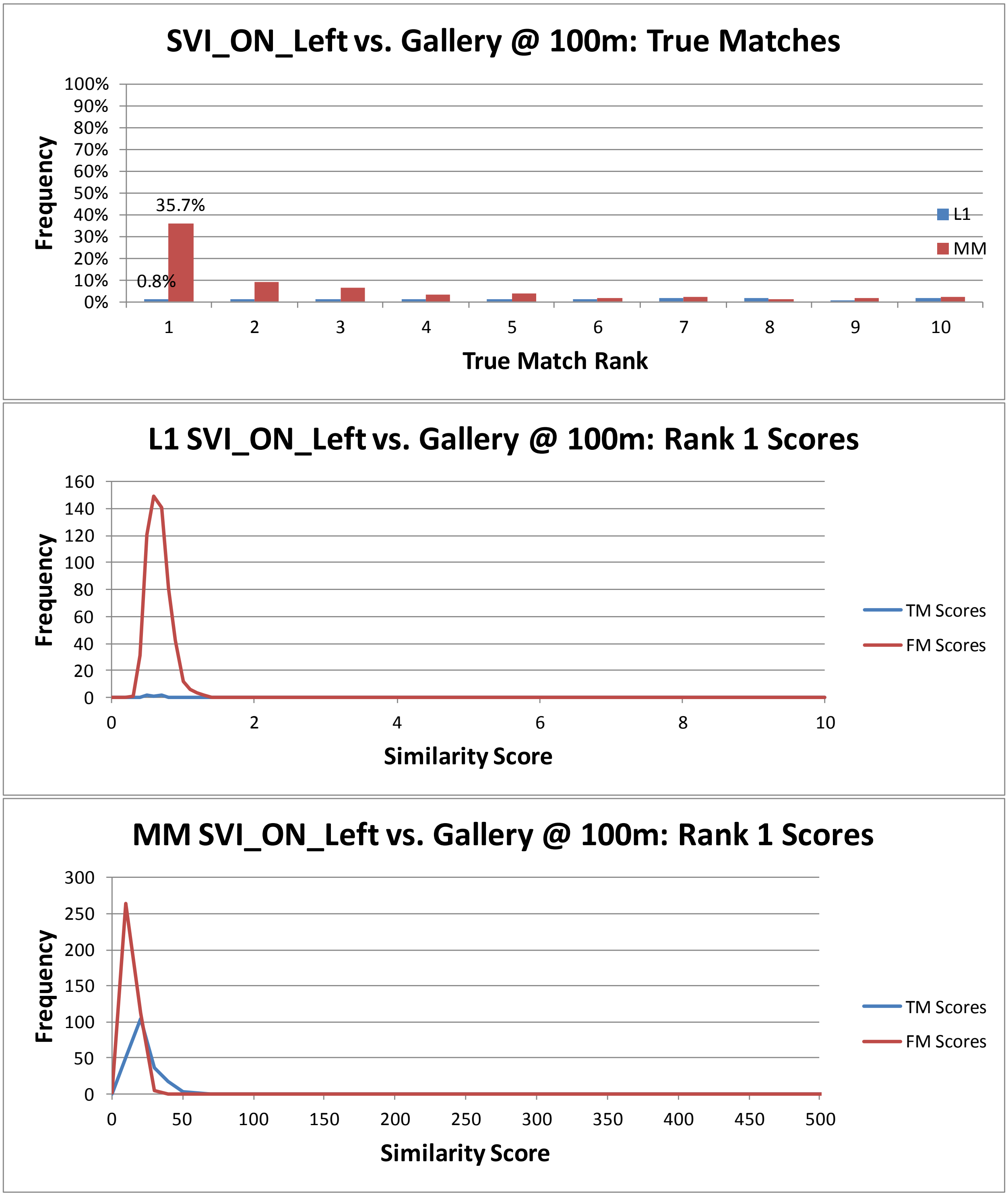


Figure 21: SVI Gen2 Tripod Left vs. Gallery @ 100m Matching Results

5.3.1.1.7 SVI, Tripod, All Left, 125 m

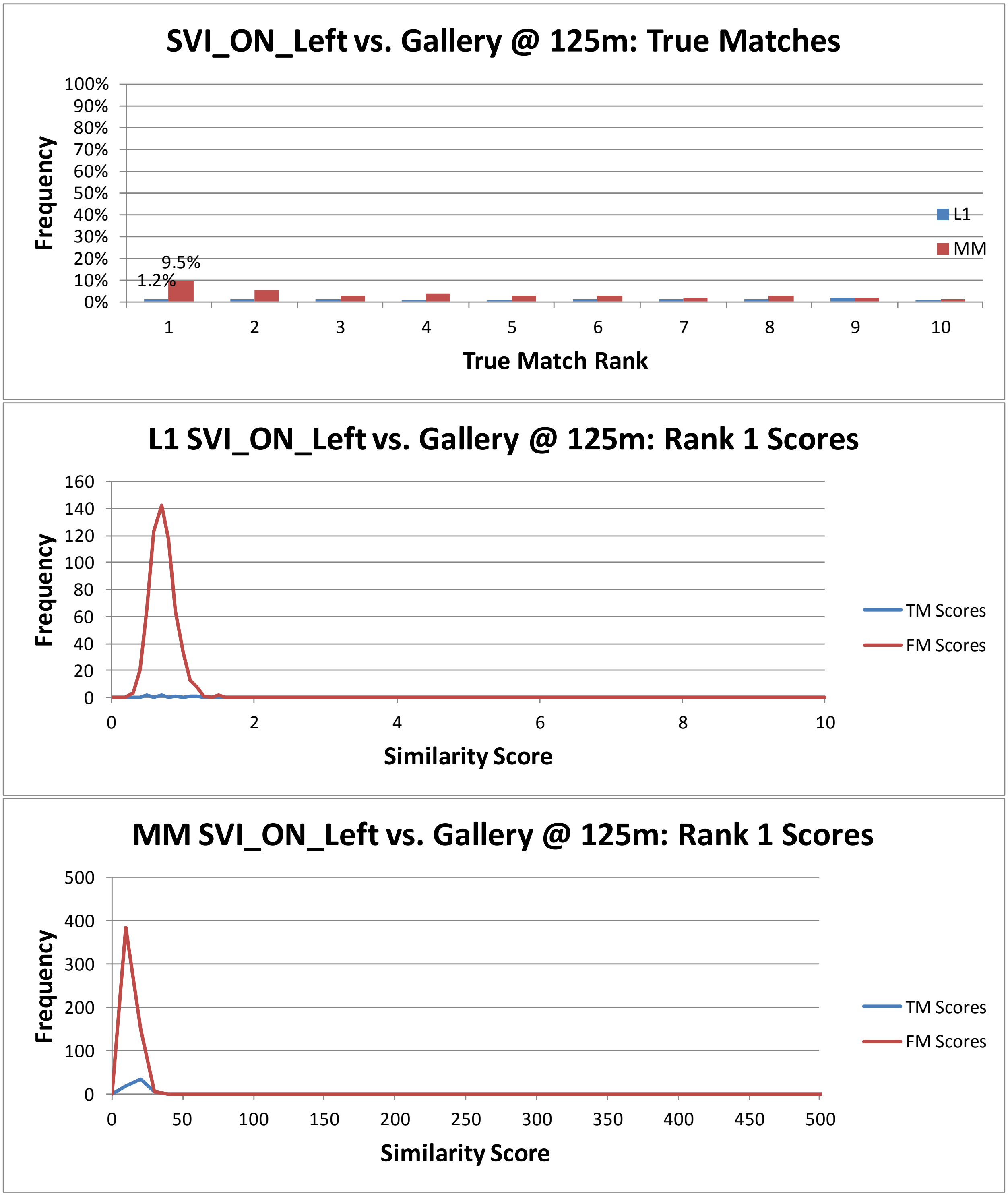


Figure 22: SVI Gen2 Tripod Left vs. Gallery @ 125m Matching Results

5.3.1.2 Tripod Mode, All Right Images

Table 13: SVI Gen2 Tripod Mode All Right vs. Gallery Matching Results

	L1		MM		L1		MM	
Range	TMR	FMR	TMR	FMR	True Score	False Score	True Score	False Score
35m	0.9%	99.1%	56.5%	43.5%	0.8 ± 0.2	0.7 ± 0.2	31 ± 17	13 ± 5
50m	1.5%	98.5%	77.5%	22.5%	0.66 ± 0.09	0.7 ± 0.2	50 ± 31	12 ± 4
65m	0.8%	99.2%	68.9%	31.1%	0.62 ± 0.05	0.62 ± 0.1	37 ± 21	12 ± 4
75m	1.5%	98.5%	59.0%	41.0%	0.5 ± 0.1	0.6 ± 0.1	29 ± 16	13 ± 4
90m	0.8%	99.2%	37.2%	62.8%	0.6 ± 0.1	0.6 ± 0.1	24 ± 11	14 ± 4
100m	1.9%	98.1%	28.6%	71.4%	0.6 ± 0.2	0.7 ± 0.2	22 ± 9	14 ± 4
125m	0.8%	99.2%	8.0%	92.0%	0.8 ± 0.2	0.7 ± 0.2	18 ± 6	13 ± 4

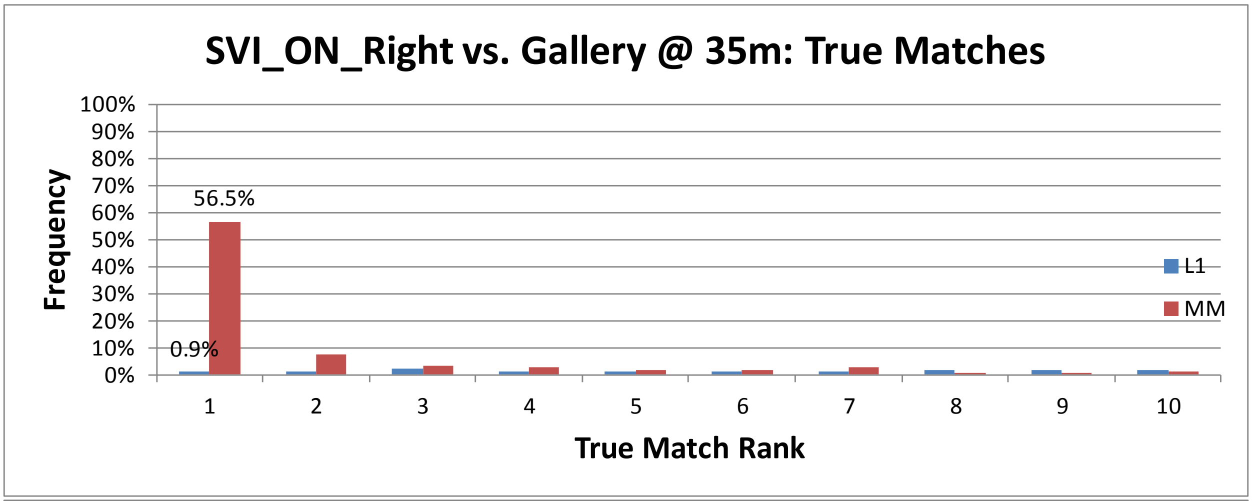
Table 14: SVI Gen2 Tripod All Right vs. Gallery, L1 Matching Run Statistics

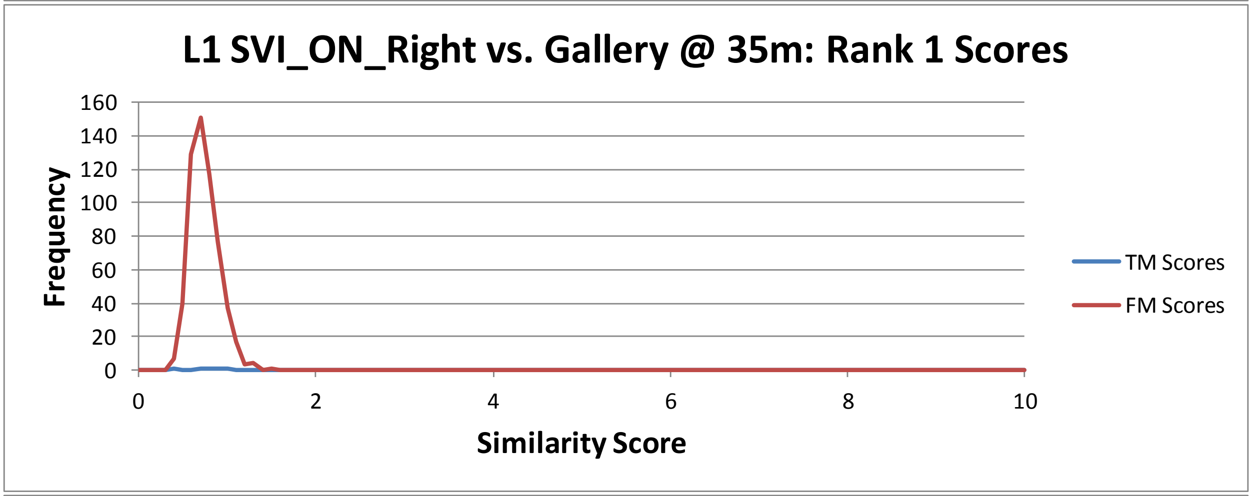
L1	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
35m	100	100	588	588	98	5	583	58800
50m	100	100	600	600	100	9	591	60000
65m	100	100	594	594	99	5	589	59400
75m	100	100	600	600	100	9	591	60000
90m	100	100	594	594	99	5	589	59400
100m	100	100	594	594	99	11	583	59400
125m	100	100	600	600	100	5	595	60000

Table 15: SVI Gen2 Tripod All Right vs. Gallery, MM Matching Run Statistics

MM	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
35m	100	100	588	588	98	332	256	58800
50m	100	100	600	600	100	465	135	60000
65m	100	100	594	594	99	409	185	59400
75m	100	100	600	600	100	354	246	60000
90m	100	100	594	594	99	221	373	59400
100m	100	100	594	594	99	170	424	59400
125m	100	100	600	600	100	48	552	60000

5.3.1.2.1 SVI, Tripod, All Right, 35 m





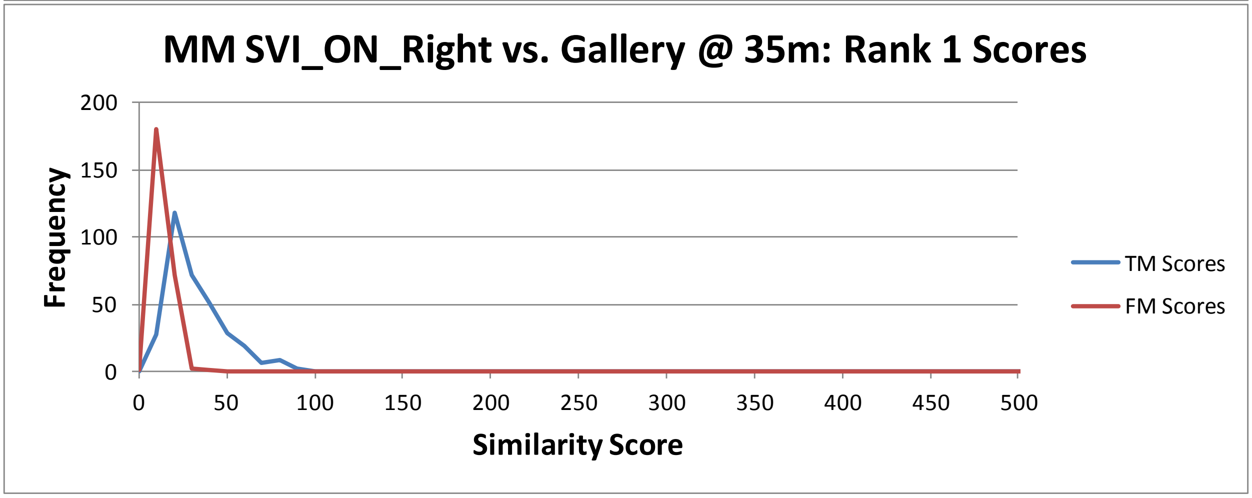


Figure 23: SVI Gen2 Tripod Right vs. Gallery @ 35m Matching Results

5.3.1.2.2 SVI, Tripod, All Right, 50 m

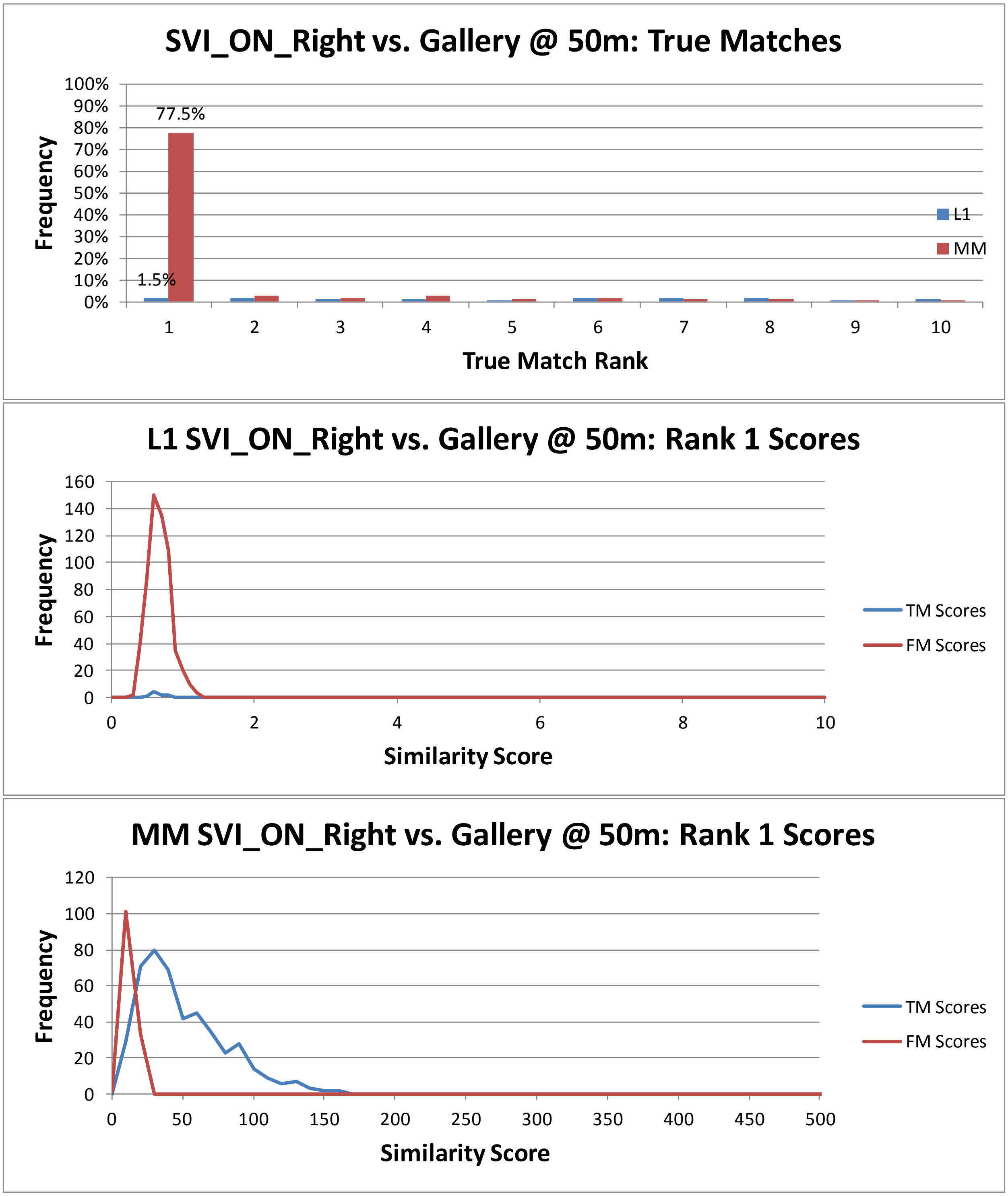


Figure 24: SVI Gen2 Tripod Right vs. Gallery @ 50m Matching Results

5.3.1.2.3 SVI, Tripod, All Right, 65 m

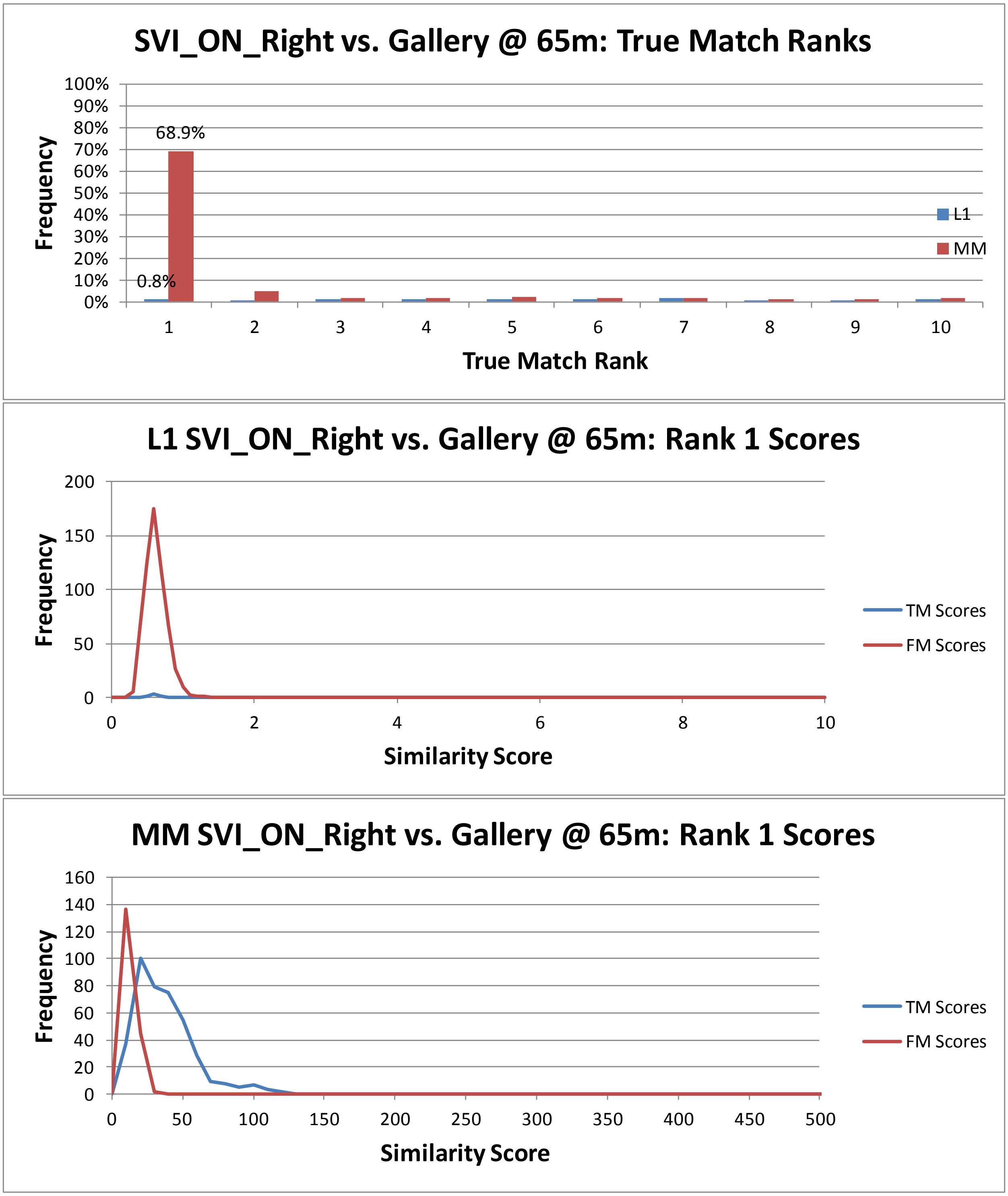


Figure 25: SVI Gen2 Tripod Right vs. Gallery @ 65m Matching Results

5.3.1.2.4 SVI, Tripod, All Right, 75 m

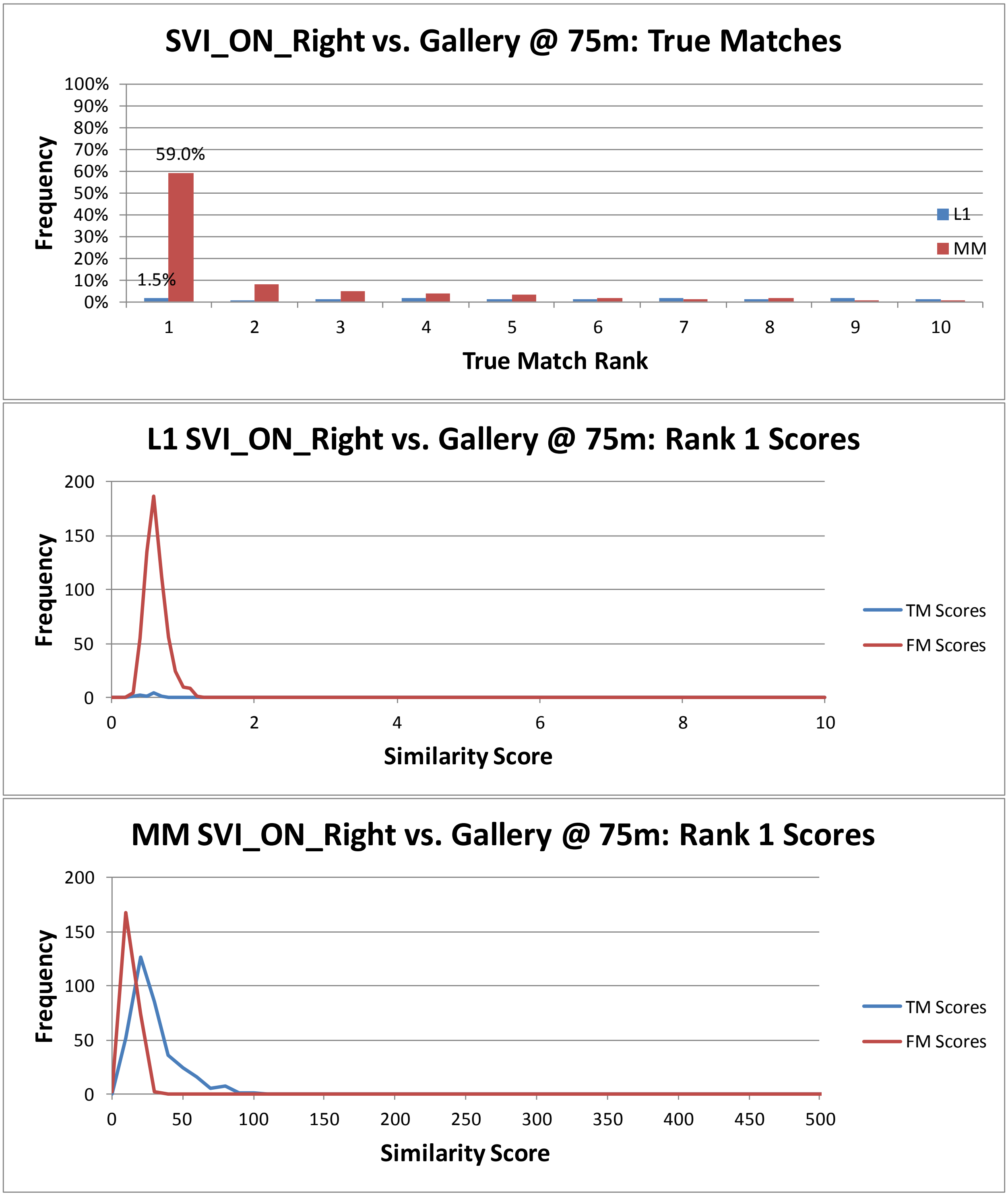
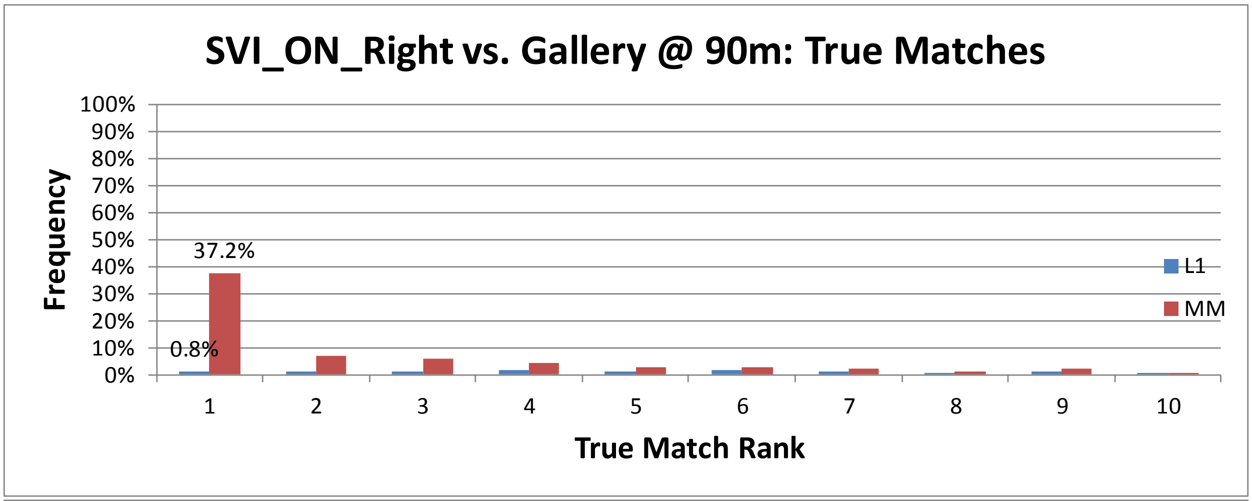
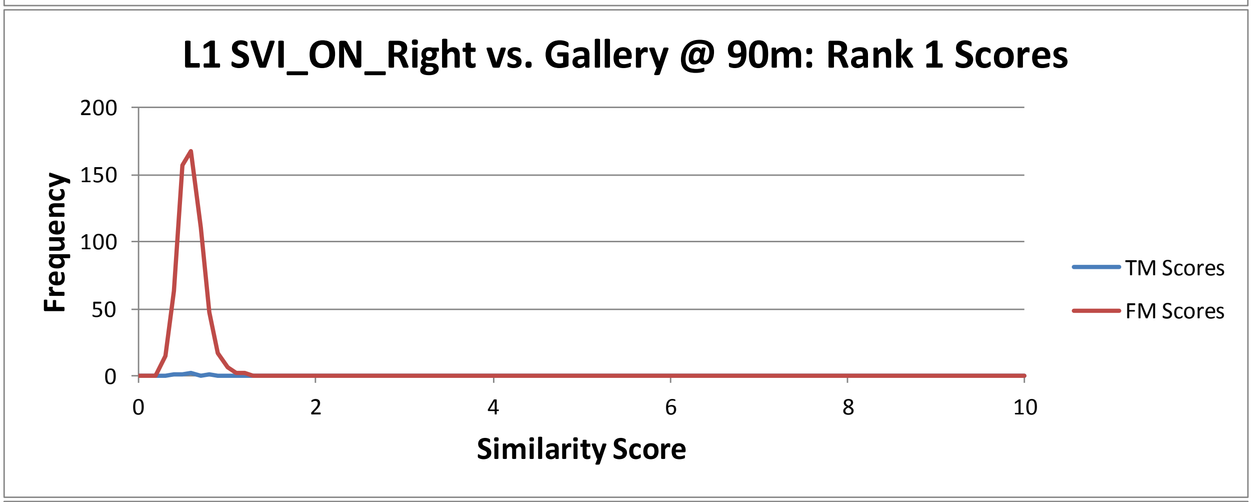


Figure 26: SVI Gen2 Tripod Right vs. Gallery @ 75m Matching Results

5.3.1.2.5 SVI, Tripod, All Right, 90 m





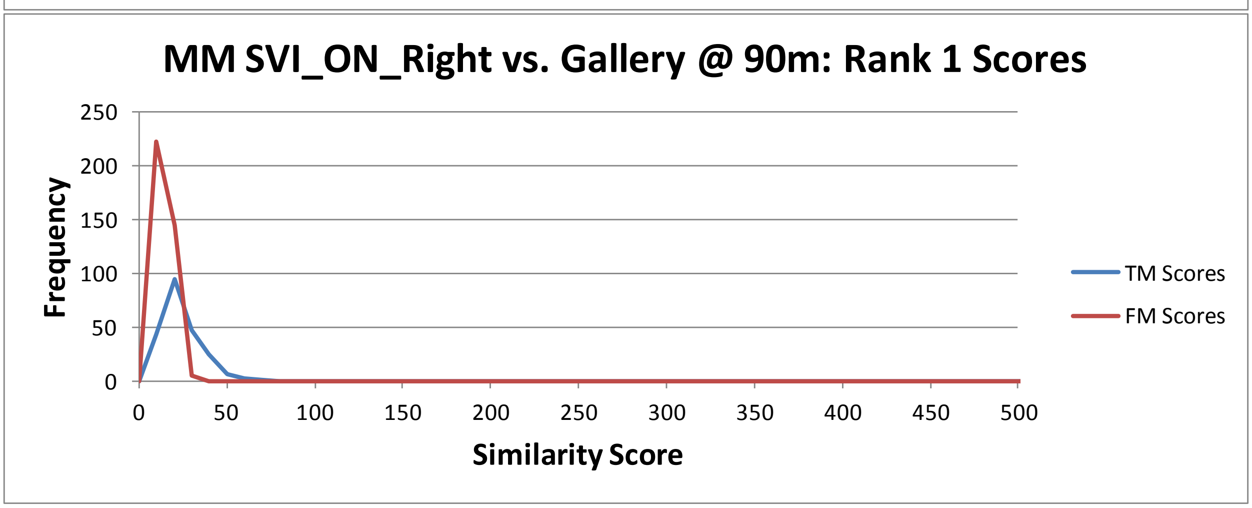


Figure 27: SVI Gen2 Tripod Right vs. Gallery @ 90m Matching Results

5.3.1.2.6 SVI, Tripod, All Right, 100 m

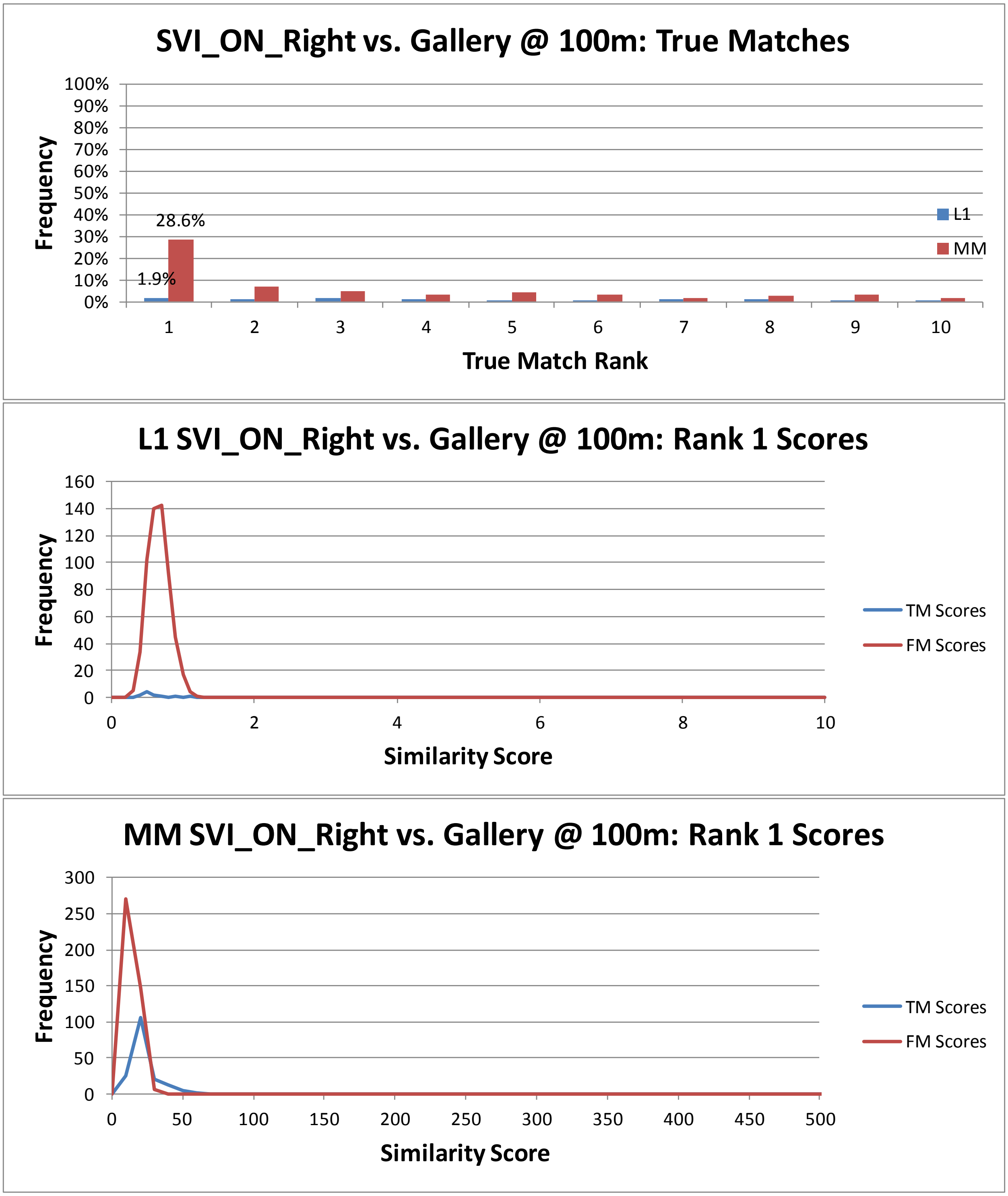


Figure 28: SVI Gen2 Tripod Right vs. Gallery @ 100m Matching Results

5.3.1.2.7 SVI, Tripod, All Right, 125 m

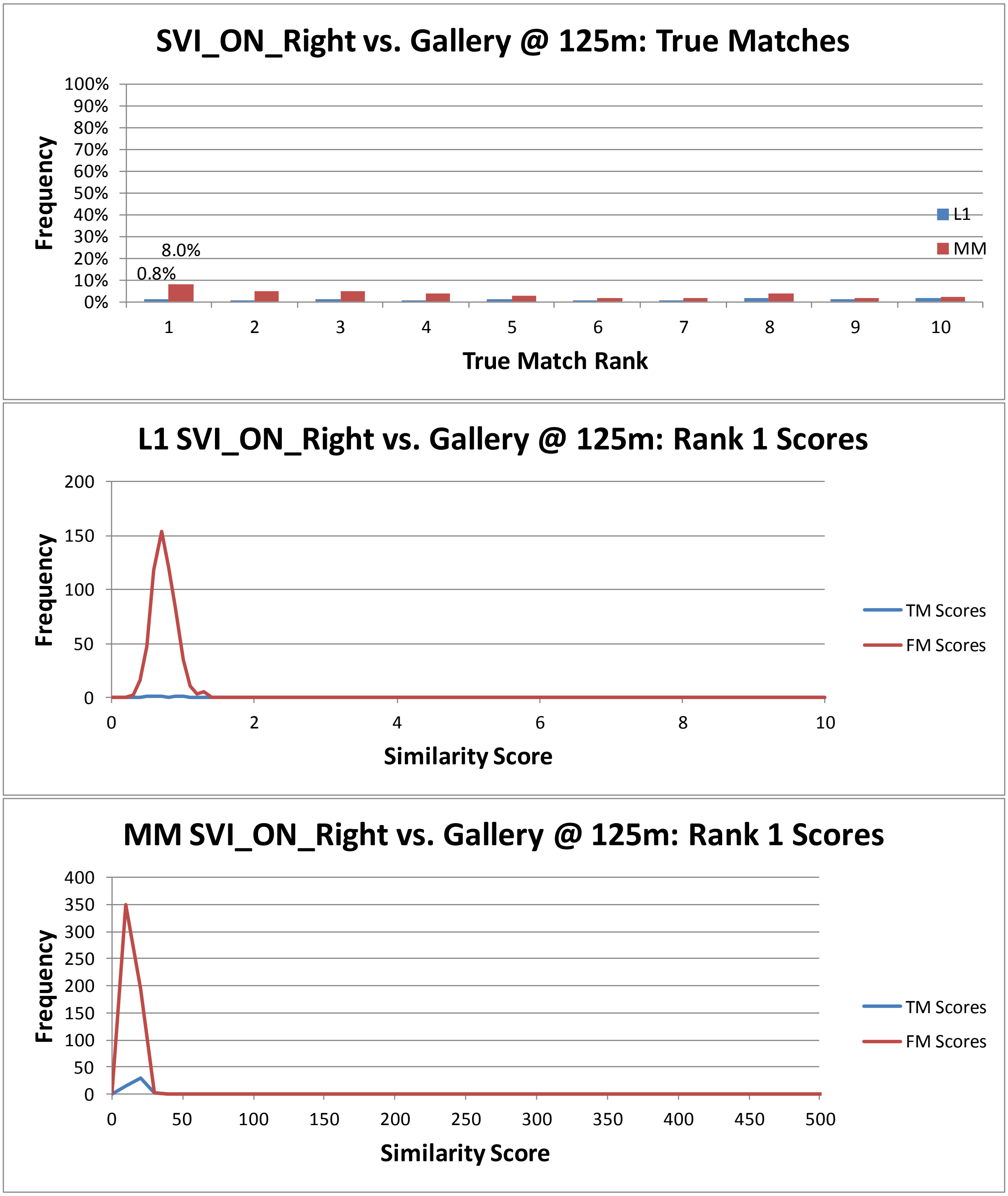


Figure 29: SVI Gen2 Tripod Right vs. Gallery @ 125m Matching Results

5.3.1.3 Tripod Mode, All Occluded Images

Table 16: SVI Gen2 Tripod Mode All Occluded vs. Gallery Matching Results

	L1		MM			L1		MM	
Range	TMR	FMR	TMR	FMR	NMR	True Score	False Score	True Score	False Score
35m	27.9%	72.1%	25.7%	47.6%	26.7%	1 ± 1	0.7 ± 0.1	29 ± 18	12 ± 5
50m	54.2%	45.8%	58.8%	35.0%	6.0%	2 ± 1	0.7 ± 0.2	48 ± 31	11 ± 4
65m	64.6%	35.4%	62.4%	35.0%	2.5%	2 ± 1	0.6 ± 0.2	38 ± 25	12 ± 4
75m	64.0%	36.0%	57.2%	42.0%	0.8%	1.5 ± 0.9	0.7 ± 0.2	33 ± 21	13 ± 4
90m	56.7%	43.3%	47.5%	52.2%	0.3%	1.4 ± 0.7	0.6 ± 0.2	27 ± 14	13 ± 4
100m	50.0%	50.0%	36.4%	60.9%	2.7%	1.2 ± 0.7	0.6 ± 0.2	21 ± 9	13 ± 4
125m	32.3%	67.7%	9.0%	78.5%	12.5%	1 ± 0.4	0.6 ± 0.2	17 ± 5	13 ± 4

Table 17: SVI Gen2 Tripod All Occluded vs. Gallery, L1 Matching Run Statistics

L1	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
35m	100	100	588	588	98	164	424	58800
50m	100	100	600	600	100	325	275	60000
65m	100	100	594	594	99	384	210	59400
75m	100	100	600	600	100	384	216	60000
90m	100	100	594	594	99	337	257	59400
100m	100	100	594	594	99	297	297	59400
125m	100	100	600	600	100	194	406	60000

Table 18: SVI Gen2 Tripod All Occluded vs. Gallery, MM Matching Run Statistics

MM	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
35m	100	100	588	431	85	151	280	43100
50m	100	100	600	563	98	353	210	56300
65m	100	100	594	585	99	365	220	58500
75m	100	100	600	595	100	343	252	59500
90m	100	100	594	592	99	282	310	59200
100m	100	100	594	578	99	216	362	57800
125m	100	100	600	525	95	54	471	52500

5.3.1.3.1 SVI, Tripod, All Occluded, 35 m

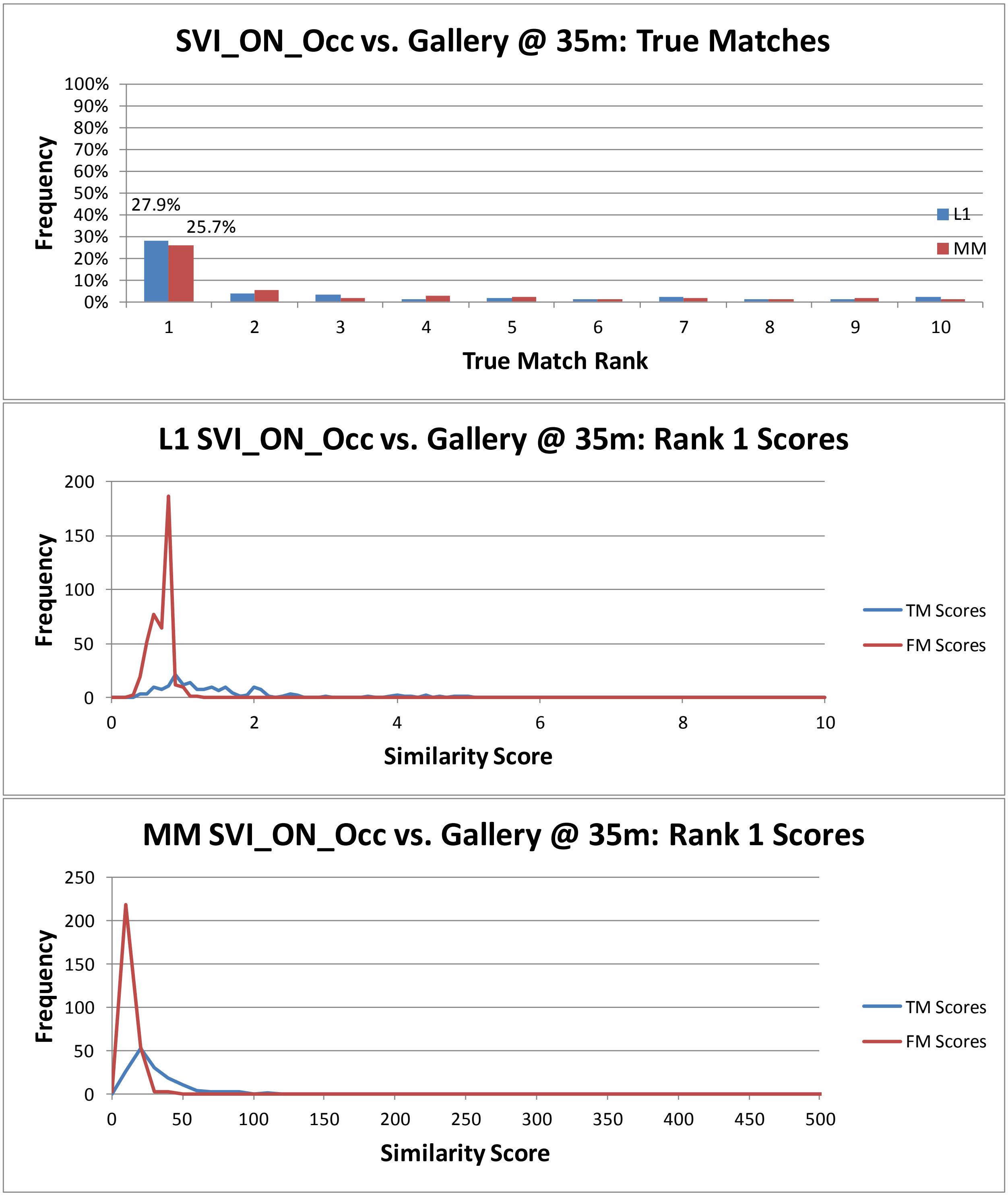


Figure 30: SVI Gen2 Tripod Occluded vs. Gallery @ 35m Matching Results

5.3.1.3.2 SVI, Tripod, All Occluded, 50 m

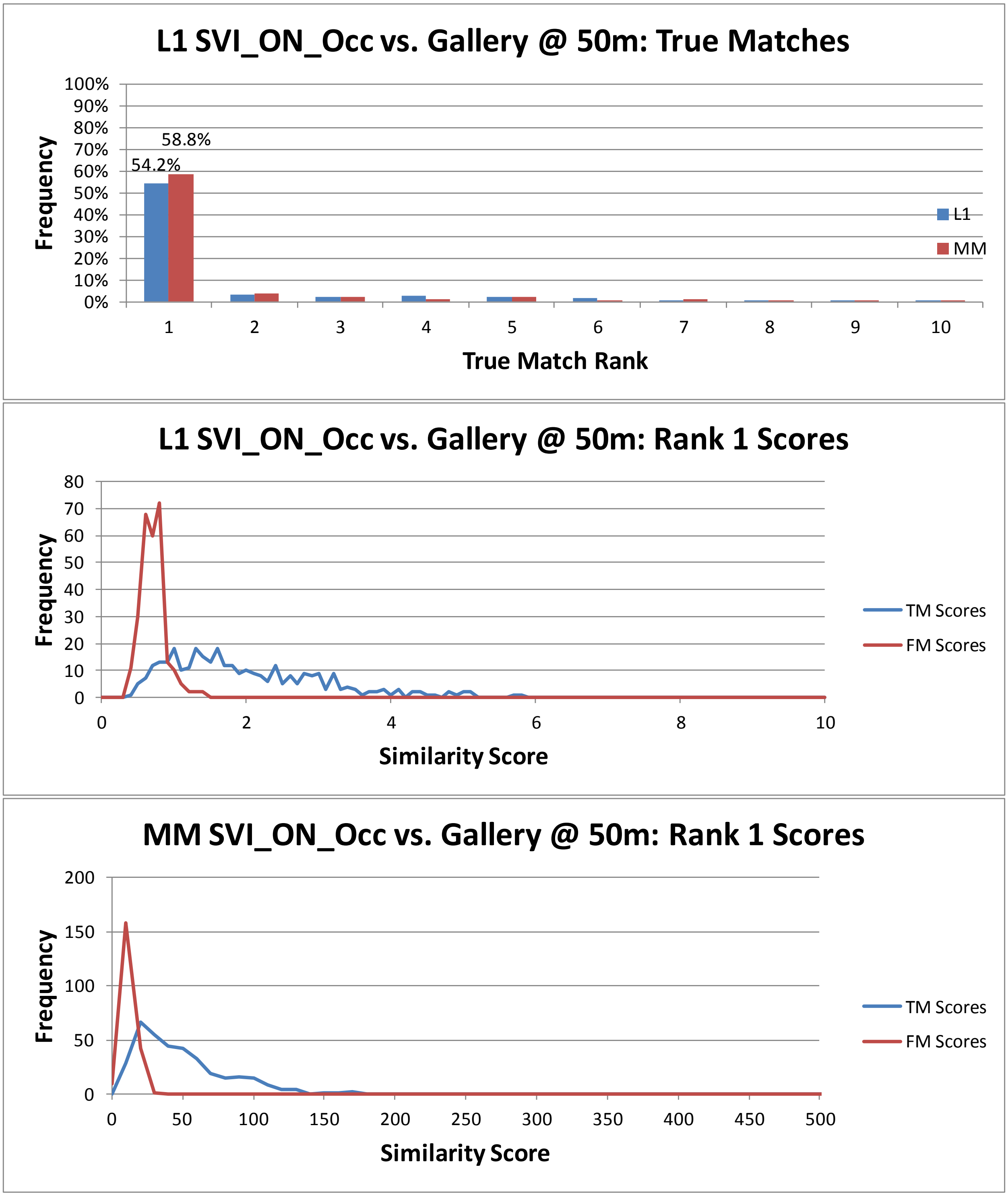


Figure 31: SVI Gen2 Tripod Occluded vs. Gallery @ 50m Matching Results

5.3.1.3.3 SVI, Tripod, All Occluded, 65 m

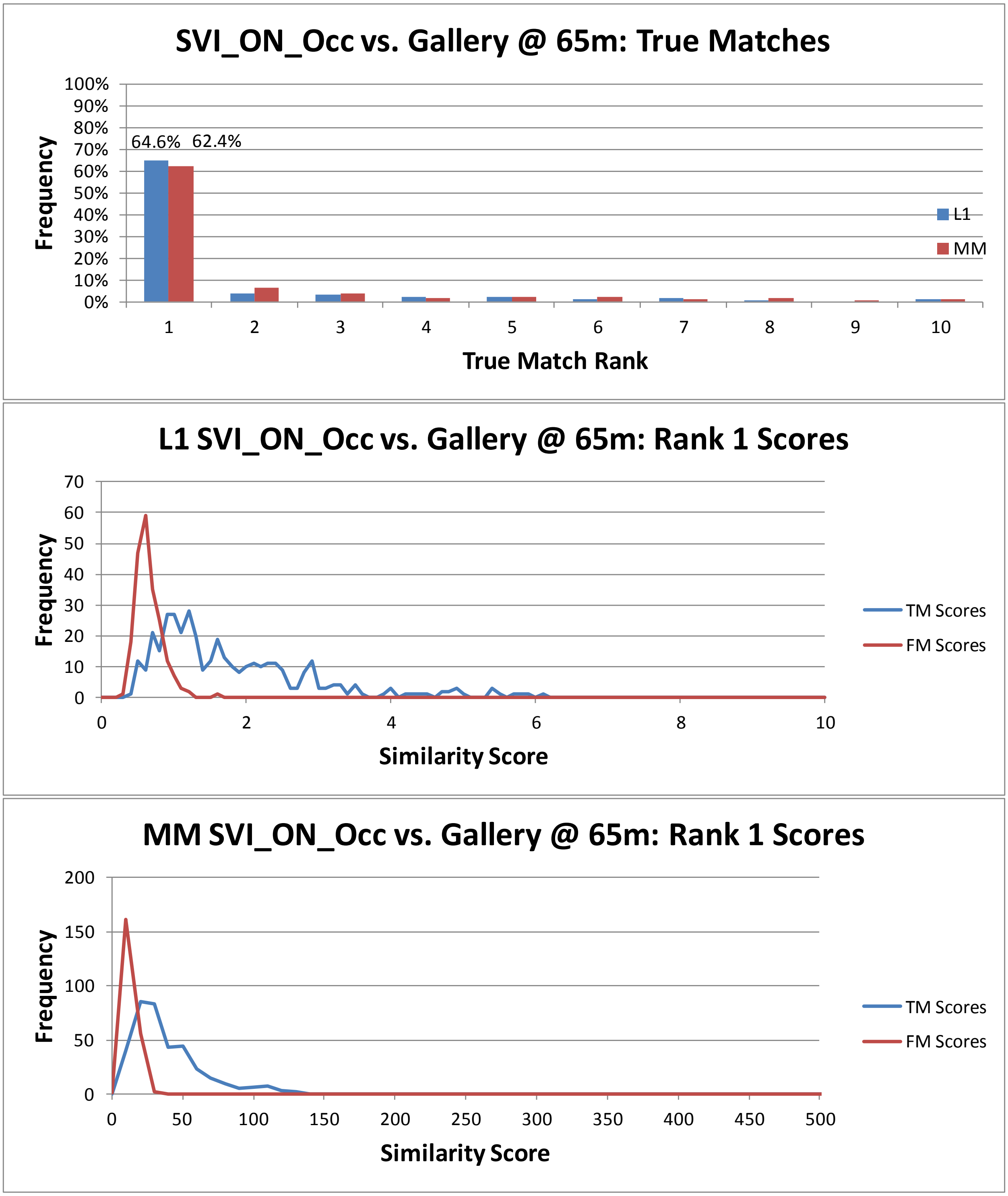
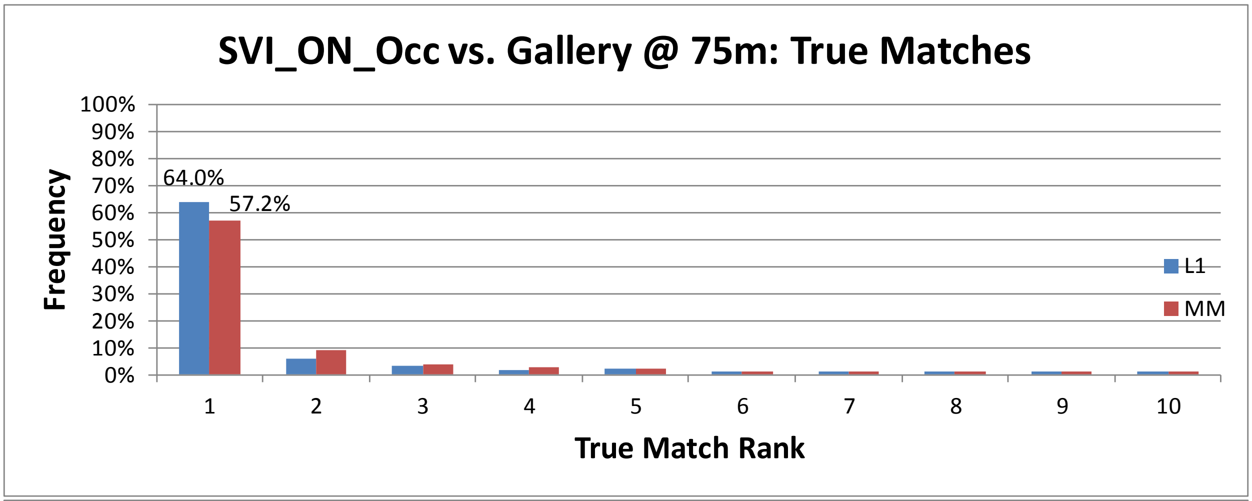
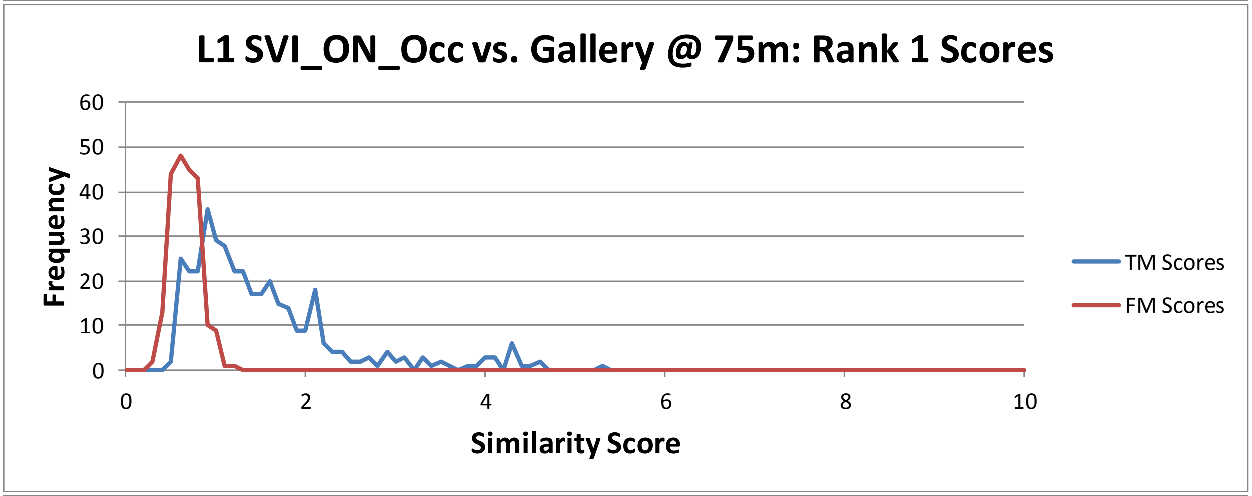


Figure 32: SVI Gen2 Tripod Occluded vs. Gallery @ 65m Matching Results

5.3.1.3.4 SVI, Tripod, All Occluded, 75 m





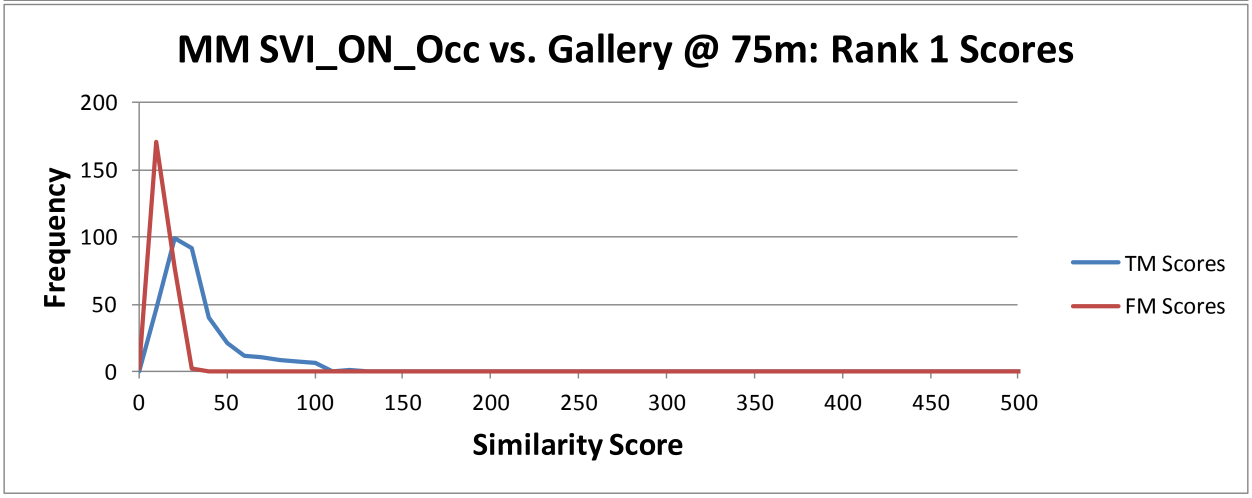


Figure 33: SVI Gen2 Tripod Occluded vs. Gallery @ 75m Matching Results

5.3.1.3.5 SVI, Tripod, All Occluded, 90 m

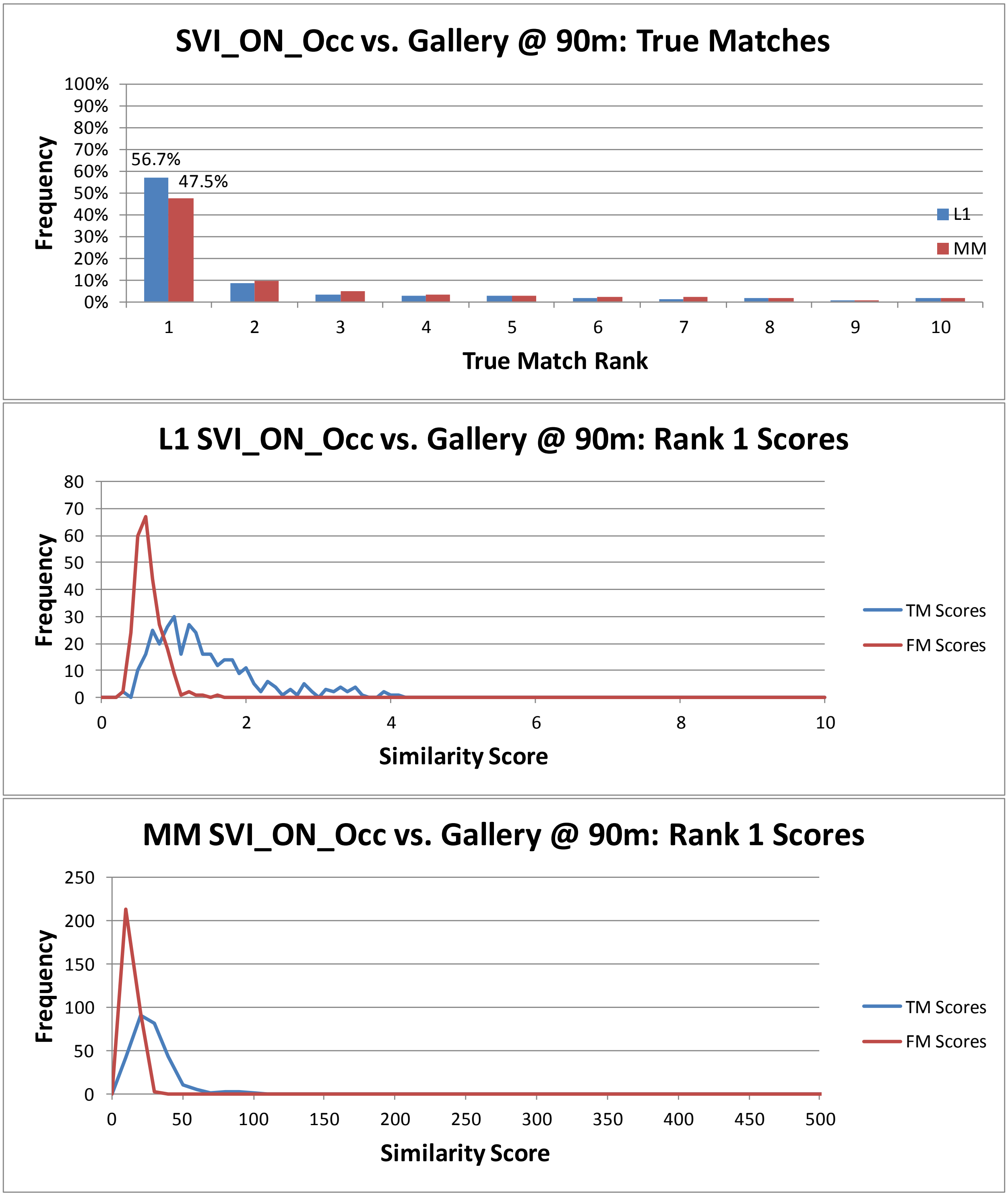
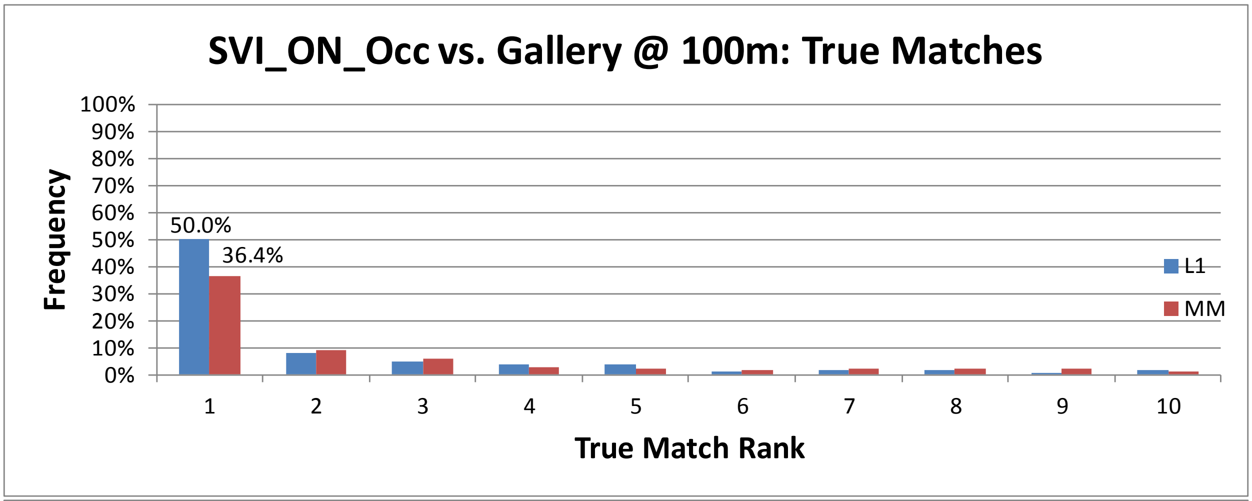
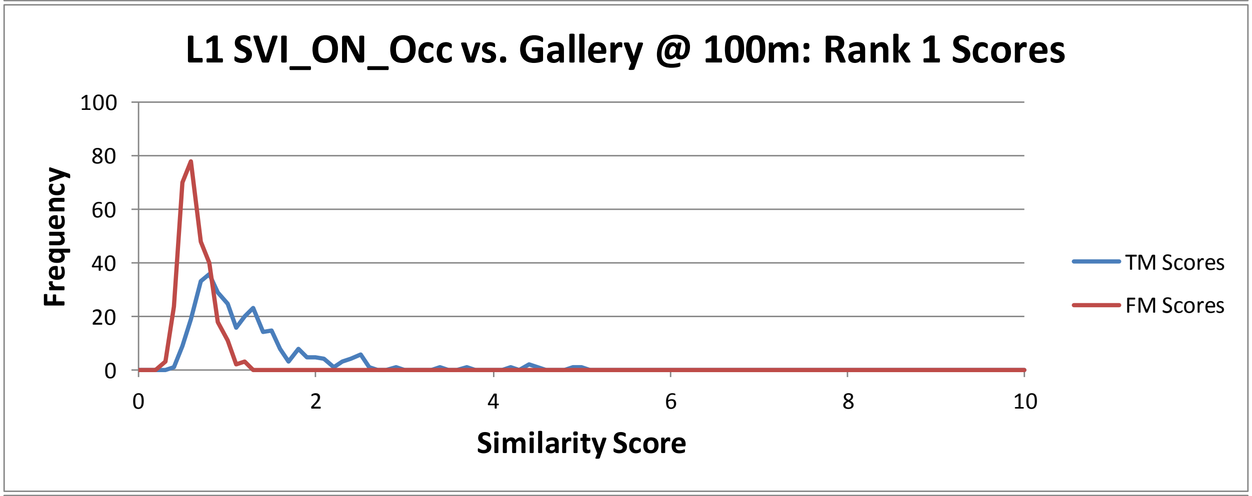


Figure 34: SVI Gen2 Tripod Occluded vs. Gallery @ 90m Matching Results

5.3.1.3.6 SVI, Tripod, All Occluded, 100 m





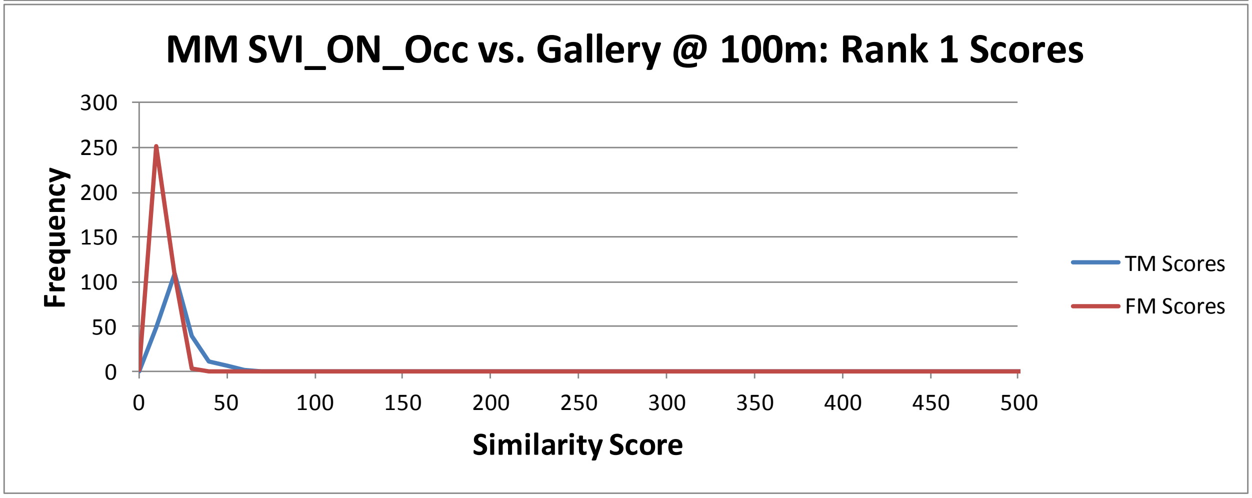


Figure 35: SVI Gen2 Tripod Occluded vs. Gallery @ 10m Matching Results

5.3.1.3.7 SVI, Tripod, All Occluded, 125 m

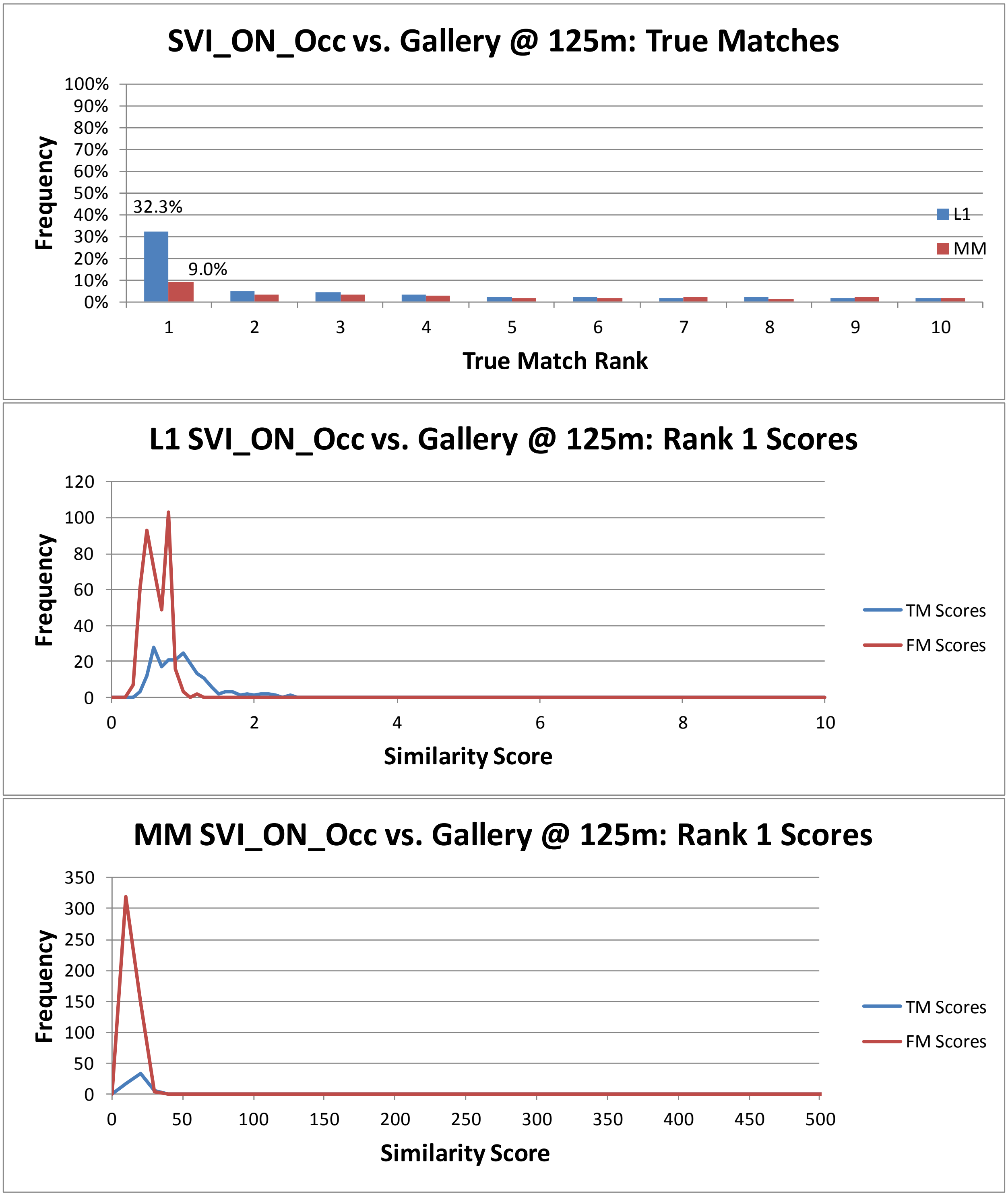


Figure 36: SVI Gen2 Tripod Occluded vs. Gallery @ 125m Matching Results

5.3.1.4 Tripod Mode, Log Based Images

Table 19: SVI Gen2 Tripod Mode Log Based vs. Gallery Matching Results

	L1		MM		L1		MM	
Range	TMR	FMR	TMR	FMR	True Score	False Score	True Score	False Score
35m	20.8%	79.2%	64.2%	35.8%	1.6 ± 1	0.8 ± 0.2	32 ± 17	13 ± 4
50m	31.9%	68.1%	82.5%	17.5%	2 ± 1	0.7 ± 0.2	51 ± 30	12 ± 4
65m	34.2%	65.8%	75.1%	24.9%	2 ± 1	0.6 ± 0.1	39 ± 22	13 ± 4
75m	32.6%	67.4%	66.7%	33.3%	1.5 ± 0.9	0.6 ± 0.2	33 ± 20	13 ± 4
90m	26.7%	73.3%	51.4%	48.6%	1.5 ± 0.8	0.6 ± 0.1	27 ± 14	14 ± 4
100m	24.2%	75.8%	41.4%	58.6%	1.3 ± 0.8	0.7 ± 0.2	21 ± 9	13 ± 4
125m	18.0%	82.0%	11.4%	88.6%	1.0 ± 0.4	0.7 ± 0.2	17 ± 5	13 ± 4

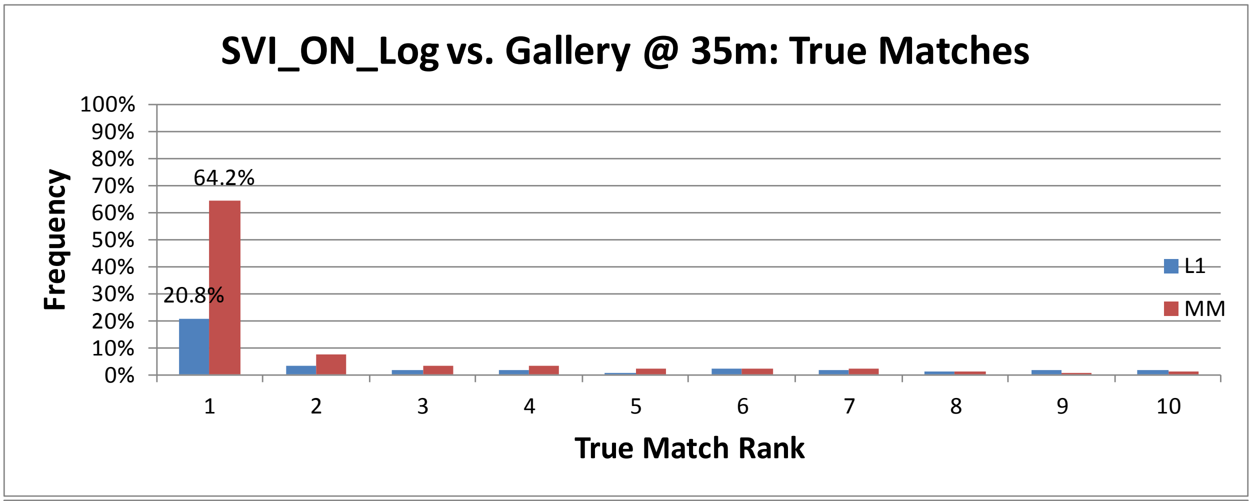
Table 20: SVI Gen2 Tripod Log Based vs. Gallery, L1 Matching Run Statistics

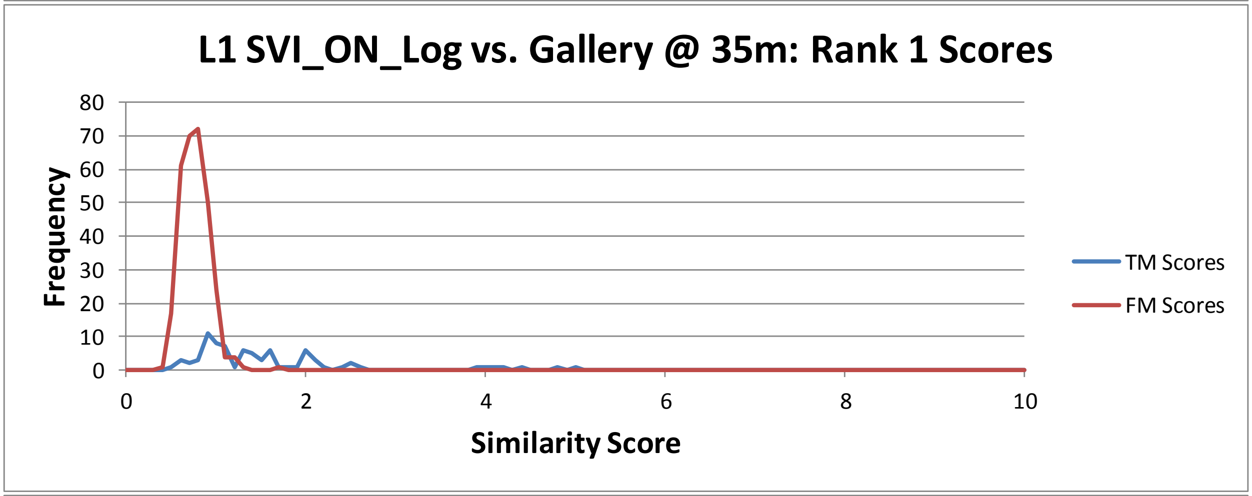
L1	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
35m	100	100	385	385	74	80	305	38500
50m	100	100	548	548	88	175	373	54800
65m	100	100	599	599	93	205	394	59900
75m	100	100	601	601	93	196	405	60100
90m	100	100	589	589	90	157	432	58900
100m	100	100	541	541	85	131	410	54100
125m	100	100	544	544	87	98	446	54400

Table 21: SVI Gen2 Tripod Log Based vs. Gallery, MM Matching Run Statistics

MM	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
35m	100	100	385	385	74	247	138	38500
50m	100	100	548	548	88	452	96	54800
65m	100	100	599	599	93	450	149	59900
75m	100	100	601	601	93	401	200	60100
90m	100	100	589	589	90	303	286	58900
100m	100	100	541	541	85	224	317	54100
125m	100	100	544	544	87	62	482	54400

5.3.1.4.1 SVI, Tripod, Log Based, 35 m





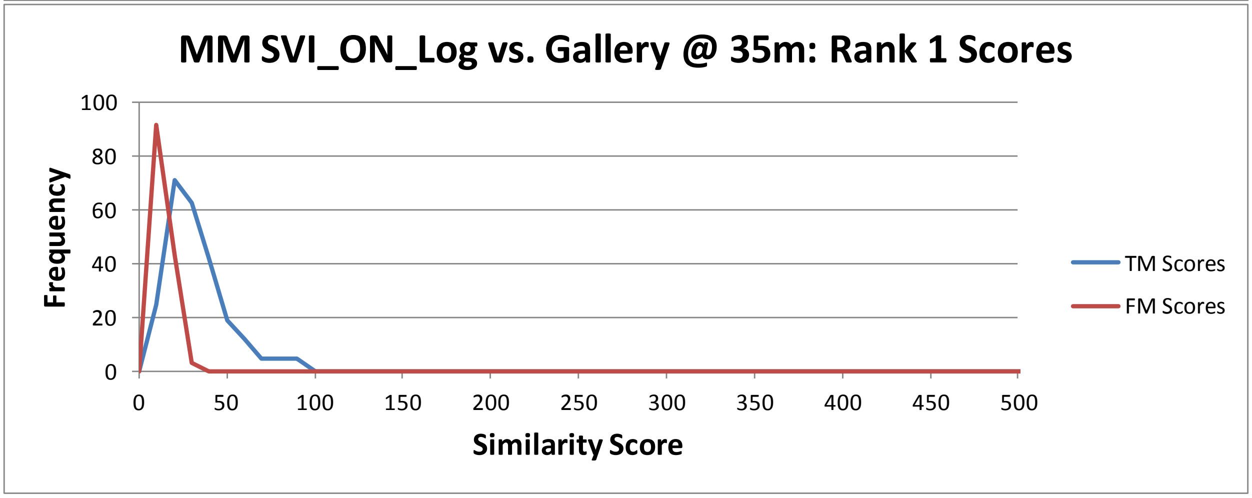


Figure 37: SVI Gen2 Tripod Log vs. Gallery @ 35m Matching Results

5.3.1.4.2 SVI, Tripod, Log Based, 50 m

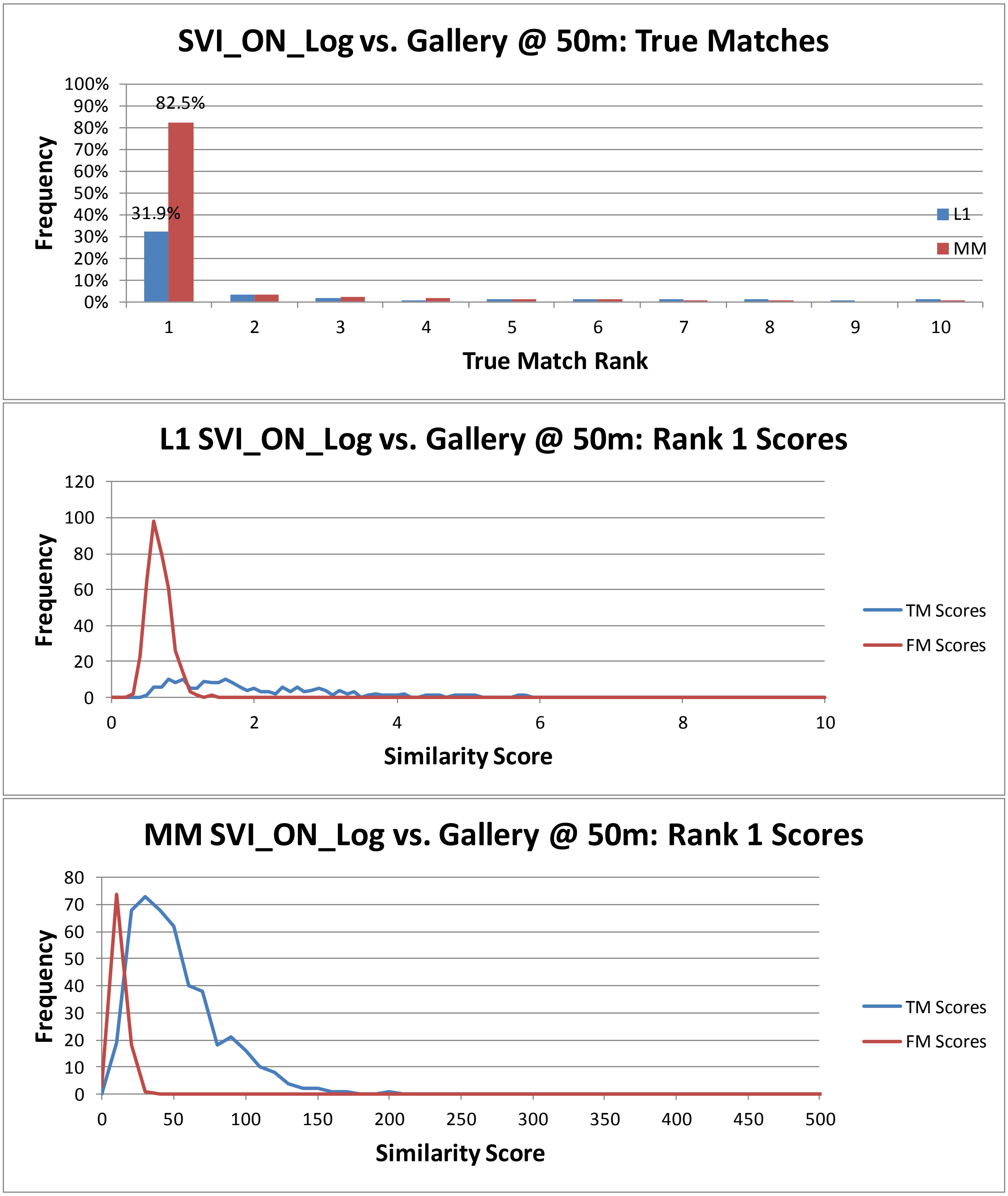


Figure 38: SVI Gen2 Tripod Log vs. Gallery @ 50m Matching Results

5.3.1.4.3 SVI, Tripod, Log Based, 65 m

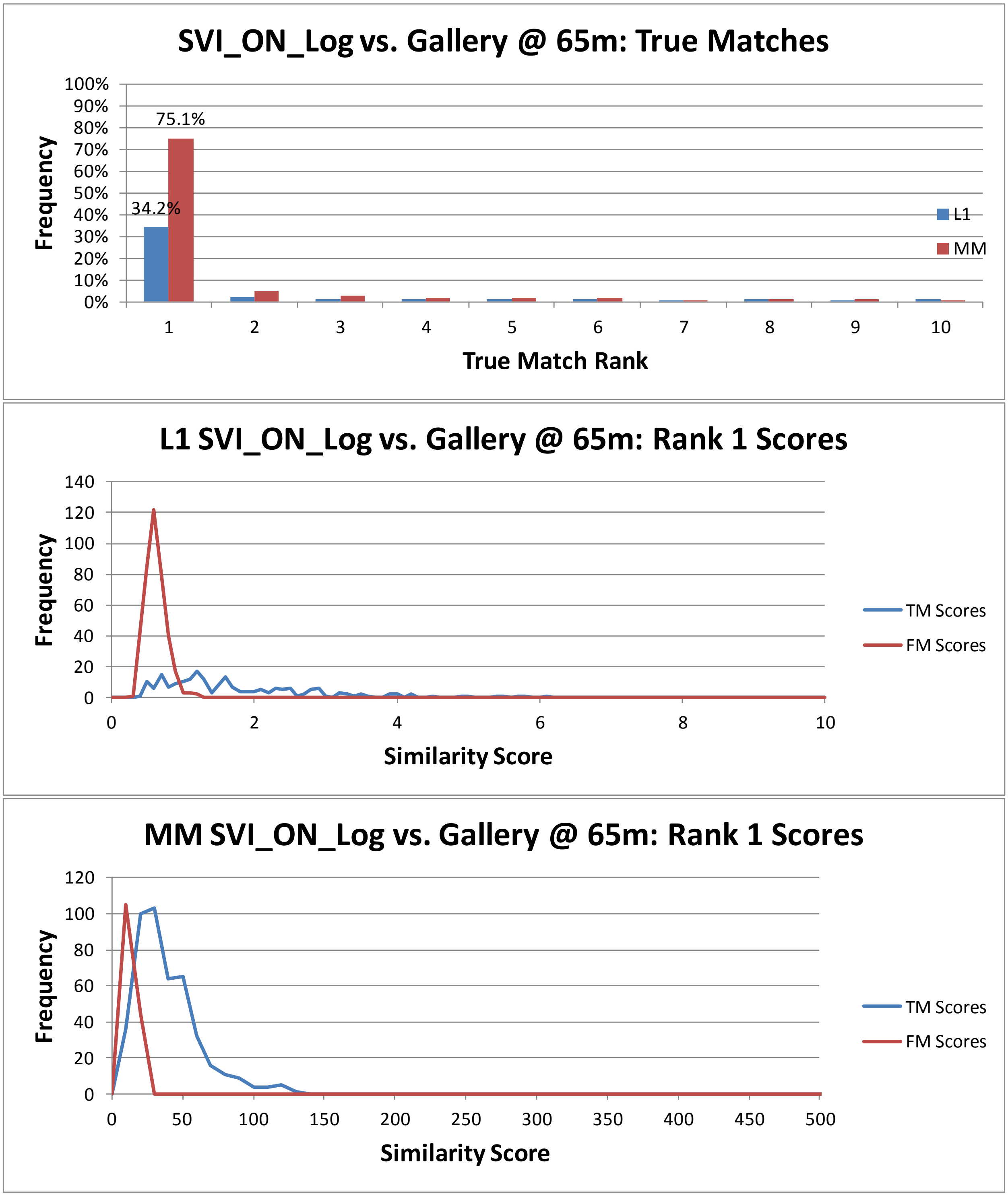


Figure 39: SVI Gen2 Tripod Log vs. Gallery @ 65m Matching Results

5.3.1.4.4 SVI, Tripod, Log Based, 75 m

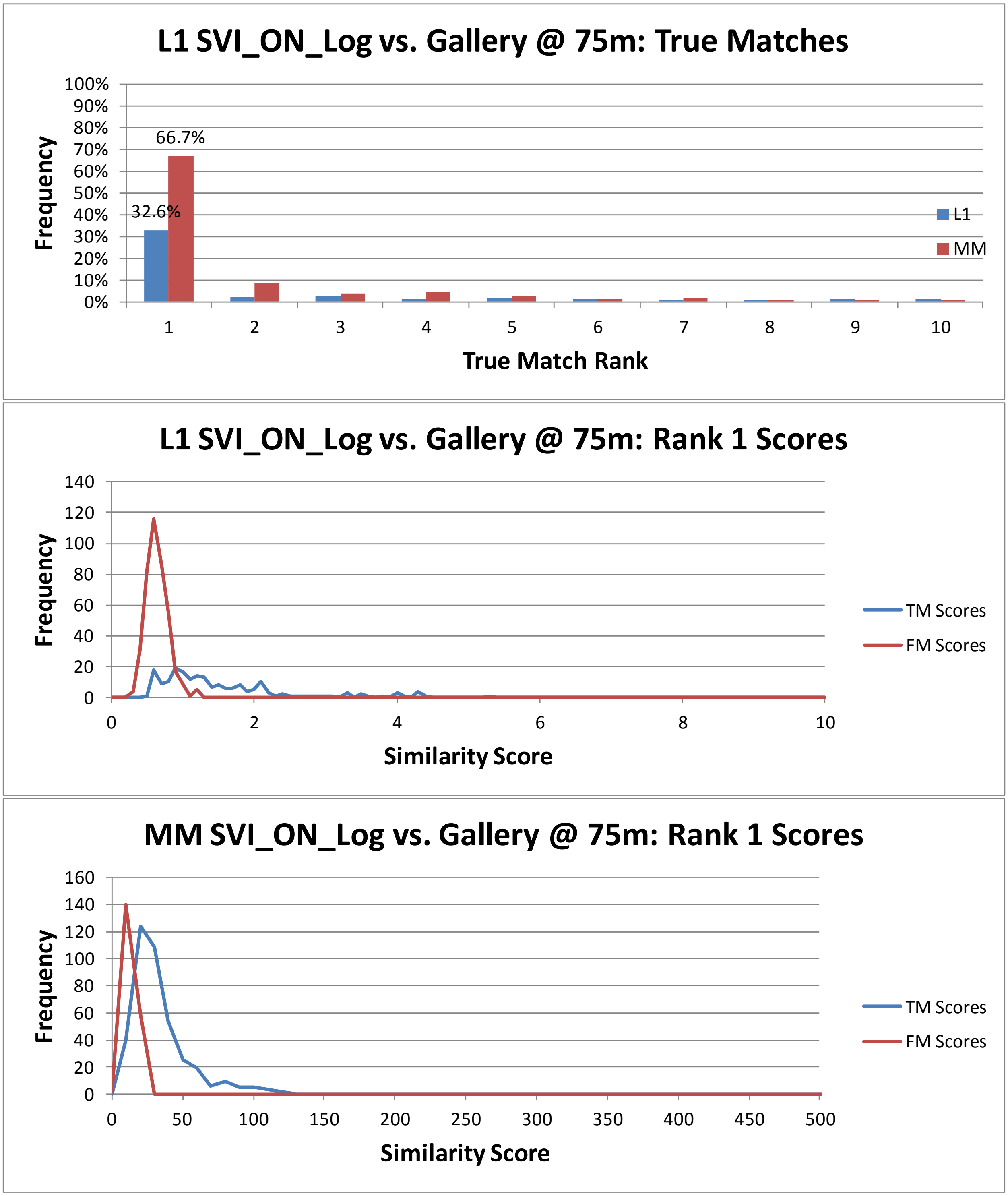


Figure 40: SVI Gen2 Tripod Log vs. Gallery @ 75m Matching Results

5.3.1.4.5 SVI, Tripod, Log Based, 90 m

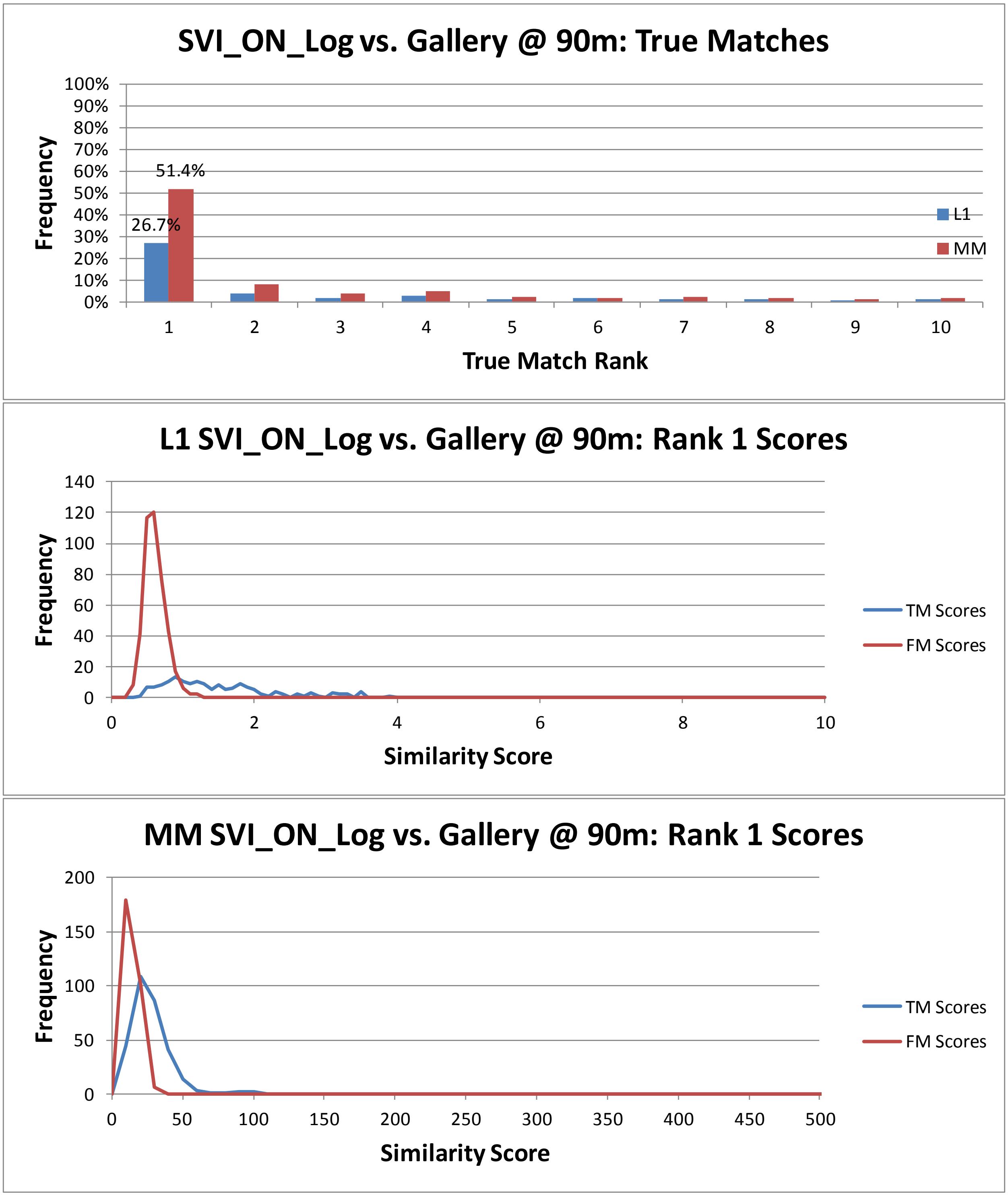


Figure 41: SVI Gen2 Tripod Log vs. Gallery @ 90m Matching Results

5.3.1.4.6 SVI, Tripod, Log Based, 100 m

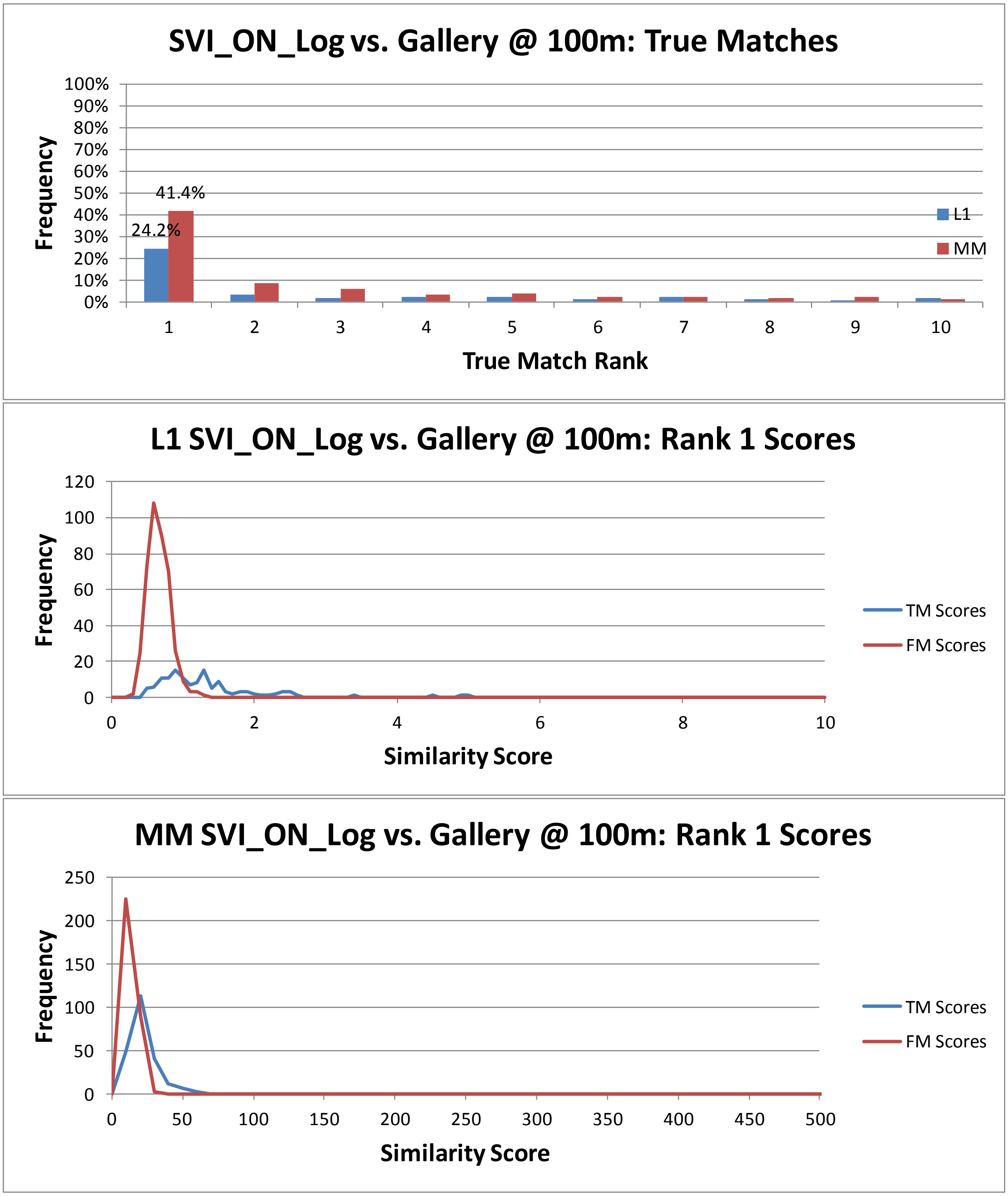


Figure 42: SVI Gen2 Tripod Log vs. Gallery @ 100m Matching Results

5.3.1.4.7 SVI, Tripod, Log Based, 125 m

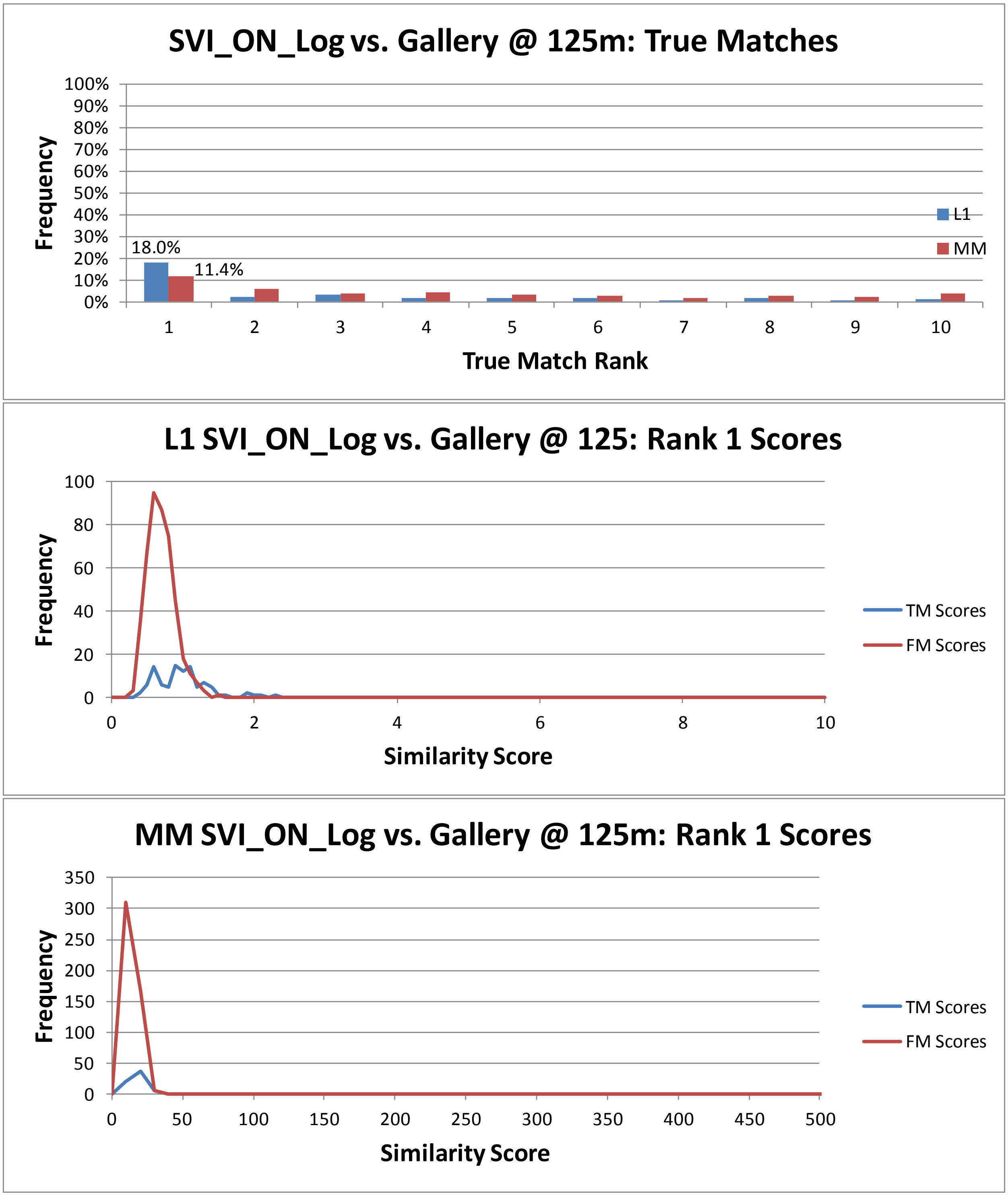


Figure 43: SVI Gen2 Tripod Log vs. Gallery @ 125m Matching Results

5.3.2 Handheld Mode

5.3.2.1 Handheld Mode, All Left Images

Table 22: SVI Gen2 Handheld Mode All Left vs. Gallery Matching Results

	L1		MM		L1		MM	
Range	TMR	FMR	TMR	FMR	True Score	False Score	True Score	False Score
50m	1.3%	98.7%	72.5%	27.5%	0.7 ± 0.2	0.7 ± 0.2	42 ± 29	13 ± 4
75m	1.5%	98.5%	55.1%	44.9%	0.7 ± 0.1	0.6 ± 0.1	30 ± 16	12 ± 4
100m	0.8%	99.2%	28.0%	72.0%	0.5 ± 0.1	0.7 ± 0.2	19 ± 7	13 ± 4

Table 23: SVI Gen2 Handheld All Left vs. Gallery, L1 Matching Run Statistics

L1	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
50m	100	100	534	534	89	7	527	53400
75m	100	100	534	534	89	8	526	53400
100m	100	100	528	528	88	4	524	52800

Table 24: SVI Gen2 Handheld All Left vs. Gallery, MM Matching Run Statistics

MM	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
50m	100	100	534	534	89	387	147	53400
75m	100	100	534	534	89	294	240	53400
100m	100	100	528	528	88	148	380	52800

5.3.2.1.1 SVI, Handheld, All Left, 50 m

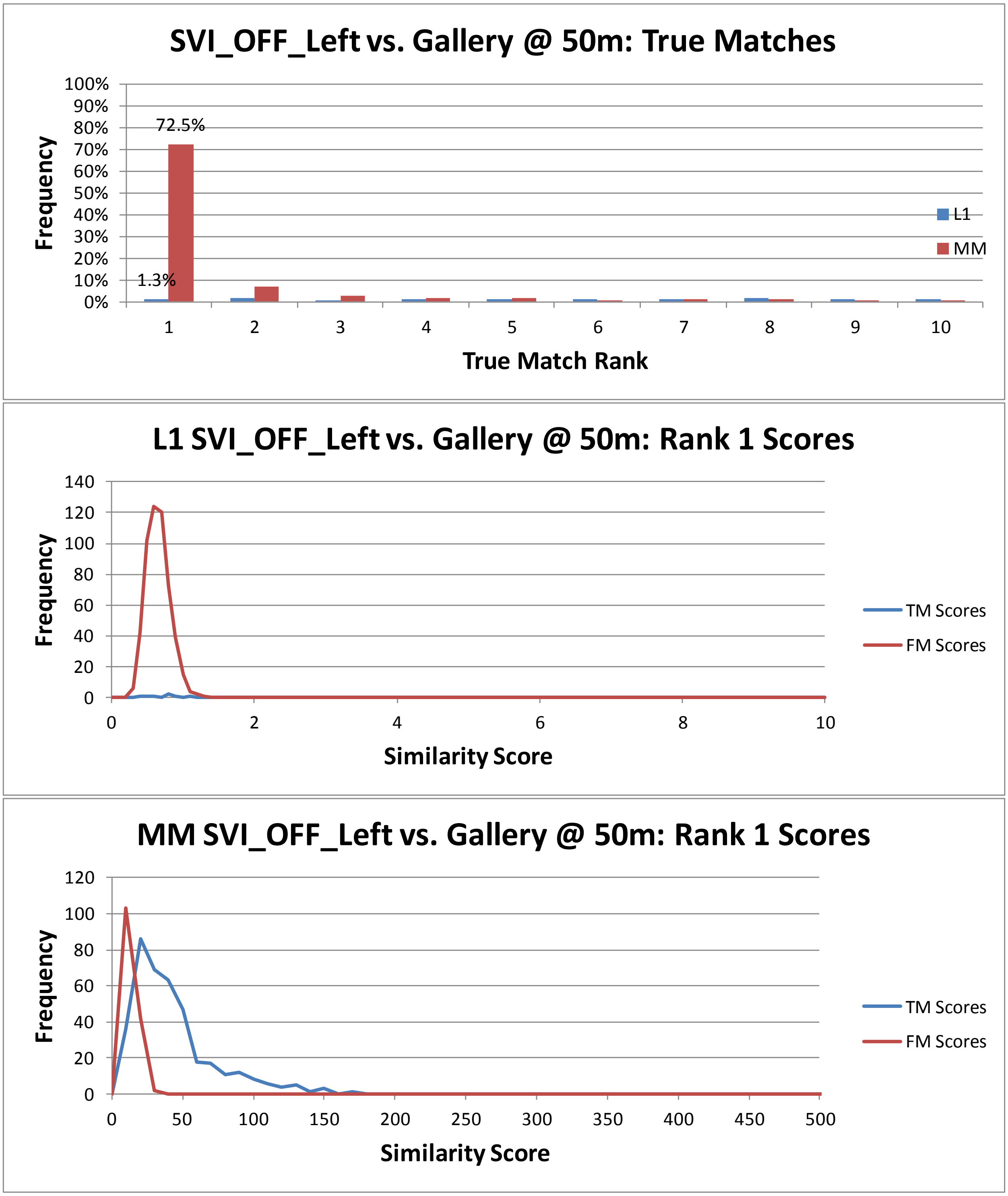


Figure 44: SVI Gen2 Handheld Left vs. Gallery @ 50m Matching Results

5.3.2.1.2 SVI, Handheld, All Left, 75 m

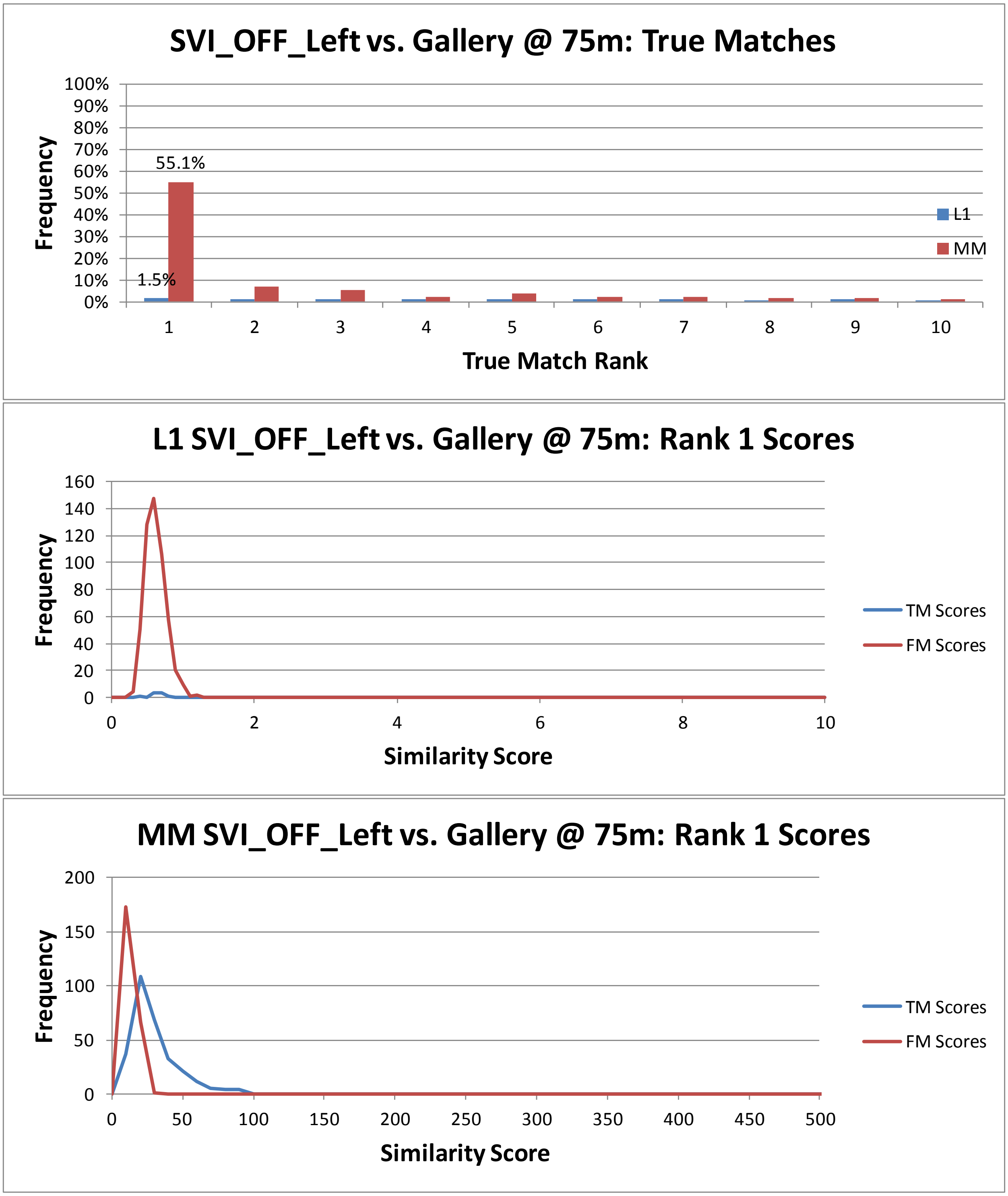


Figure 45: SVI Gen2 Handheld Left vs. Gallery @ 75m Matching Results

5.3.2.1.3 SVI, Handheld, All Left, 100 m

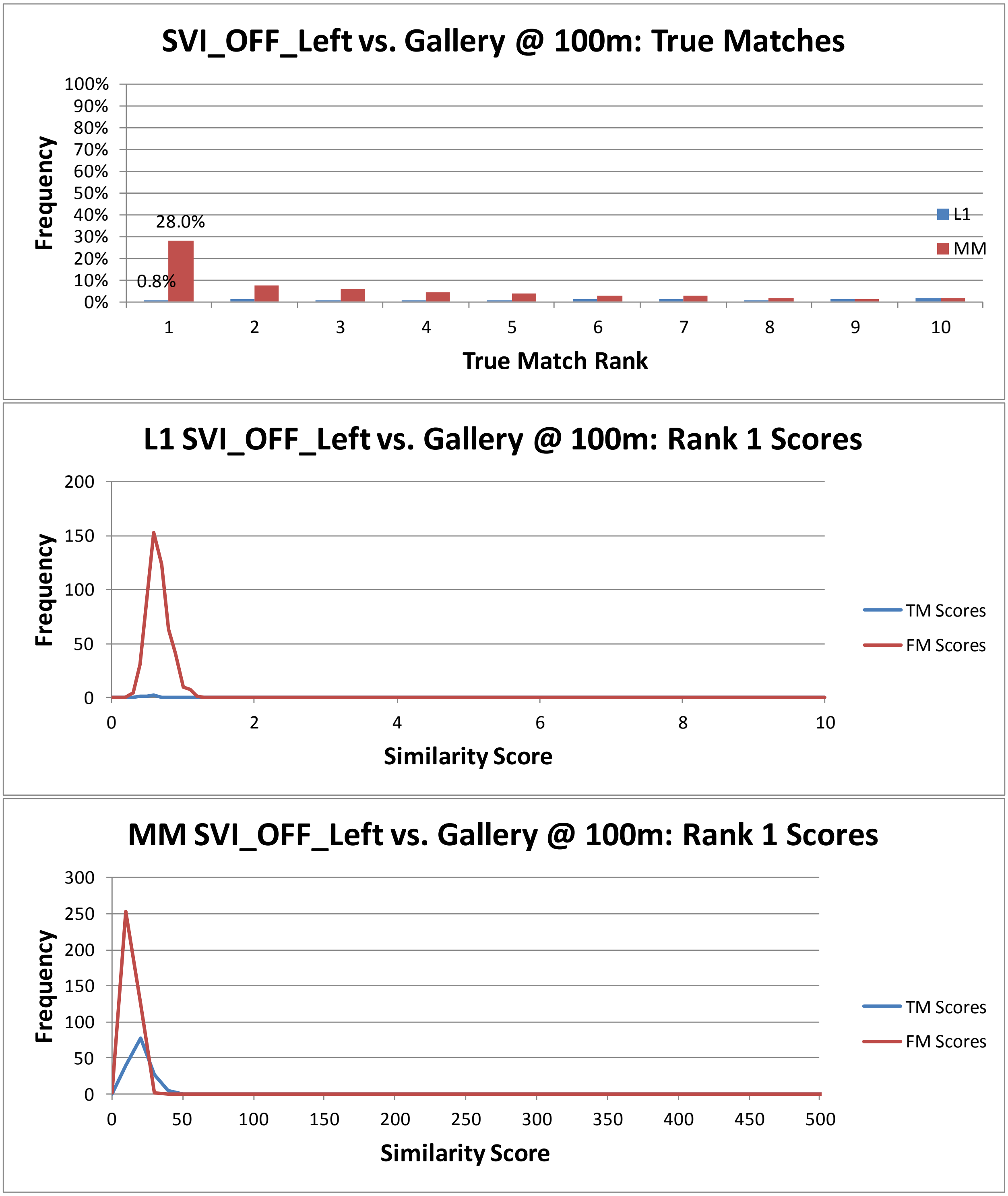


Figure 46: SVI Gen2 Handheld Left vs. Gallery @ 100m Matching Results

5.3.2.2 Handheld Mode, All Right Images

Table 25: SVI Gen2 Handheld Mode All Right vs. Gallery Matching Results

	L1		MM		L1		MM	
Range	TMR	FMR	TMR	FMR	True Score	False Score	True Score	False Score
50m	0.4%	99.6%	77.3%	22.7%	0.5 ± 0.2	0.7 ± 0.2	42 ± 27	13 ± 4
75m	0.9%	99.1%	49.4%	50.6%	0.56 ± 0.09	0.6 ± 0.1	26 ± 14	13 ± 4
100m	1.3%	98.7%	20.1%	79.9%	0.7 ± 0.2	0.6 ± 0.1	18 ± 7	14 ± 4

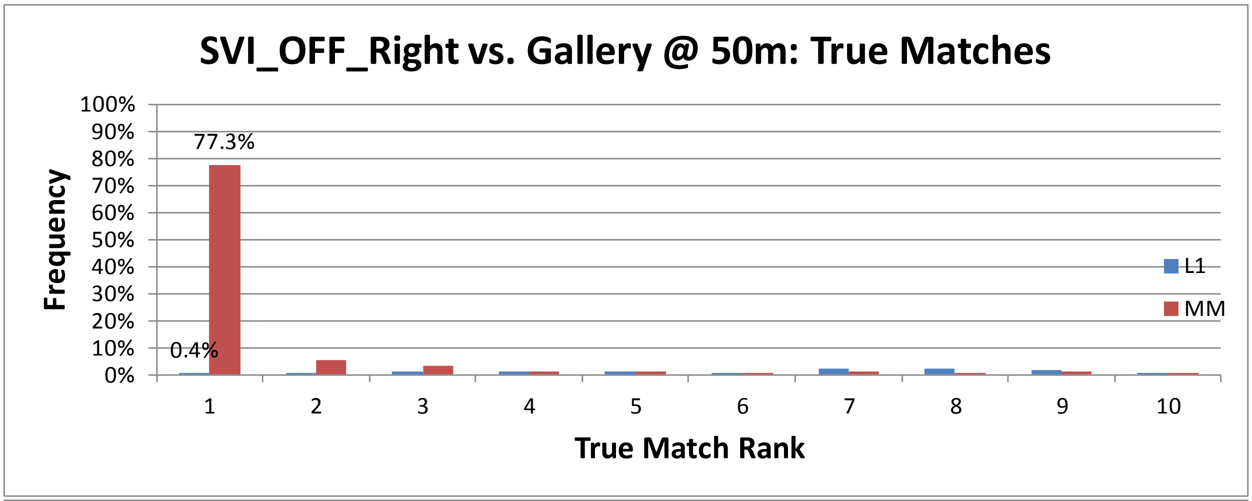
Table 26: SVI Gen2 Handheld All Right vs. Gallery, L1 Matching Run Statistics

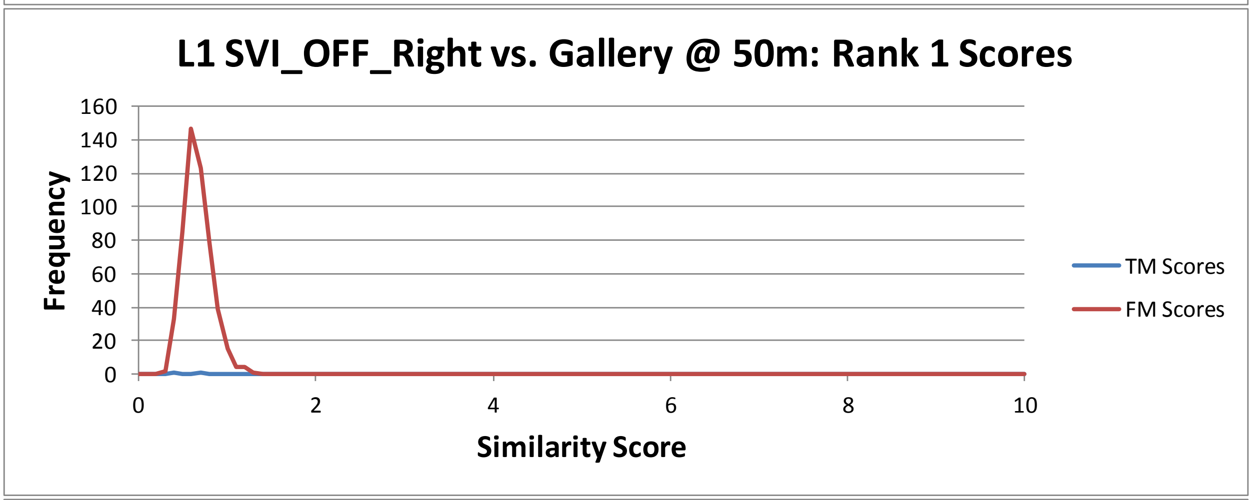
L1	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
50m	100	100	534	534	89	2	532	53400
75m	100	100	534	534	89	5	529	53400
100m	100	100	528	528	88	7	521	52800

Table 27: SVI Gen2 Handheld All Right vs. Gallery, MM Matching Run Statistics

MM	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
50m	100	100	534	534	89	413	121	53400
75m	100	100	534	534	89	264	270	53400
100m	100	100	528	528	88	106	422	52800

5.3.2.2.1 SVI, Handheld, All Right, 50 m





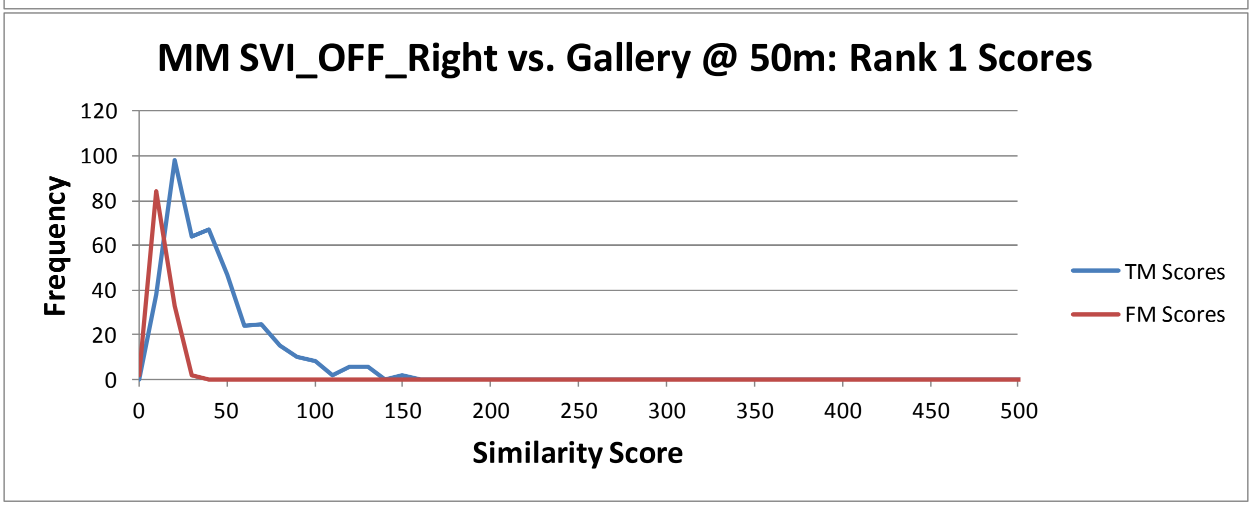


Figure 47: SVI Gen2 Handheld Right vs. Gallery @ 50m Matching Results

5.3.2.2.2 SVI, Handheld, All Right, 75 m

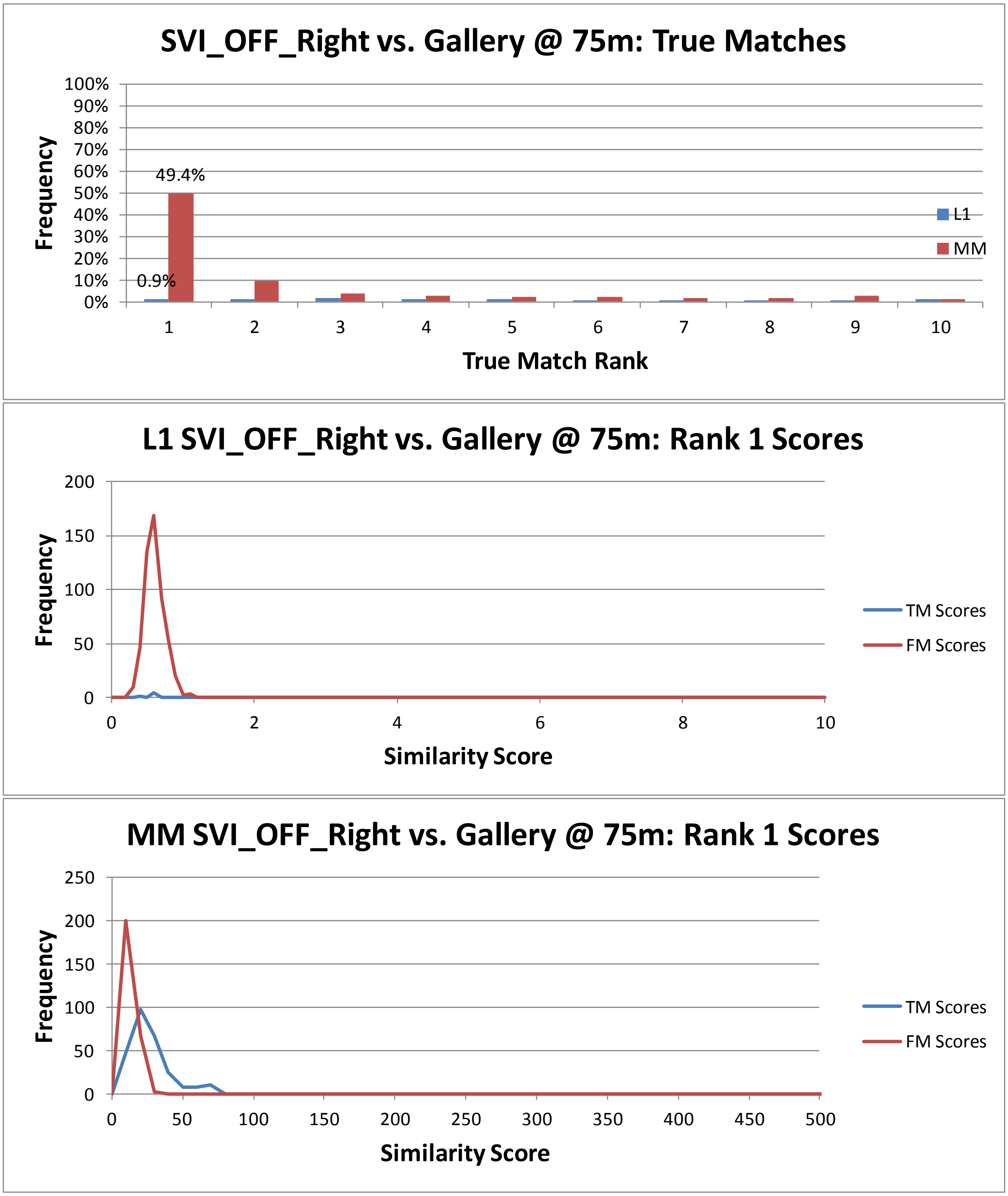


Figure 48: SVI Gen2 Handheld Right vs. Gallery @ 75m Matching Results

5.3.2.2.3 SVI, Handheld, All Right, 100 m

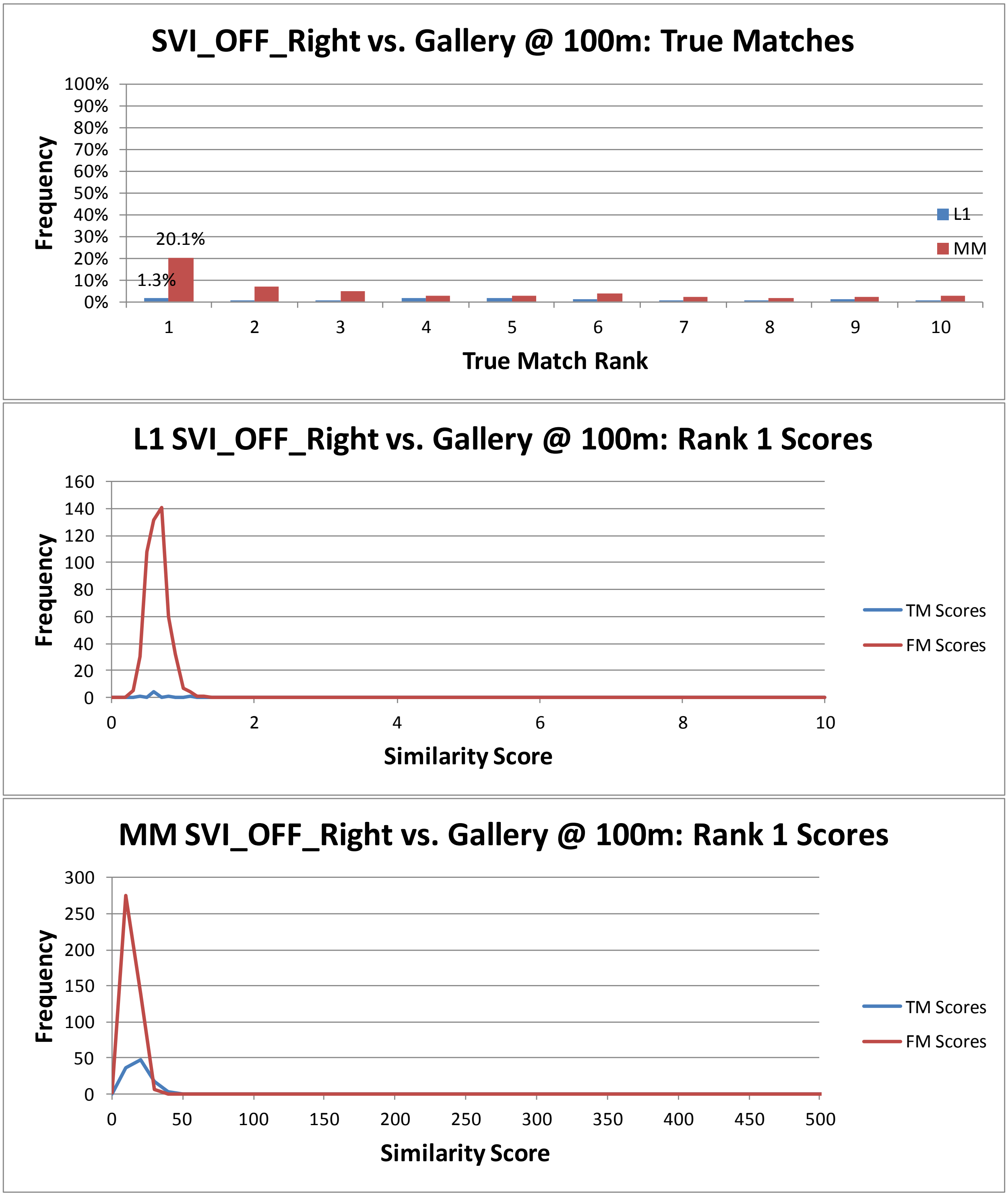


Figure 49: SVI Gen2 Handheld Right vs. Gallery @ 100m Matching Results

5.3.2.3 Handheld Mode, All Occluded Images

Table 28: SVI Gen2 Handheld Mode All Occluded vs. Gallery Matching Results

	L1		MM			L1		MM	
Range	TMR	FMR	TMR	FMR	NMR	True Score	False Score	True Score	False Score
50m	55.2%	44.8%	53.9%	36.5%	9.6%	1.4 ± 0.8	0.7 ± 0.2	40 ± 28	12 ± 5
75m	55.8%	44.2%	55.1%	43.6%	1.3%	1.3 ± 0.6	0.7 ± 0.2	28 ± 16	12 ± 4
100m	41.1%	58.9%	27.3%	72.5%	0.2%	1.0 ± 0.3	0.6 ± 0.2	19 ± 7	13 ± 4

Table 29: SVI Gen2 Handheld All Occluded vs. Gallery, L1 Matching Run Statistics

L1	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
50m	100	100	534	534	89	295	239	53400
75m	100	100	534	534	89	298	236	53400
100m	100	100	528	528	88	217	311	52800

Table 30: SVI Gen2 Handheld All Occluded vs. Gallery, MM Matching Run Statistics

MM	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
50m	100	100	534	483	85	288	195	48300
75m	100	100	534	527	89	294	233	52700
100m	100	100	528	527	88	144	383	52700

5.3.2.3.1 SVI, Handheld, All Occluded, 50 m

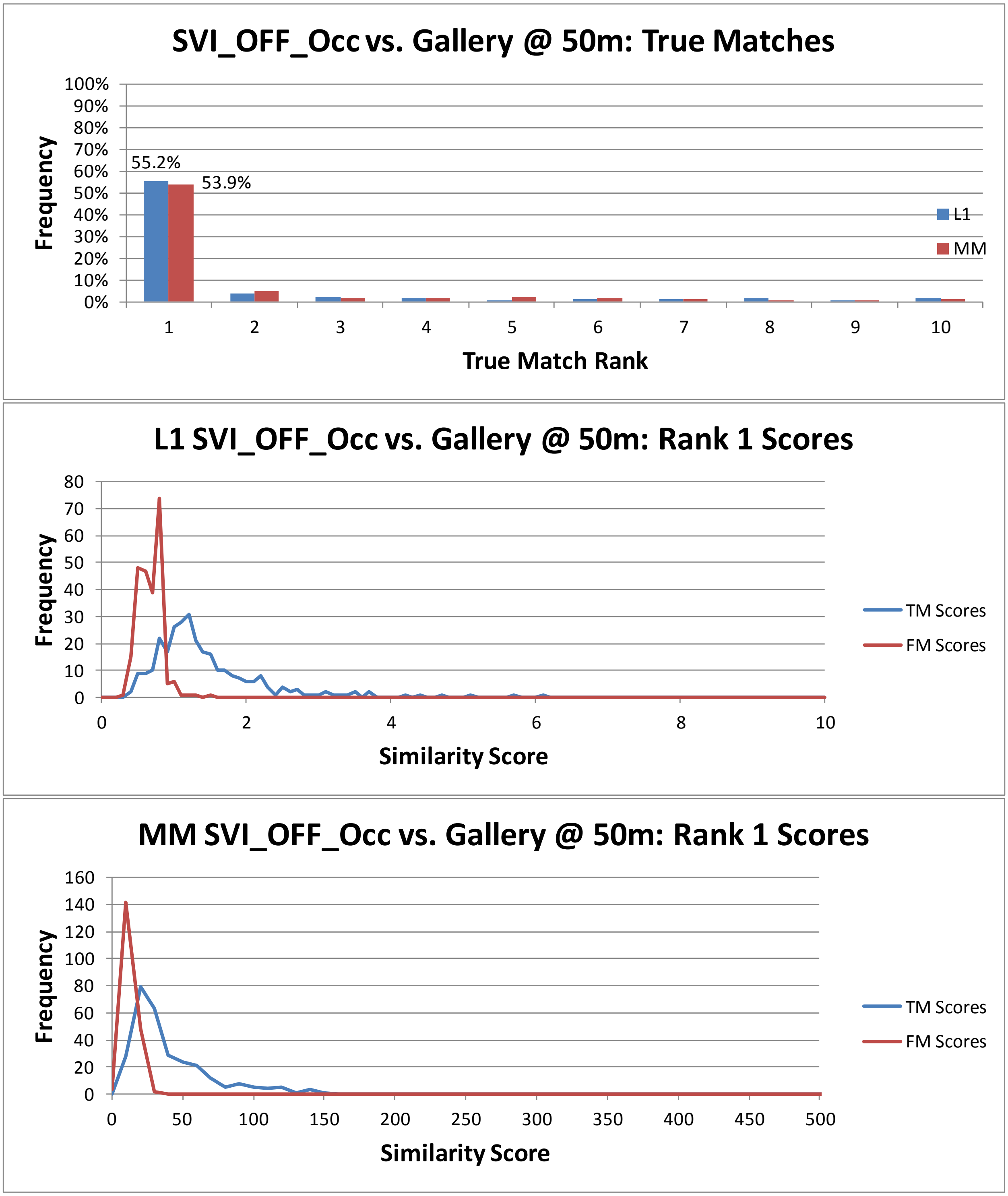
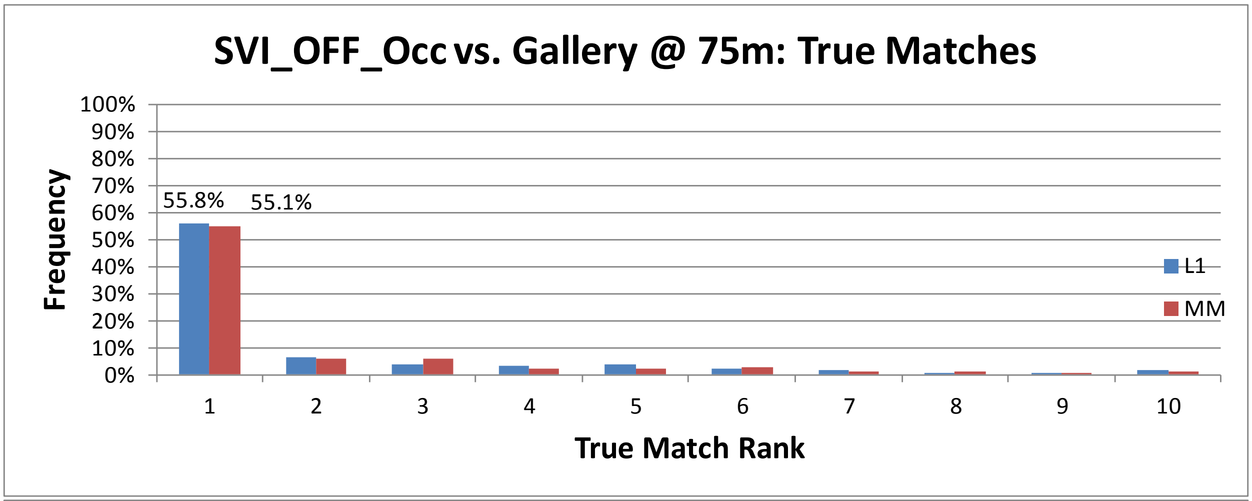
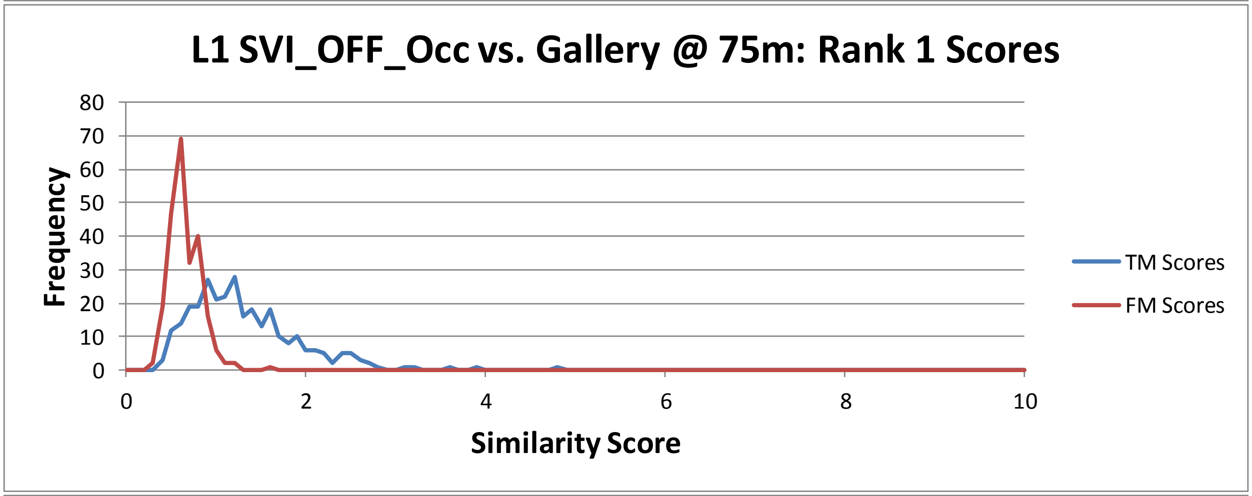


Figure 50: SVI Gen2 Handheld Occluded vs. Gallery @ 50m Matching Results

5.3.2.3.2 SVI, Handheld, All Occluded, 75 m





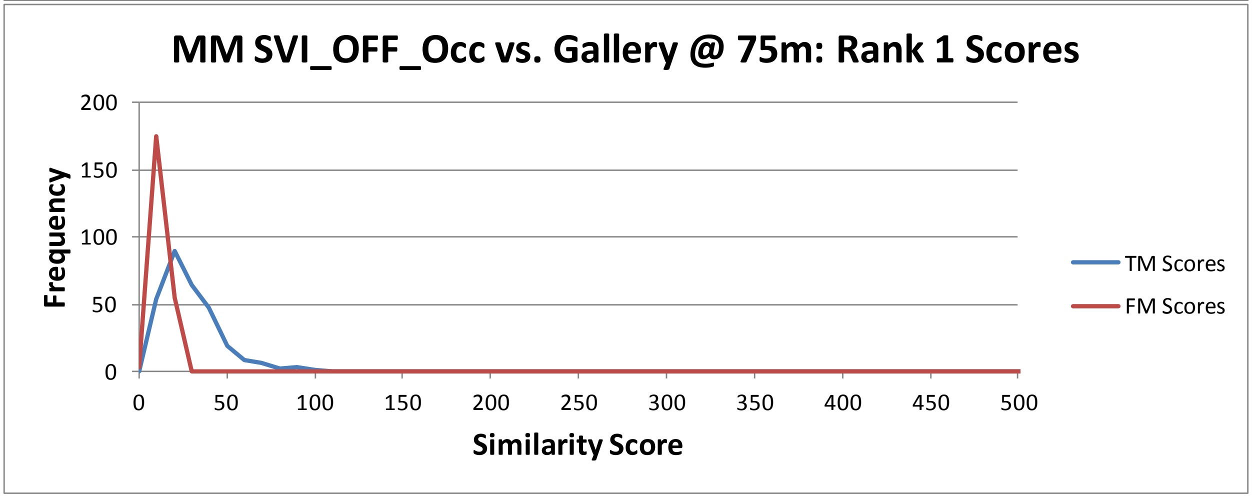


Figure 51: SVI Gen2 Handheld Occluded vs. Gallery @ 75m Matching Results

5.3.2.3.3 SVI, Handheld, All Occluded, 100 m

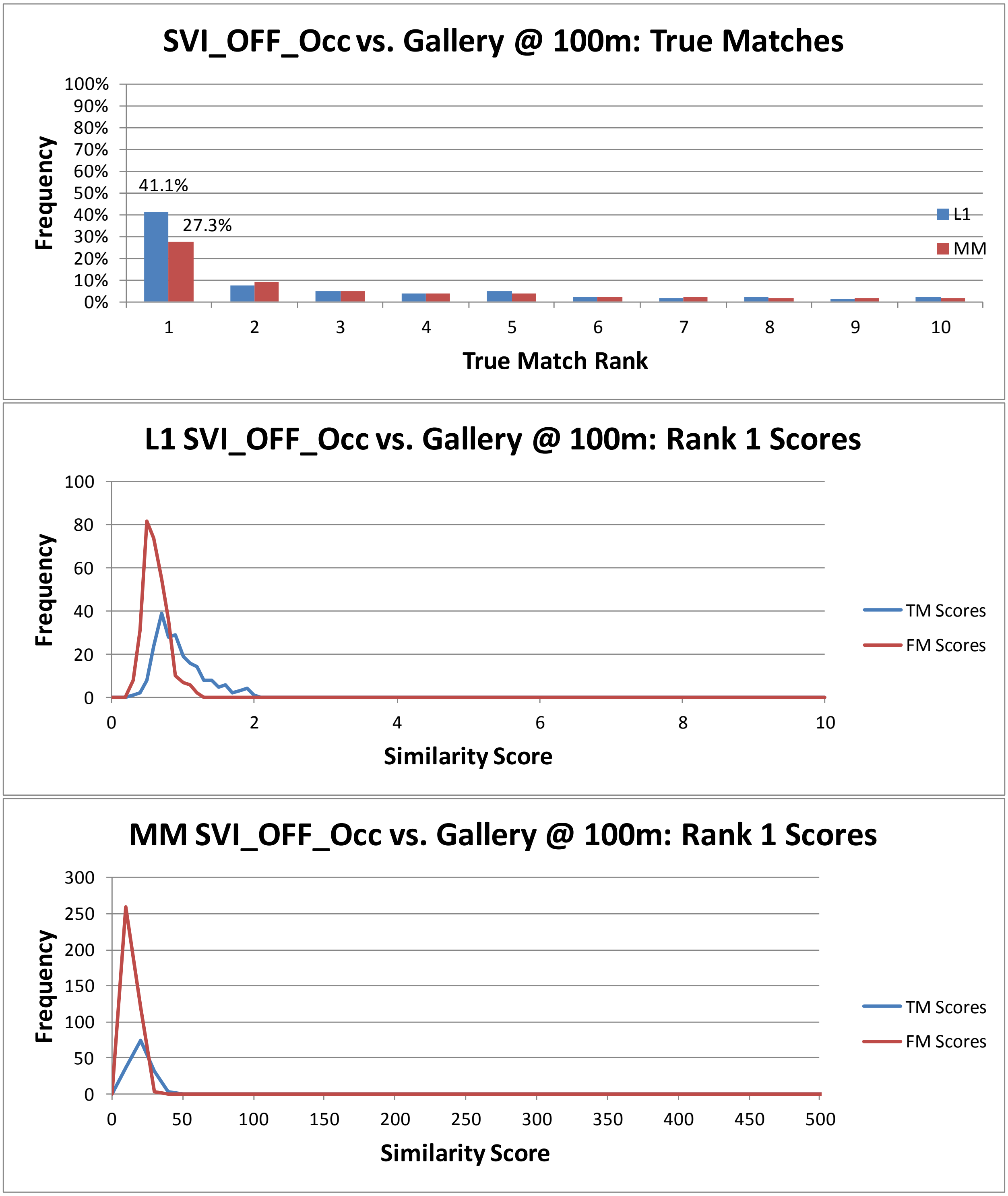


Figure 52: SVI Gen2 Handheld Occluded vs. Gallery @ 100m Matching Results

5.3.2.4 Handheld Mode, Log Based Images

Table 31: SVI Gen2 Handheld Mode Log Based vs. Gallery Matching Results

	L1		MM		L1		MM	
Range	TMR	FMR	TMR	FMR	True Score	False Score	True Score	False Score
50m	29.6%	70.4%	76.3%	23.7%	1.5 ± 0.9	0.7 ± 0.2	43 ± 29	13 ± 4
75m	29.7%	70.3%	57.6%	42.4%	1.3 ± 0.6	0.6 ± 0.1	30 ± 15	13 ± 4
100m	18.5%	81.5%	30.0%	70.0%	0.9 ± 0.3	0.6 ± 0.2	20 ± 7	13 ± 4

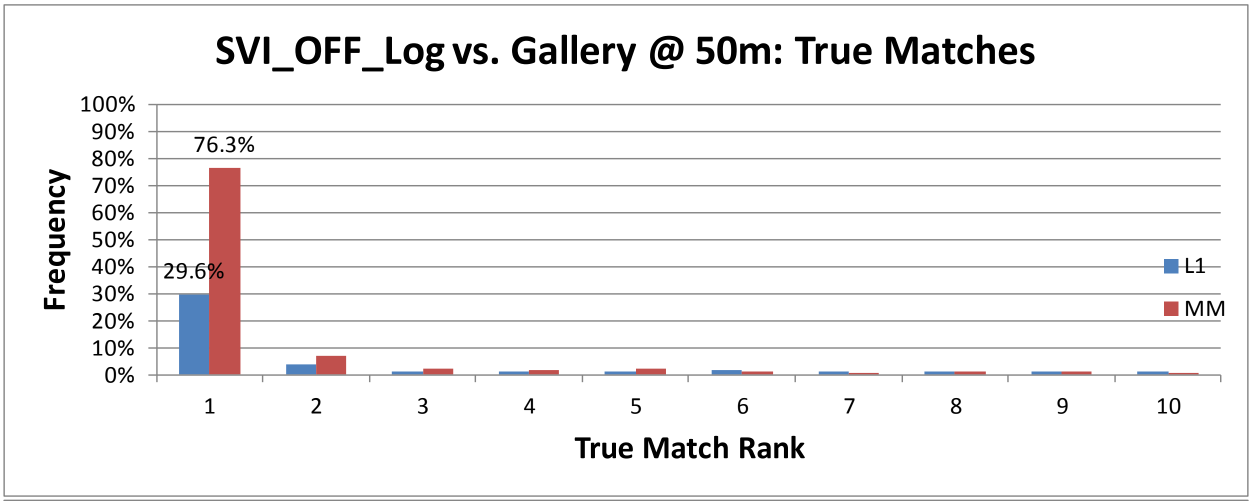
Table 32: SVI Gen2 Handheld Log Based vs. Gallery, L1 Matching Run Statistics

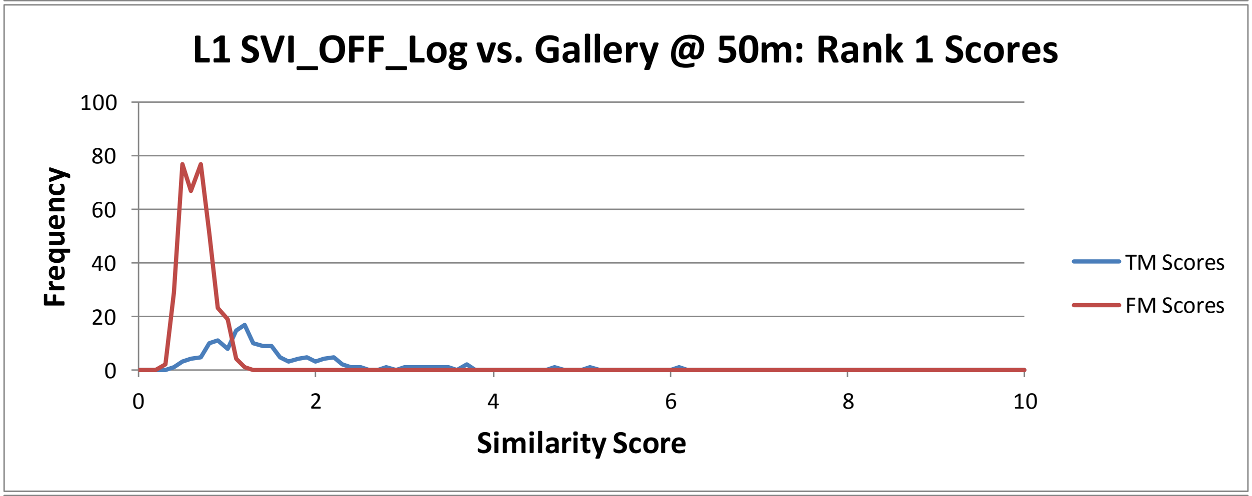
L1	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
50m	100	100	497	497	82	147	350	49700
75m	100	100	519	519	82	154	365	51900
100m	100	100	470	470	77	87	383	47000

Table 33: SVI Gen2 Handheld Log Based vs. Gallery, MM Matching Run Statistics

MM	Gallery		Probe			Matches		
Range	Total	Unique Subjects	Submit	Accepted	Unique Subjects	True Matches	False Matches	Total Matches
50m	100	100	497	497	82	379	118	49700
75m	100	100	519	519	82	299	220	51900
100m	100	100	470	470	77	141	329	47000

5.3.2.4.1 SVI, Handheld, Log Based, 50 m





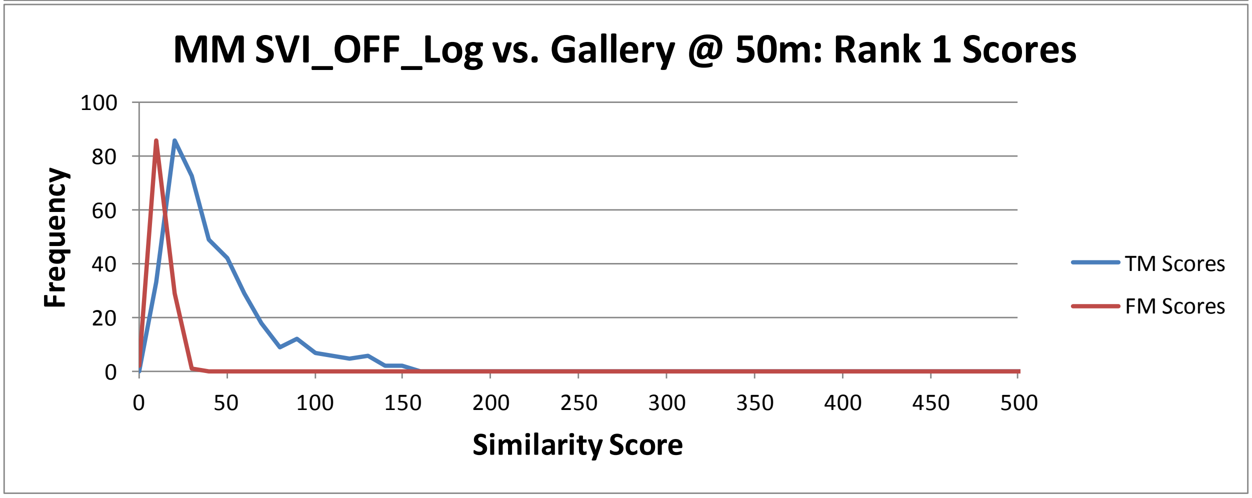


Figure 53: SVI Gen2 Handheld Log vs. Gallery @ 50m Matching Results

5.3.2.4.2 SVI, Handheld, Log Based, 75 m

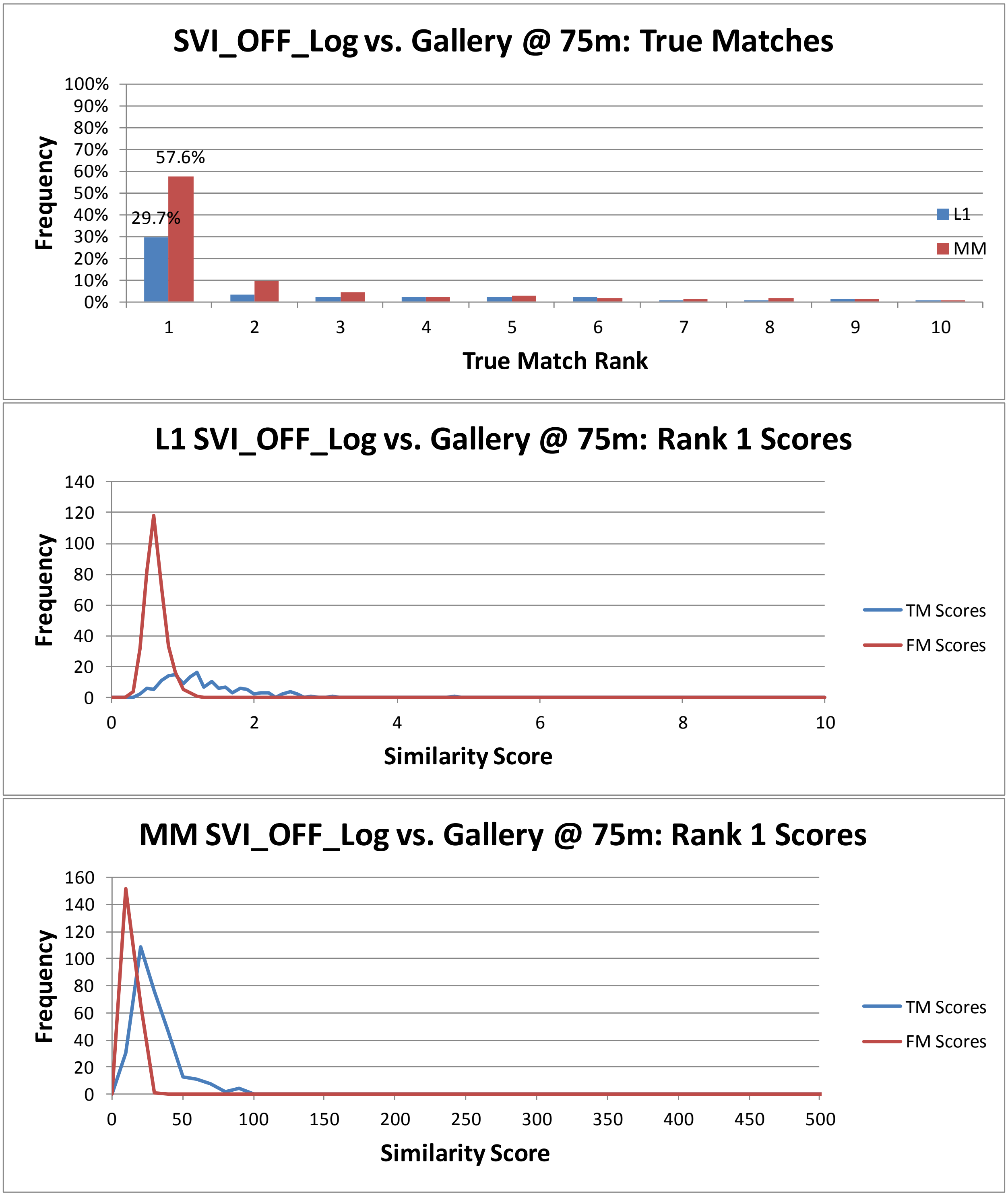


Figure 54: SVI Gen2 Handheld Log vs. Gallery @ 75m Matching Results

5.3.2.4.3 SVI, Handheld, Log Based, 100 m

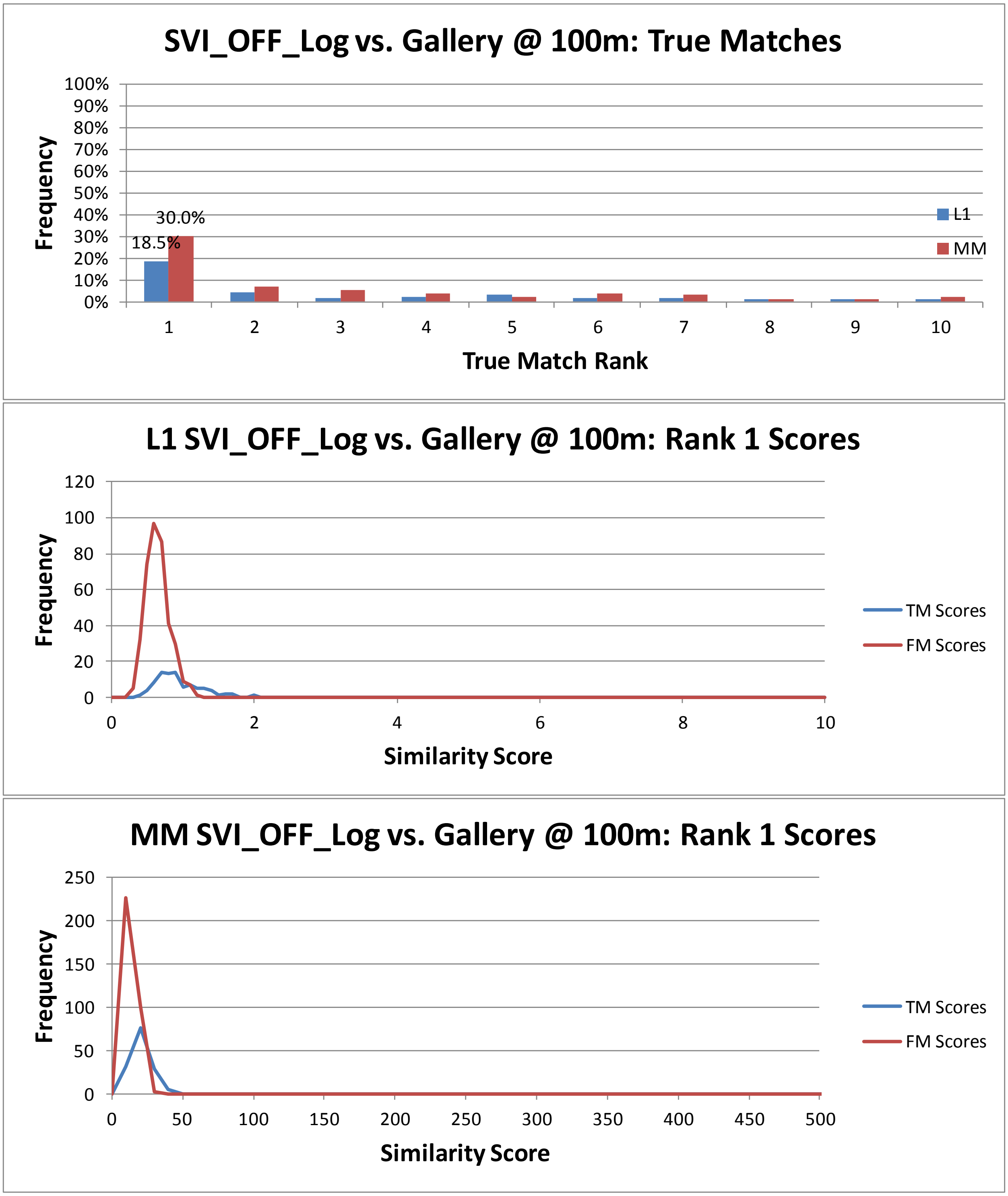


Figure 55: SVI Gen2 Handheld Log vs. Gallery @ 100m Matching Results

5.4 SVI FRT 3DVuCAM (Generation 1) Matching Runs

Additional matching runs were conducted using the datasets collected for the SVI Gen1 FRT 2DVuCAM to enhance the performance evaluations of the current SVI Gen2 system. Other results from the Gen1 T&E will be utilized in Section 7.0 ANALYSIS & DISCUSSION as needed, but presented here are new matching runs.

As a refresher, the SVI Gen1 system was a similar binocular system but contained some notable differences in its operation. The device did not possess autofocus and instead had three preset focal stop positions (p1, p2, p3) that were selected prior to image capture. The p1 – p3 positions corresponded to 50, 75, and 100m respectively.[3]

Otherwise, the same matching run statistics and results are reported here for the SVI Gen 1 All Occluded probe set matched against the Gen1 Canon Indoor enrollment gallery.

Table 34: SVI Gen1 All Occluded vs. Gallery Matching Results

	L1		MM			L1	
Range	**TMR**	**FMR**	**TMR**	**FMR**	**NMR**	**True Score**	**False Score**
50m	30.4%	69.6%	25.9%	74.1%	0.0%	2 ± 1	0.6 ± 0.2
75m	12.8%	87.2%	8.0%	92.0%	0.0%	0.9 ± 0.5	0.6 ± 0.2
100m	11.1%	88.9%	5.9%	94.1%	0.0%	0.9 ± 0.5	0.6 ± 0.2

Table 35: SVI Gen1 All Occluded vs. Gallery, L1 Matching Run Statistics

L1	Gallery		Probe			Matches		
Range	**Total**	**Unique Subjects**	**Submit**	**Accepted**	**Unique Subjects**	**True Matches**	**False Matches**	**Total Matches**
50m	99	99	1455	1455	99	443	1012	144045
75m	99	99	1450	1450	98	185	1265	143550
100m	99	99	1435	1435	97	159	1276	142065

Table 36: SVI Gen1 All Occluded vs. Gallery, MM Matching Run Statistics

MM	Gallery		Probe			Matches		
Range	**Total**	**Unique Subjects**	**Submit**	**Accepted**	**Unique Subjects**	**True Matches**	**False Matches**	**Total Matches**
50m	99	99	1455	1455	99	377	1078	144045
75m	99	99	1450	1450	98	116	1334	143550
100m	99	99	1435	1435	97	85	1350	142065

5.4.1 SVI Gen1, All Occluded, 50 m (L1R650, MMR650)

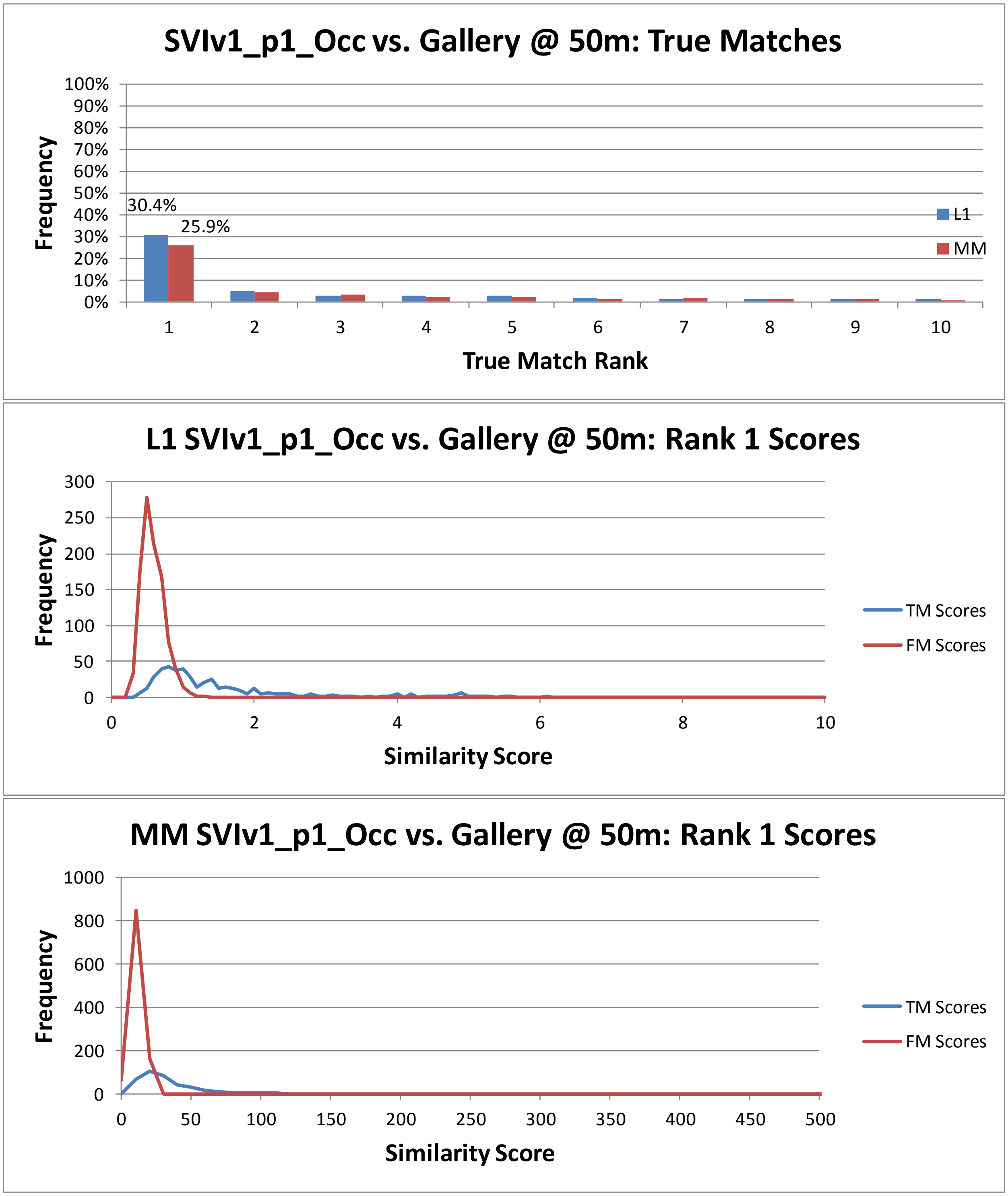


Figure 56: SVI Gen1 Handheld Occluded vs. Gallery @ 50m Matching Results

5.4.2 SVI Gen 1, All Occluded, 75 m (L1R675, MMR675)

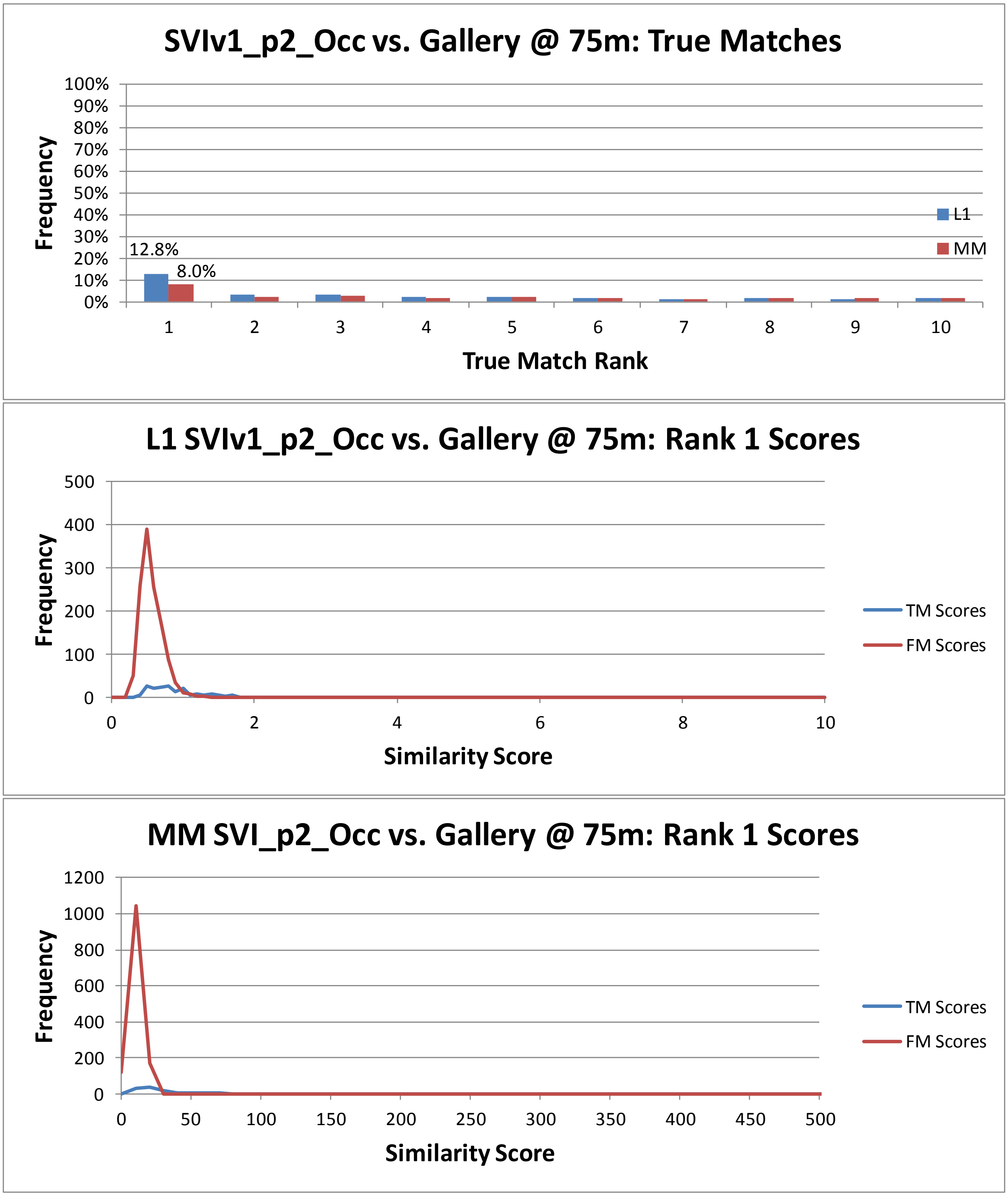


Figure 57: SVI Gen1 Handheld Occluded vs. Gallery @ 75m Matching Results

5.4.3 SVI Gen 1, All Occluded, 100 m (L1R675, MMR675)

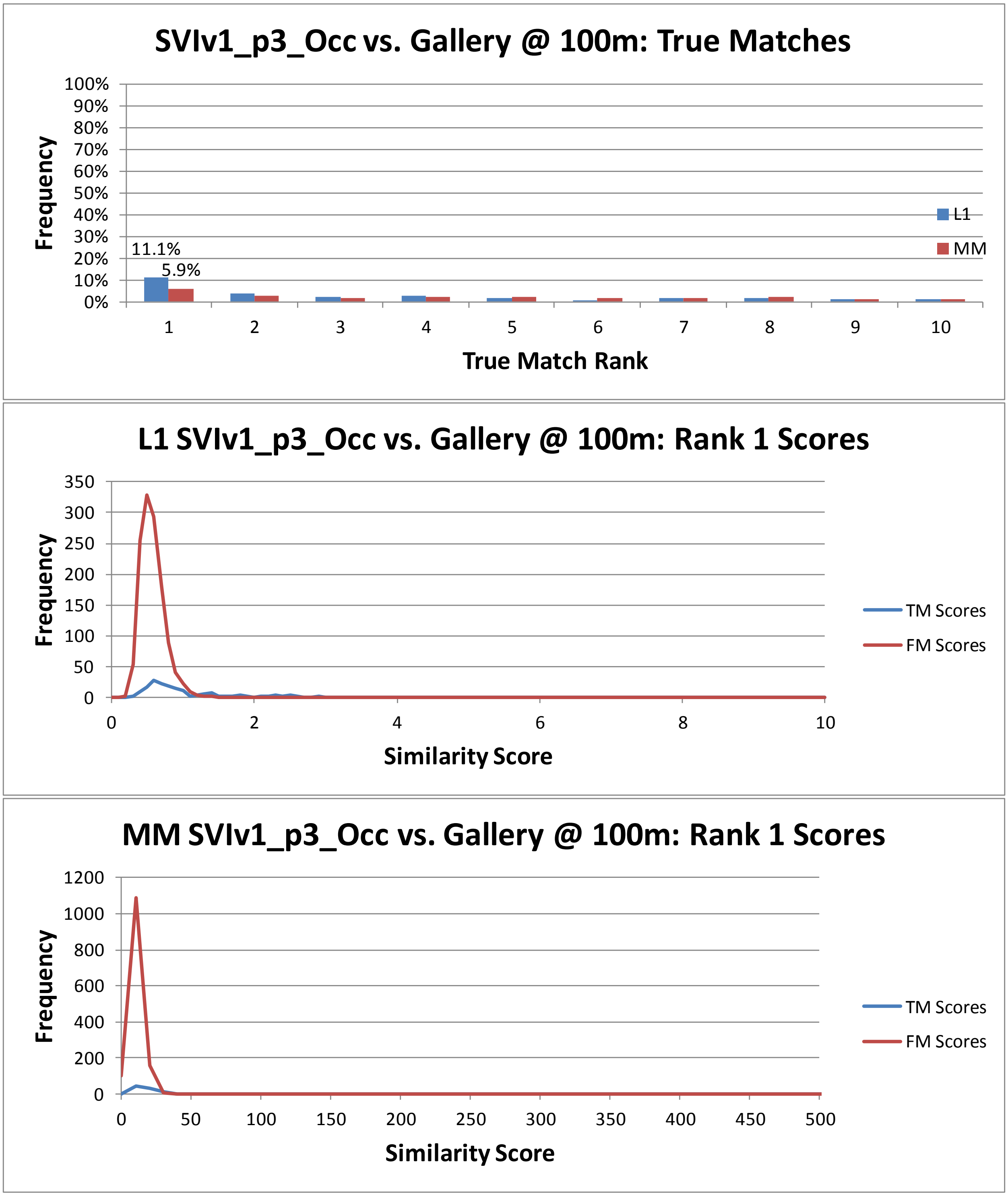


Figure 58: SVI Gen1 Handheld Occluded vs. Gallery @ 100m Matching Results

7.0 ANALYSIS & DISCUSSION

The biometric face image dataset collection by WVU (see Section 2.2 WVU Face Collection) was used to conduct matching runs using the L1 and MM algorithms. The resulting matching run results have been used to investigate and analyze the performance of the SVI Gen2 device. The overarching objectives of this T&E effort are as follows:

1. Evaluate the ability of the SVI Gen2 3DMobileID to match a target to its true gallery enrollment entry.
2. Compare the matching performance of the SVI Gen2 system (and control datasets) when using the MM algorithm as compared to the L1 algorithm.
3. Determine the level of improvement in matching performance and functionality from the SVI Gen1 system to the Gen2.
4. Identify any anomalies or issues associated with the Gen2 binoculars or its backend software (e.g., L1 probe selection).

7.1 Galleries

The Canon Indoor enrollment gallery was submitted as a probe dataset against itself to baseline the performance of both algorithms. The MM matching run resulted in a 100% TMR. The L1 matching run required the use of lower quality probe images to mitigate processing issues likely caused by hardware errors. The full resolution images should perform at least as well as the lower quality image set under ideal hardware conditions. The fact that the lower quality image set produced a TMR of 100% for the L1 algorithm supports the case that the underlying enrollment gallery is suitable for the remaining T&E matching runs and will not introduce any systemic deviations or errors in the algorithm performances.

7.2 Occlusion Image Processing

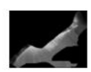
As discussed in the Section 4.2 Face Image Datasets for Evaluation, the SVI Gen2 system utilizes stereoscopic optics hardware combined with software processing to remove the background from target images. The Disparity Calculator software has a number of image processing parameters and variables that affect the occlusion process. However, this T&E did not alter those settings during any image processing or analysis efforts. The parameters would not be changed during standard field operation and would require a trained data analyst to be knowledgeable enough to do so. The vendor, SVI, did not provide instructions for using these settings as this functionality was not a component of the NIJ deliverable. With that in mind, it is still interesting to examine the occlusion images using the default settings to understand the types of images and occlusion effects that could impact match performance.

Table 37: SVI Gen2 Occlusion Examples provides example images for all seven ranges at different degrees of occlusion. Generally, occluded images fall into four categories. The first, "Full Face," depicts the full face without any removed features. In this case, the Disparity Calculator has performed well in removing the background from the image. The majority of images included a clean demarcation between subject and background. This image type is the ideal goal for any capture. The second type of image, "Partial Face," includes most of the face and the majority of key features (e.g., eyes, nose, and mouth) are present for use in facial template generation by the matcher. Upon visual examination of the images, one would likely conclude that the images performed well during matching runs. However, the true match rank is often poorer than expected, which is an indicator of the sensitivity of the matchers to the topography of the face. Each Partial Face image also includes the True Match rank for the L1 and MM algorithms pulled from the matching results for specific images. Of the fourteen Partial Face matching runs, only two produced a True Match in rank 1. The third type of image is the "Obscured Face." In this image type, there are some indications of an image but there are no usable features. Finally, all matching runs produced at a least one example of a completely blank black image from the occlusion processing.

Table 37: SVI Gen2 Occlusion Examples

Example occluded images from each range at varying degrees of occlusion. For each Partial Face example, the L1 True Match rank position is also included for reference. Note that the subjects provided permission to reproduce their face images for research reporting purposes in accordance with IRB-approved protocols.

Range	Full Face	Partial Face	Obscured Face	Blank
35 m		 L1: 51, MM: 5		

Range	Full Face	Partial Face	Obscured Face	Blank
50 m		 L1: 12, MM: 1		
65 m		 L1: 57, MM: 8		
75 m		 L1: 14, MM: 2		
90 m		 L1: 15, MM: 3		
100 m		 L1: 1, MM: 9		
125 m		 L1: 70, MM: 78		

7.3 SVI Gen2 Tripod vs. Canon 800mm

The performance of the SVI Gen2 binoculars in Tripod Mode was examined as a function of target distance. The TMR as a function of target distance using the L1 matcher is shown in Figure 59. The SVI Gen2 performed poorly when using the Left or Right subset of images (TMR < 2%) – the device cannot be used to any effect with just the camera images and the L1 matcher. However, the performance improved dramatically upon removal of the background through the stereoscopic occlusion process. The vendor reported an optimal range of 50 – 100 m, with trade-offs in depth of focus to achieve the full capture ranges. This is confirmed in these results. Using the L1 matcher, the SVI Gen2 Occluded image subset resulted in a high TMR of 64.6% at 65 m and a low TMR of 27.9% at 35 m. One issue can be seen in the performance of the Log Based subset of images. In theory, this subset of images should perform at least as well as all the other subsets since the L1 matcher should be taking the best candidates from them for submission to the gallery. However, this is not the case. At all ranges, the Occluded subset out performs the Log Based subset by a measurable amount. This is a strong indicator that the integration of the L1 algorithm with the SVI Disparity Calculator is not optimized and needs further work.

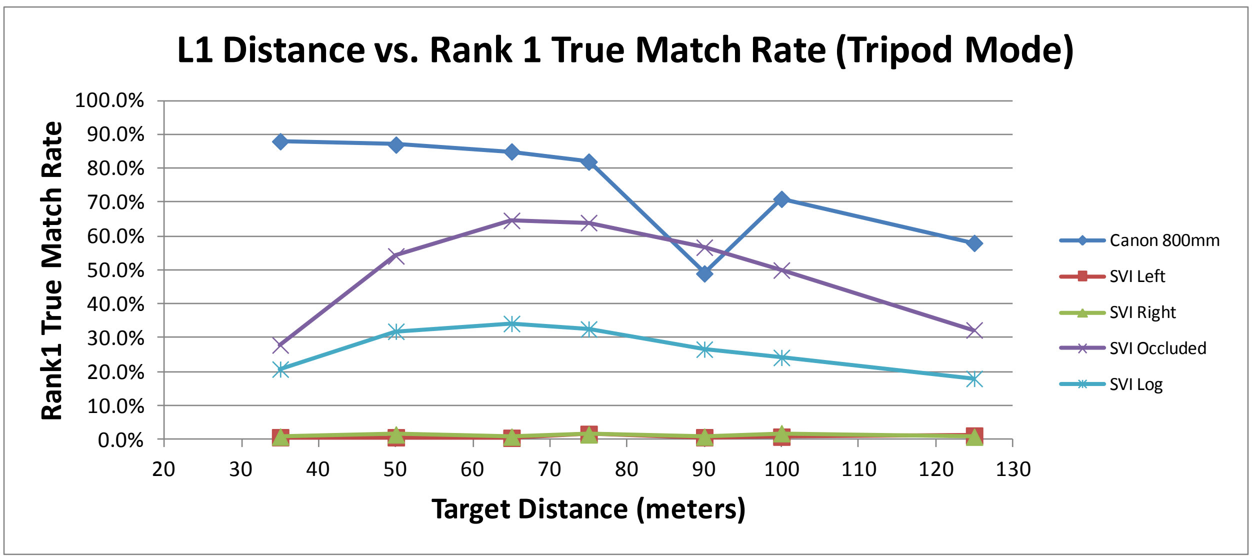


Figure 59: SVI Gen2 Tripod vs. Canon, Rank 1 True Match Rates (L1)

The Canon 800mm outdoor images were used a control comparison. They resulted in a good match performance, with a TMR of 88% at 35 m down to 58% at 125 m. The dip in performance at 90 m is unusual and stands out as a deviation due to some environmental factor during collection. The only explanation identified by the researchers was a decrease in algorithm performance due to the homogeneous pattern-like background of the collection station at that distance (see Figure 60). The SVI Gen2 results did not show a similar dip. This could be because the spatial capture area is smaller than the Canon's. The SVI Left and Right might have poor enough performance that it is not as sensitive to background changes, and in the case of the SVI Occluded, the background was removed and is not a factor. This is mostly speculation, but points to possible future research in the area of facial recognition background removal.

Figure 60: Example Canon Outdoor Image at 90 m
Note that the subject provided permission to reproduce his face image for research reporting purposes in accordance with IRB-approved protocols.

A comparison of the TM rank 1 mean scores at various distances for the SVI Gen2 Tripod Mode L1 matching runs is provided in Figure 61. The Canon 800m has the best set of scores with the SVI Log and Occluded image sets as second best. Unlike the TMRs for the Log and Occluded sets, those matching runs produce equivalent TM rank 1 scores. The cause for that difference is unclear. As expected, the SVI Left and Right image sets produced poor scores, resulting in the poor TMR in Figure 59.

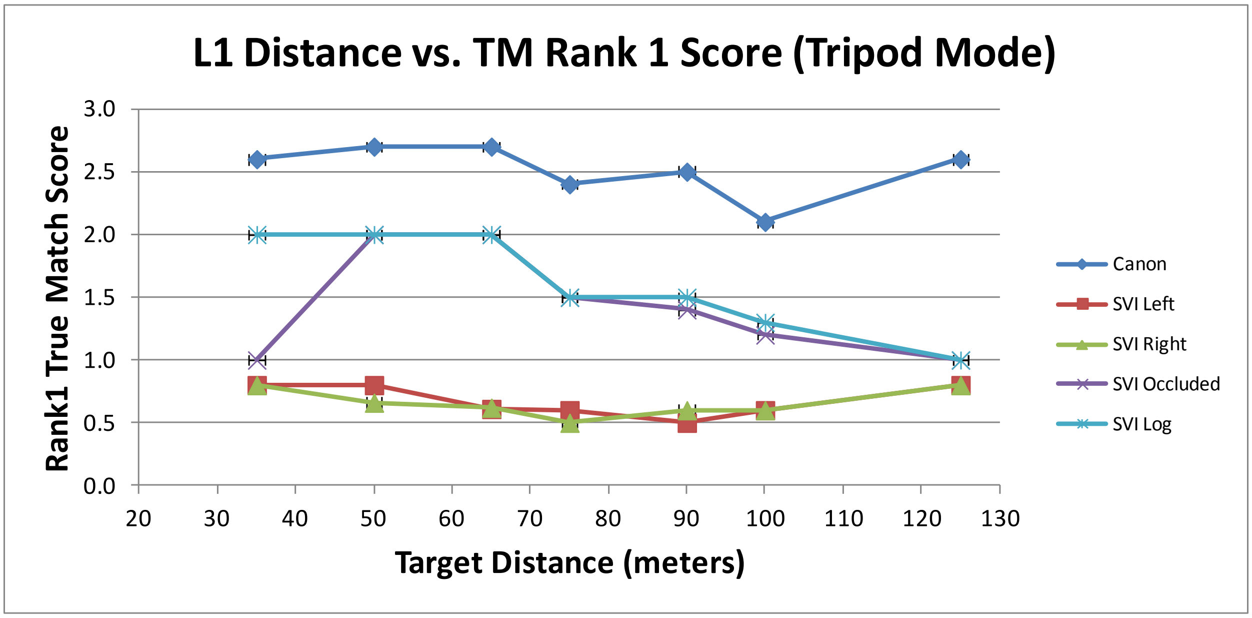


Figure 61: SVI Gen2 Tripod vs. Canon, Rank 1 True Match Similarity Scores (L1)

For completeness, a comparison of the FM rank 1 mean scores at various distances for the SVI Gen2 Tripod Mode L1 matching runs is provided in Figure 62. Because no matching threshold was used during the matching runs, the mean score for false matches would be expected to be independent of the image sets submitted as probes. The results for the various runs confirm this, with all matching runs possessing a score of approximately 0.7.

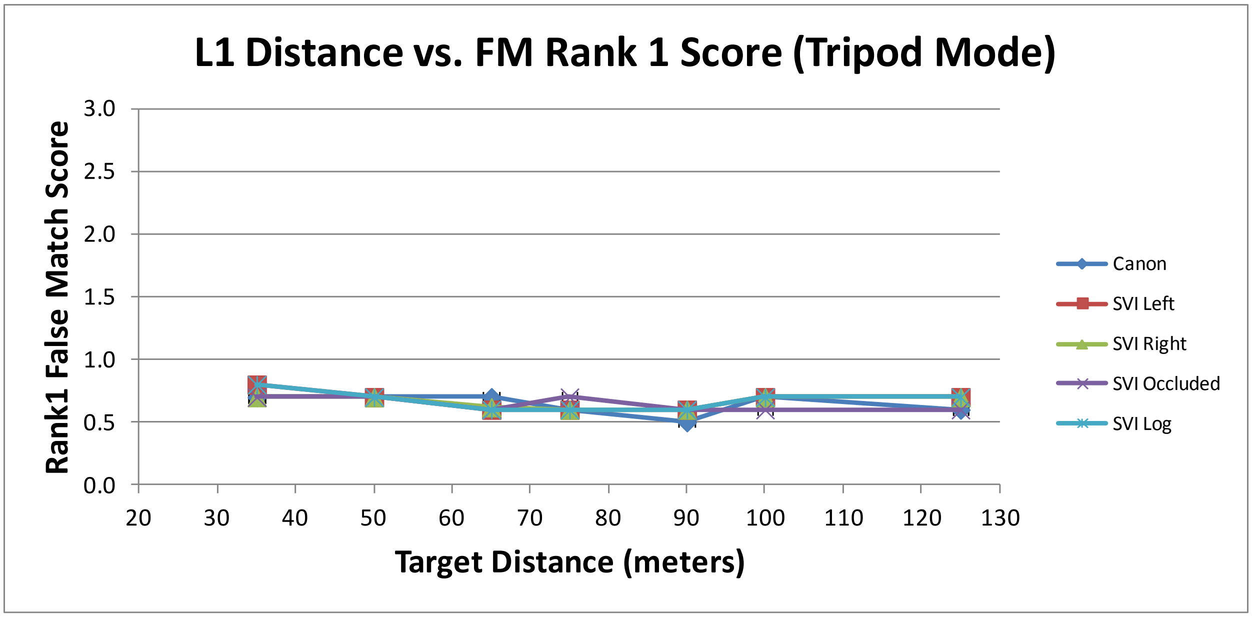


Figure 62: SVI Gen2 Tripod vs. Canon, Rank 1 False Match Similarity Scores (L1)

The SVI Gen2 performance was also evaluated using the MM matcher (see Figure 63). The system performed notable better using this algorithm than with the L1 matcher. A comparison of the matcher performances can be found in Section 7.6 SVI Gen2 Tripod L1 vs. MM. The SVI Gen2 Log Based image subset resulted in a high TMR of 82.5% at 50 m and a low TMR of 11.4% at 125 m. However, all of the image subsets performed at about the same level with respect to TMR, including the Left and Right images. In fact, the Occluded subset resulted in lower or equal TMR at all ranges as compared to the Left and Right. With this matcher, the Log Based approached seemed to work as intended, with its TMR equal or better than all the other image sets. However, since the Left and Right sets performed at roughly the same level as Log Based, the use of background subtraction by including the Occluded images does not appear to have had much (if any) beneficial effect on the overall Log set performance. The Canon 800mm image set performed similarly here as when submitted to the L1 matcher, but without the 90 m dip anomaly.

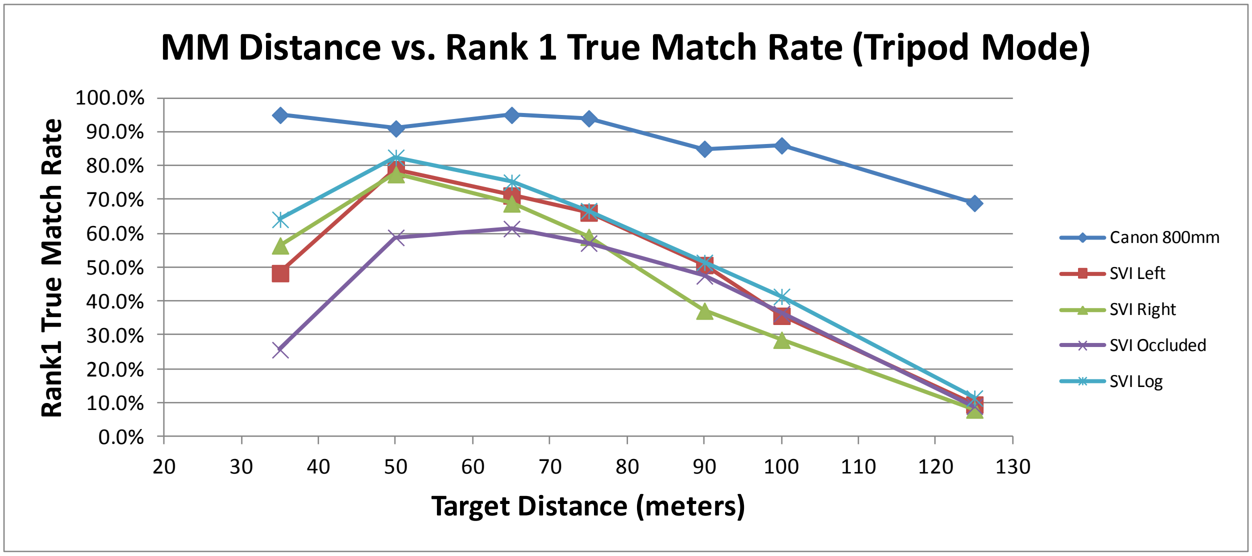


Figure 63: SVI Gen2 Tripod vs. Canon, Rank 1 True Match Rates (MM)

Similar to the L1 matching runs, a comparison of the TM rank 1 mean scores at various distances is provided in Figure 64. The scores parallel the TMRs in Figure 63, with the Canon set having a high average score, decreasing at farther ranges, and the SVI image sets all equal with a peak at 50 m and decreasing farther out.

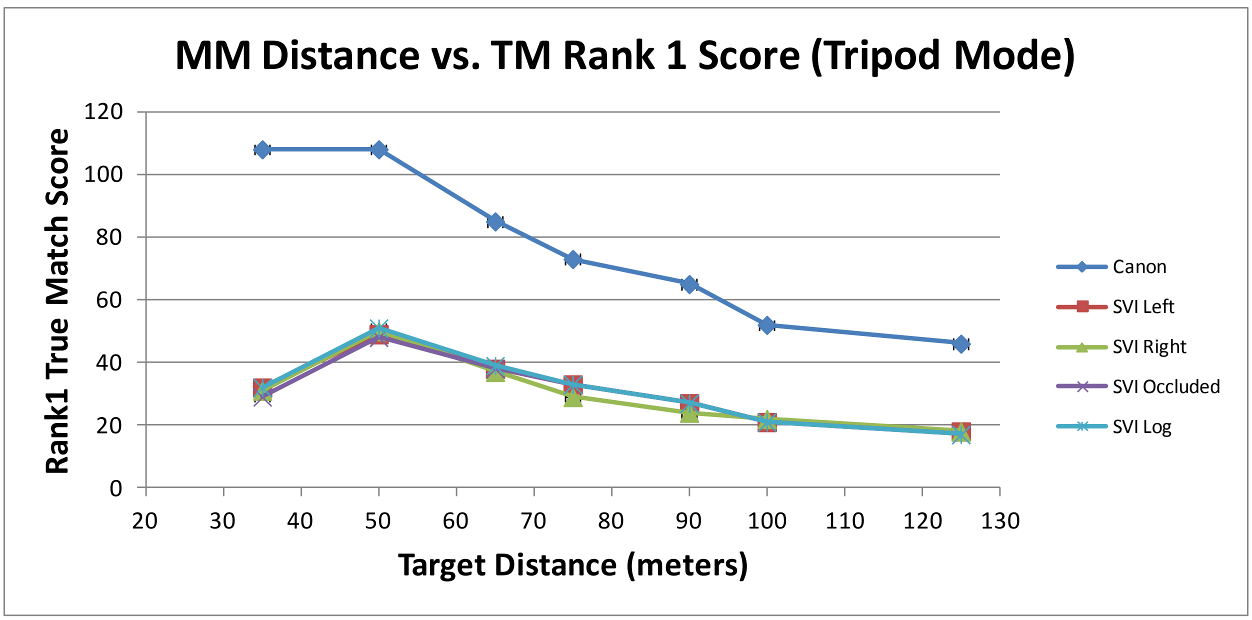


Figure 64: SVI Gen2 Tripod vs. Canon, Rank 1 True Match Similarity Scores (MM)

The FM similarity scores for the MM matching runs of the SVI Gen2 Tripod Mode perform similarly to the L1 matching runs, with all image sets producing the same constant low mean score.

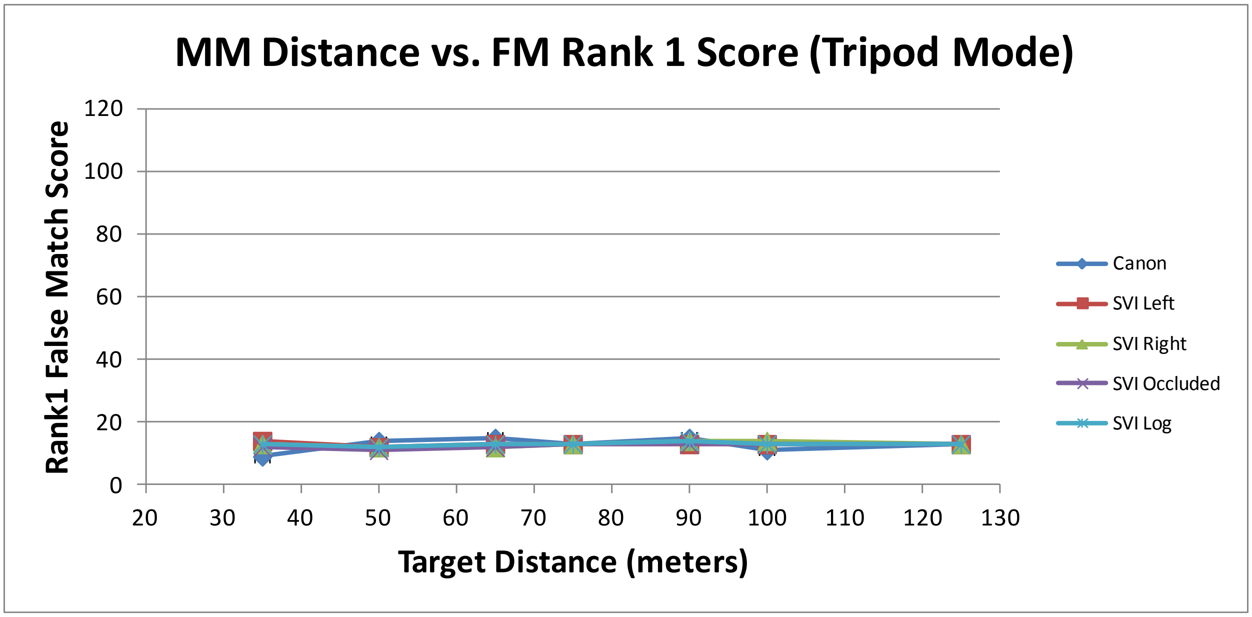


Figure 65: SVI Gen2 Tripod vs. Canon, Rank 1 False Match Similarity Scores (MM)

7.4 SVI Gen2 Handheld vs. Canon 800mm

The performance of the SVI Gen2 system in its alternate Handheld Mode was evaluated as a function of distance. Due to schedule limitations, data could not be collected at the same full range of distances, but the key distances (i.e., 50, 75, and 100m) of the optimal usage and SVI Gen1 functionality were used. Similar to the performance in Tripod Mode (see Figure 59), the Occluded image sets using the L1 matcher outperformed the Log Based images at all ranges, with both sets paralleling each other over the collected ranges. The Occluded matching run resulted in a peak TMR of 55.8% at 75 m; the Log Based matching run resulted in a peak TMR of 29.7% at 75 m. The Left and Right image sets performed poorly, with near zero TMRs.

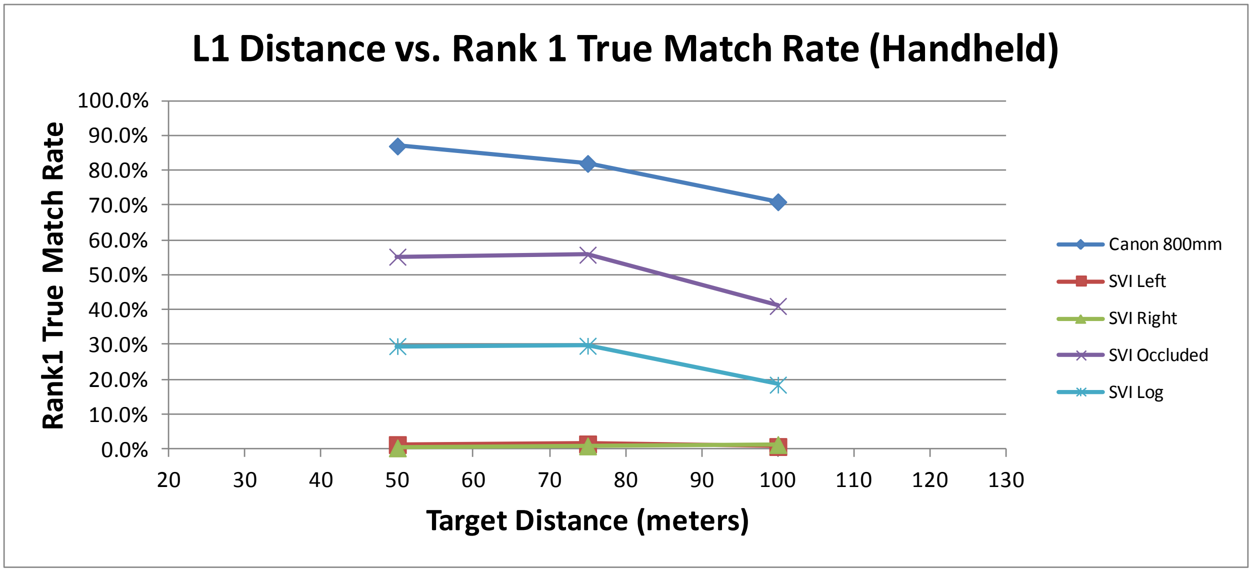


Figure 66: SVI Gen2 Handheld vs. Canon, Rank 1 True Match Rates (L1)

Using the MM matcher, the SVI Gen2 system in Handheld Mode performed adequately at short distances, degrading at long ranges. There was little differentiation across the image sets (see Figure 67). The Left, Occluded, and Log Based image sets all performed equivalently, with a TMR of 55.1%, 55.1%, and 57.6% at 75 m, respectively. The Log Based matching run results did not appear to receive any benefit from the inclusion of images with background subtraction.

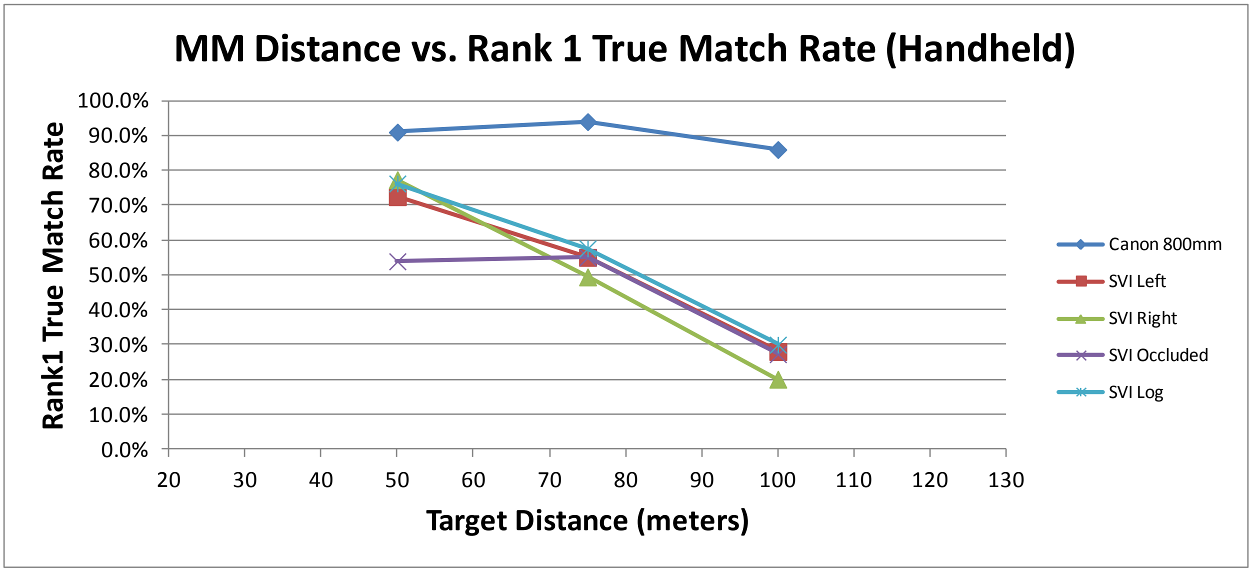


Figure 67: SVI Gen2 Handheld vs. Canon, Rank 1 True Match Rates (MM)

7.5 SVI Gen2 Tripod vs. Handheld

The performance of the SVI Gen2 Tripod Mode was compared to the alternate Handheld Mode to determine. The L1 TMRs as a function of distance for the two system modes is shown in Figure 68. Both modes performed at the same level for all three image sets. One would expect the handheld mode to have poorer starting images due to faster shutter speed and shorter exposure times and therefore poorer matching performance, but that does not appear to be the case. It is the goal of SVI to develop handheld device for use in the field. However, given that there are no target performance benchmarks or requirements for the SVI Gen2, these results do not address whether or not the Tripod and Handheld Modes are performing at a satisfactory level. Note that the handheld images were taken with the device mounted on a tripod and not freely held by an operator. As a result, the stability and reticle alignment issues described in the technology assessment would have played a more significant role and likely reduced the match performances (see Section 3.3 Assessment Negatives).

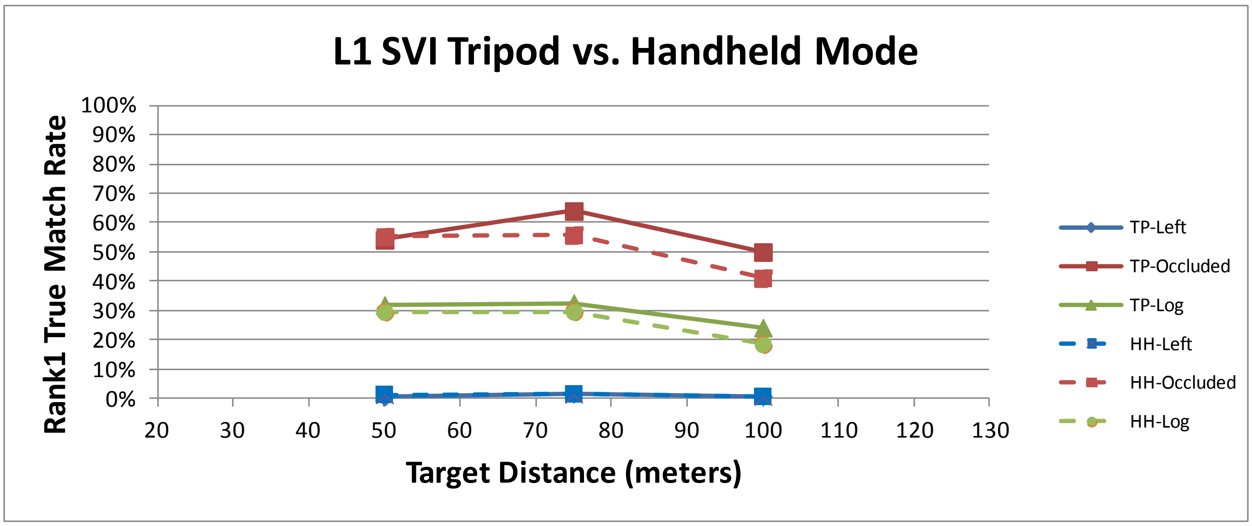


Figure 68: SVI Gen2 Tripod vs. Handheld, Rank 1 True Match Rates (L1)

A comparison of the Tripod and Handheld Modes using the MM matcher also resulted in the same performance across all distances. The MM TMRs as a function of distance for the two system modes is shown in Figure 69.

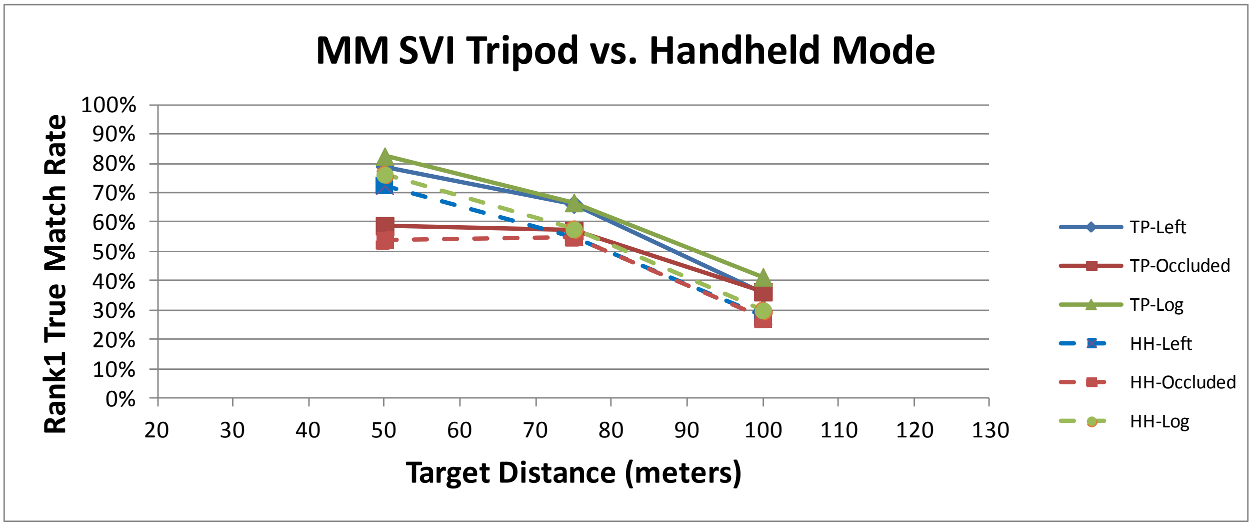


Figure 69: SVI Gen2 Tripod vs. Handheld, Rank 1 True Match Rates (MM)

7.6 SVI Gen2 Tripod L1 vs. MM

The SVI Gen2 Tripod Mode matching runs were evaluated as a function of matching algorithm (i.e., L1 vs. MM). The same data from previous sections is included in a combined manner in Figure 70. The plots are color coded such that Left, Occluded, and Log matching runs have the same color for both L1 and MM for easier comparisons. Examining the Left matching runs, one can see that the TMR was poor for L1, but significantly improved when using the MM algorithm. However, the Occluded matching runs for L1 and MM are comparable in their TMRs across the various distances, with L1 outperforming MM at long distances, such as 125 m. However, the Log matching runs were notably different, with MM again better than L1. In Section 7.3 SVI Gen2 Tripod vs. Canon 800mm the observation was made that the Log matching runs should perform as good or better than both the Left and Occluded matching runs, but that was not the case for L1. This is further emphasized when the data is presented alongside the MM results in this case. Note that in Figure 70, MM Occluded matching runs actually performed less well than the MM Left run. This suggests that the occlusion image processing does not universally improve the match performance of any algorithm. The L1 and MM algorithms probably utilize different (proprietary) methods for generating facial templates from images. These results suggest that MM actually incorporates or takes advantage of some aspect of the background to create an accurate template and that by removing this background in the occlusion process actually degrades the match performance.

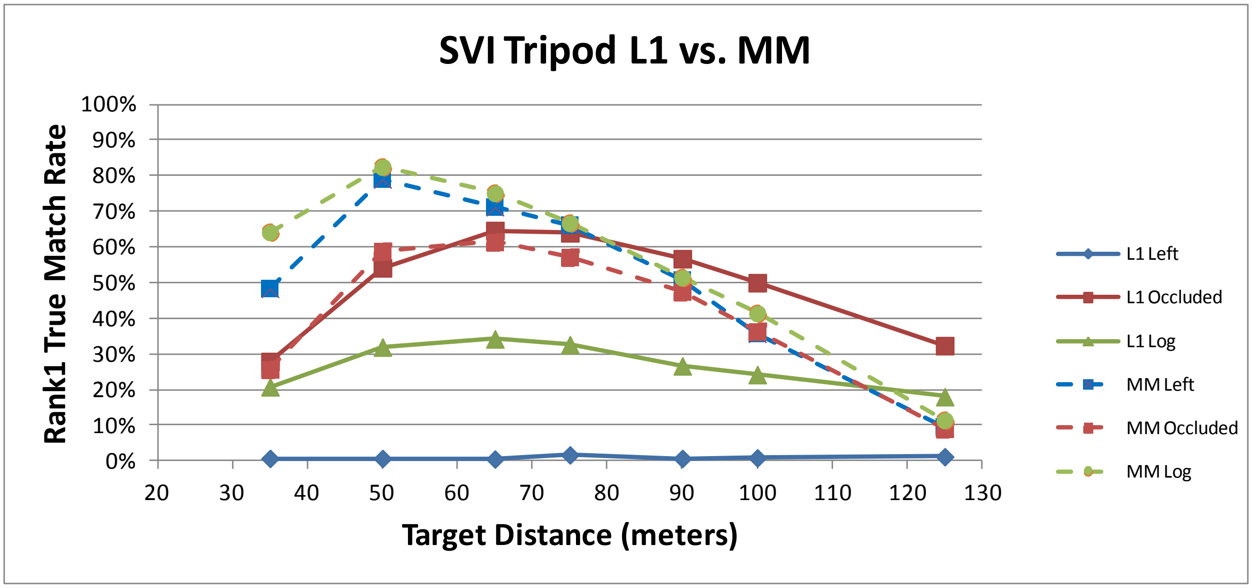


Figure 70: SVI Gen2 Tripod L1 vs. MM, Rank 1 True Match Rates

7.7 SVI Gen2 Tripod vs. SVI Gen1

Data from the Gen1 data collection was used to conduct matching runs that could be directly compared to the SVI Gen2 performance. Figure 71 depicts the TMR at rank 1 for Gen1 and Gen2 using both L1 and MM; the plots are color coded such that between Gen1 and Gen2 for easier comparisons. The SVI Gen1 Log Based matching run results were copied from the Gen1 T&E report, which had covered the full range for that image set.[3] The SVI Gen2 system incorporates many hardware and software changes over the first system (e.g., auto exposure, auto focus, monochromatic cameras). These differences have an apparent positive effect on the TMR performance under both L1 and MM for the Occluded and Log Based image sets. For example, the L1 Occluded matching runs improved from 12.8% to 64.0% at the 75 m distance, while the MM Occluded matching runs improved from 8.0% to 57.2% at 75 m. The system changes performed by SVI have dramatically improved the performance of the binocular system.

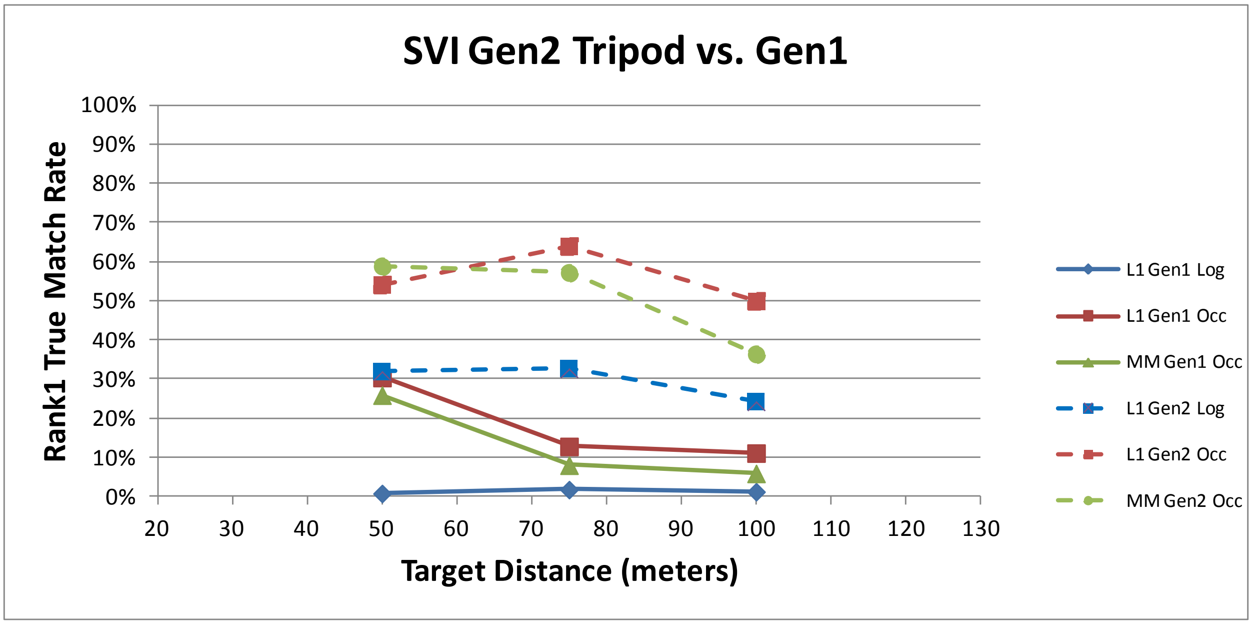


Figure 71: SVI Gen2 Tripod vs. SVI Gen1, Rank 1 True Match Rates

7.8 SVI Gen2 Full System

The data and analysis presented in previous sections has focused on evaluating individual components or image subsets related to the SVI Gen2 system so as to better control and bound the test conditions and parameters. However, the full system functionality for the binoculars involves a more complex use of images to provide the intended capability of identifying a target subject. To better evaluate the full system functionality, additional processes were applied to matching run results.

The intended full use of the SVI Gen2 binoculars functions is detailed in Figure 72 as a process flow diagram. A description of the full system is as follows:

1. A paired set of VUR image clips is captured for a target
2. The image pair is processed by the Disparity Calculator to produce six Left, six Right, and six Occluded images.
3. The resulting images are examined by the L1 quality algorithm and a log is generated identifying the best subset of images to be used as probes.
4. A subset of images is submitted to the matching algorithm for matching against a pre-established gallery. For evaluation purposes, this subset could be the Left, Right, Occluded, or Log Based images. For operational purposes, this would **always** be just those images identified by the L1 quality algorithm (i.e., Log Based image set).
5. All the submitted probes are matched against all the gallery entries, generating a similarity score. Each probe-gallery pair is ranked based on its similarity score within a given probe.
    a. *Note that this is the point that all previous matching run evaluations in this report have stopped. The True Matches at Rank 1 (i.e., TMR) is then used for comparison and analysis.*
6. In the full system use, the gallery manager would identify the probe-gallery match with the best similarity score and return the Rank 1-10 (or whatever threshold rank range selected in a given system) for that probe image to the operator as the top result for review, with the Rank 1 prominently displayed as the "best match."

It is this last step that is important for true operational use because it inherently weights the results based on the best image within each subject's subset of images. For example, take the case where for a given subject five images are selected by the quality algorithm to be bundled as a set of probes. If one of those images is high quality, but the other four are poor quality, the returned results will actually have a high probability of being a correct True Match at Rank 1. Under the approach of processing each of the five probe-gallery matches separately and then combining the results, the TMR will be notable lower.

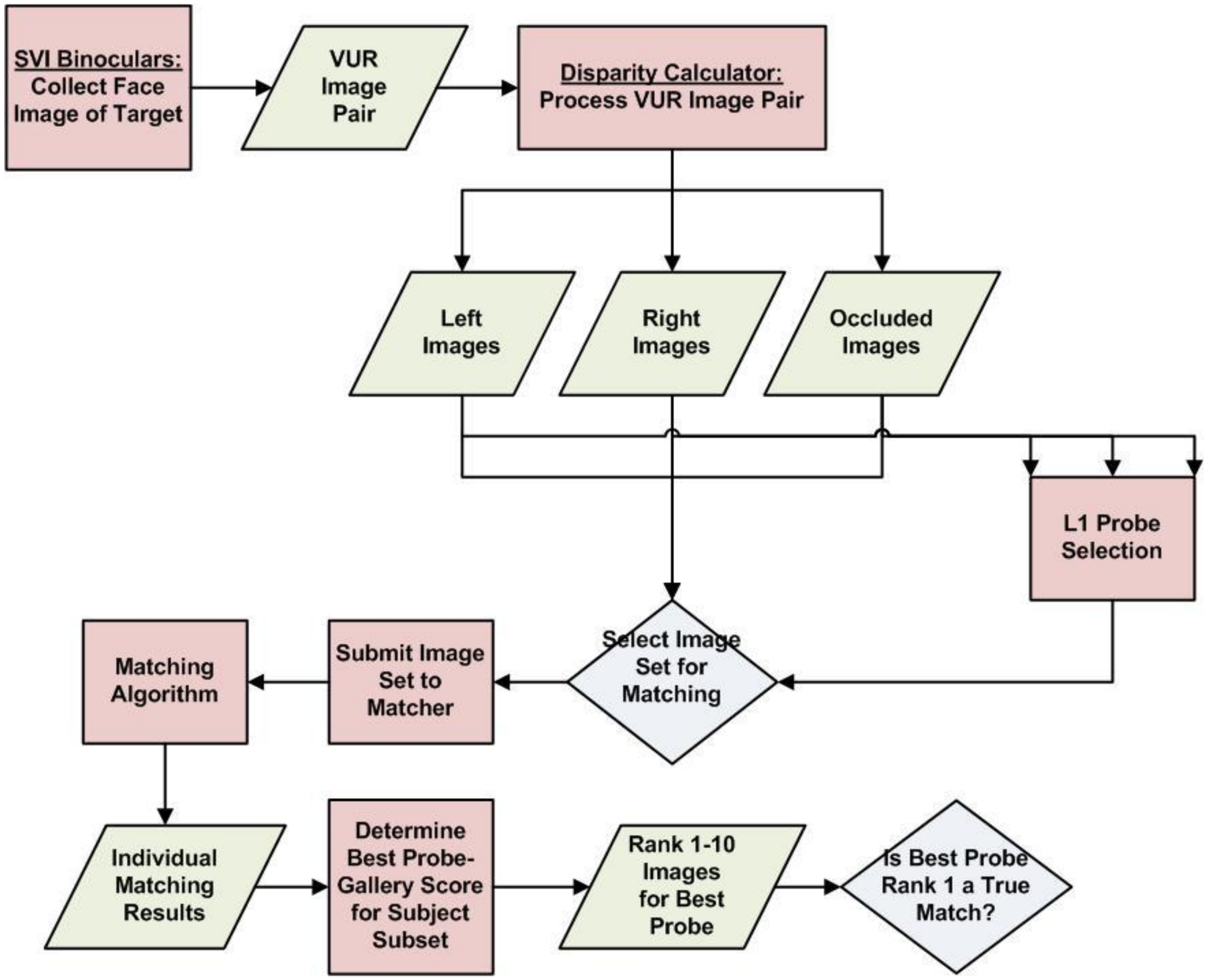


Figure 72: SVI Gen2 Full System Process

Using the full system process, the L1 Left, Occluded, and Log Based image sets were processed using the Best Probe approach described here, and the resulting TMR compared to the default evaluation results using all those images as separate probes. Table 38 summarizes the results.

Table 38: SVI Gen2 Tripod Best Probes, Rank 1 True Match Rates (L1)

Range (meters)	L1 Log Best	L1 Left Best	L1 Occ Best	L1 Log All	L1 Left All	L1 Occ All
35	33%	3%	47%	21%	0.7%	27.9%
50	68%	2%	74%	32%	0.7%	54.2%
65	74%	3%	78%	34%	0.5%	64.6%
75	75%	9%	84%	33%	1.7%	64.0%
90	68%	4%	78%	27%	0.7%	56.7%
100	59%	4%	76%	24%	0.8%	50.0%
125	47%	6%	55%	18%	1.2%	32.3%

The full system matching results for L1 are plotted against distance in Figure 73 and compared with the standard matching runs. There are three important results from this evaluation.

1. The most important one is that given a more operationally-relevant performance metric, the SVI Gen2 system is providing reasonable results with a TMR of 59 – 68% for Log Based image sets in the optimal ranges of 50 – 100 m. The extreme range produces lower TMR, but that is not surprising given the engineering challenges of extending the range of a compact optical system expected to performance over a wide range of focal distances.

2. The second conclusion is that the traditional evaluation method underestimates the performance of the SVI Gen2 system by placing too much value on the poor quality images of a given subject's probe set. Both the Log Based and Occluded image sets performed notable better when allowed to emphasize the best probes as the primary return for a given subject.

3. Finally, this evaluation approach suggests that the issues associated with optimizing the integration of the L1 algorithm in selecting the probe set is not as significant of an issue as the previous matching runs would indicate, but still present (see Section 7.3 SVI Gen2 Tripod vs. Canon 800mm). As stated previously, if the L1 quality algorithm was an accurate reflection of the performance of a given probe, then the Log Based matching runs should produce a TMR equal to or greater than the Occluded matching runs. In the full system evaluation this is still not the case, with the Occluded Best Probe matching run performing 4 – 17% better, depending on the given distance. However, this is certainly better than the 20 – 30% difference observed in the standard evaluations.

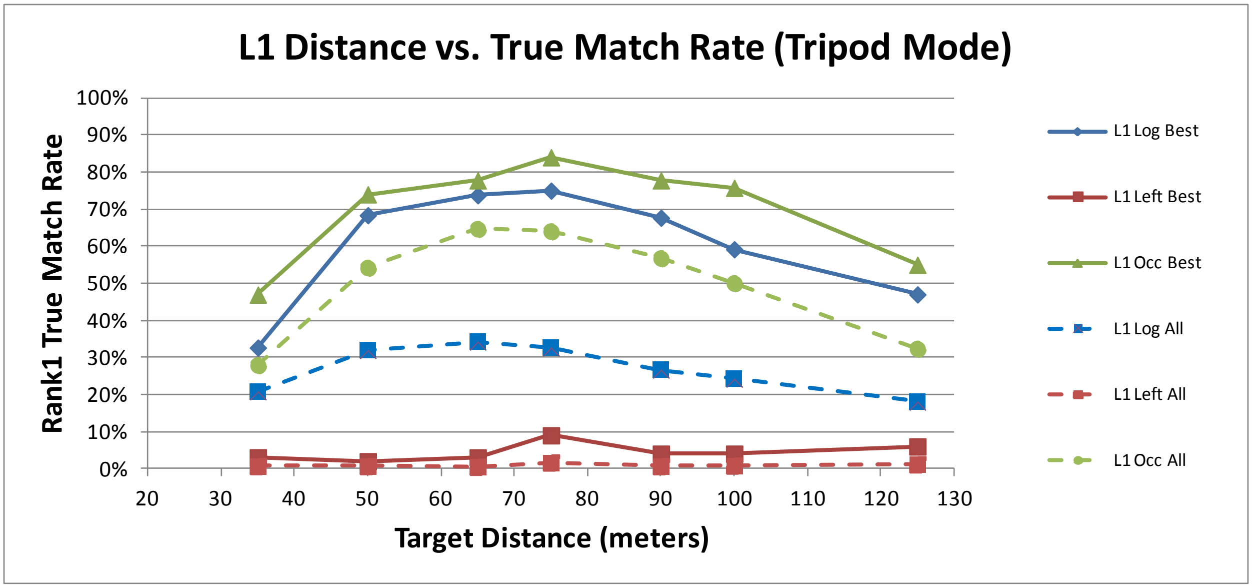


Figure 73: SVI Gen2 Tripod Best Probes, Rank 1 True Match Rates (L1)

Table 39 summarizes the results of the full system performance evaluation using the same image sets submitted to the MM algorithm. The SVI Gen2 system is currently integrated with the L1 ABIS, but for comparison this evaluation is assuming the same image sets are submitted to MM.

Table 39: SVI Gen2 Tripod Best Probes, Rank 1True Match Rates (MM)

Range (meters)	MM Log Best	MM Left Best	MM Occ Best	MM Log All	MM Left All	MM Occ All
35	60%	73%	50%	64%	48%	26%
50	83%	88%	83%	82%	79%	59%
65	80%	86%	89%	75%	71%	61%
75	79%	84%	84%	67%	66%	57%
90	70%	79%	77%	51%	51%	48%
100	63%	74%	71%	41%	36%	36%
125	29%	34%	25%	11%	10%	9%

The full system matching results for MM are plotted against distance in Figure 74 and compared with the standard matching runs. Similar to L1, the full system performs better than processing the image sets as separate probes. However, the improvements are not nearly as significant as in the case of L1. In addition, the Left, Occluded, and Log Based image sets all performed at approximately the same TMR across the full range of distances. This was the case for the standard evaluations as well (as shown in the comparison figure). It is important to note that the L1 algorithm was used as a quality metric for selecting which images to use as probes for a given subject. It is likely that this quality metric is suboptimal for determining the best probes for MM and that if MM was fully integrated with the SVI Disparity Calculator instead of L1, a more notable improvement would be observed between the Left/Occluded and Log Based matching runs. In its current configuration, the full system evaluation further supports the conclusion that the occlusion processing does not provide a significant benefit to TMR when using the MM as the matching algorithm.

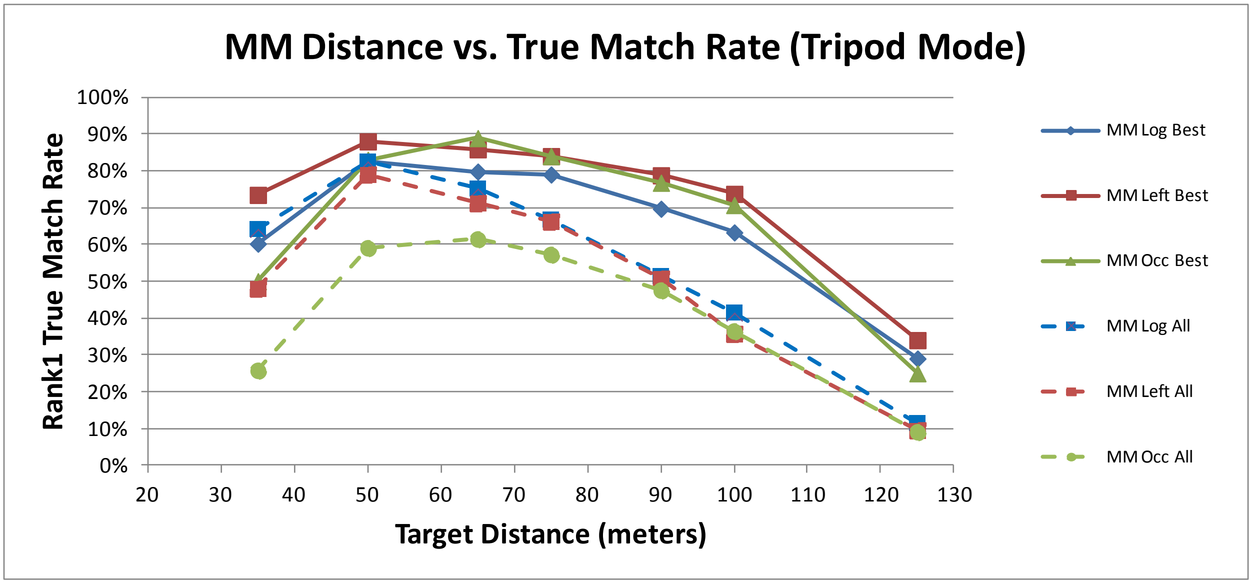


Figure 74: SVI Gen2 Tripod Best Probes, Rank 1 True Match Rates (MM)

7.9 Receiver Operating Characteristic (ROC) Curves

In general signal detection, Receiver Operating Characteristic (ROC) curves are an established method of analyzing the performance trade-off between true and false positives for an imperfect pattern matching system when varying a detection threshold. This report has not focused on ROC curves to conduct its primary analyses and evaluations for a number of reasons:

1. The evaluation methods were chosen to mirror those conducted for the SVI Gen1 system[3] so that a one-to-one comparison of performance with respect to True/False Match Rate could be performed.
2. From an operational perspective, the SVI binocular system was delivered as a black box without instructions on modifying the matching parameters in the L-1 ABIS backend matcher or gallery manager.
3. SVI did not report any ROC curves in its final report for which to serve as a benchmark for comparison.
4. Biometric ROC curves are not as meaningful to practitioners and end-users.

However, two example ROC curves have been provided here to illustrate the biometric system performance and to demonstrate that the existing WVU dataset could be leveraged to perform this type of analysis. Biometric ROC curves are often of primary value to the engineers and scientists conducting the system R&D so as to optimize and improve overall performance. As such, the existing data is available for these purposes if SVI opts to pursue this avenue (see Section 2.2 WVU Face Collection).

7.9.1 Standard ROC Curve

For biometric systems, ROC curves are typically produced by determining the portion of genuine and imposter matches for a given matching run dataset that exceed a threshold value for the matching algorithm being used.[12,13] This calculated data can then be plotted to produce a threshold-independent graph the captures the system performance at a fundamental parametric level. For a given matching run, the Genuine Accept Rate (GAR) and False Accept Rate (FAR) are defined as follows:

Genuine Accept Rate (GAR) – Percentage fraction of all probe-gallery true matches (regardless of return rank) that possess a similarity score equal to or greater than a given matcher threshold value.

False Accept Rate (FAR) – Percentage fraction of all probe-gallery false matches (regardless of return rank) that possess a similarity score equal to or greater than a given matcher threshold value.

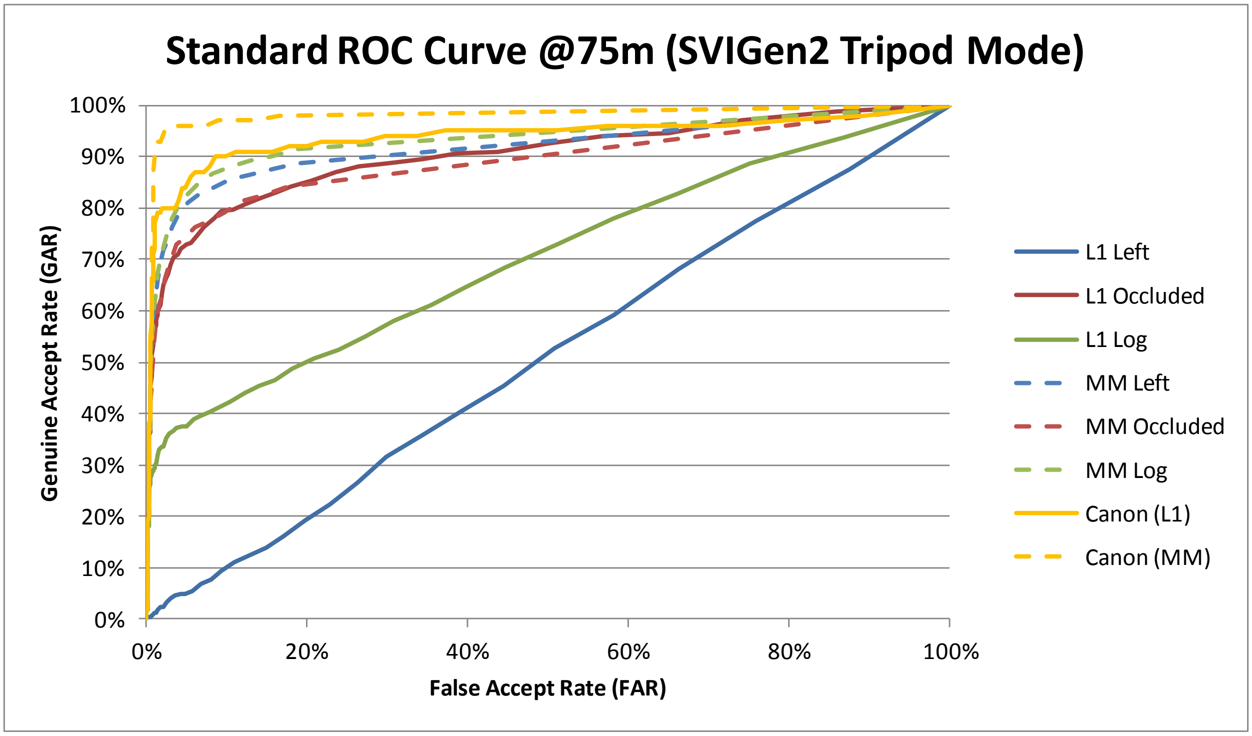


Figure 75: Standard ROC Curve, 75m

Figure 75 shows the ROC curve for the SVI Gen2 (and Canon) at 75m target distance for the various image subsets. Note that the ROC curve does not take into account the ranking of a given true or false match, only whether that probe-gallery match is above a given threshold. The upper right of the plots are the threshold = 0 case where no matches are excluded. Moving from right to left along a given curve represents increasing the threshold value, and subsequently disqualifying some portion of the matches from being returned to the operator. The ideal ROC curve is one that hugs the upper left quadrant such that an increase in the threshold reduces the FAR, but has minimal effect on the GAR. This improves the probability that a returned gallery entry is a True Match, but increases the frequency of a null match response (i.e., no qualified candidate is returned).

In the above example ROC curve, the performances of the various subsets are similar to those in the earlier analysis sections. The SVI Gen2 system using L1 demonstrates poor performance for the Left image set, significantly improved performance for the Occluded images, but a counterintuitive lesser result for the Log Based image set. This is due to the suboptimal L1 integration discussed previously (see Section 7.3 SVI Gen2 Tripod vs. Canon 800mm). The MM matching runs all outperform the L1 for SVI Gen2 and show little sensitivity to which dataset is used for the probes. The Canon shows the best performance, as expected.

7.9.2 Rank 1 ROC Curve

An alternative ROC curve can also be produced that examines the effect of threshold on TMR and FMR at Rank 1. In this approach, a threshold is applied to the list of TMs and FMs at Rank 1 for a given image set and a revised TMR and FMR determined for the entire probe set.

Figure 76 shows this rank 1 ROC curve for the same 75m data used for the previous standard ROC curves.

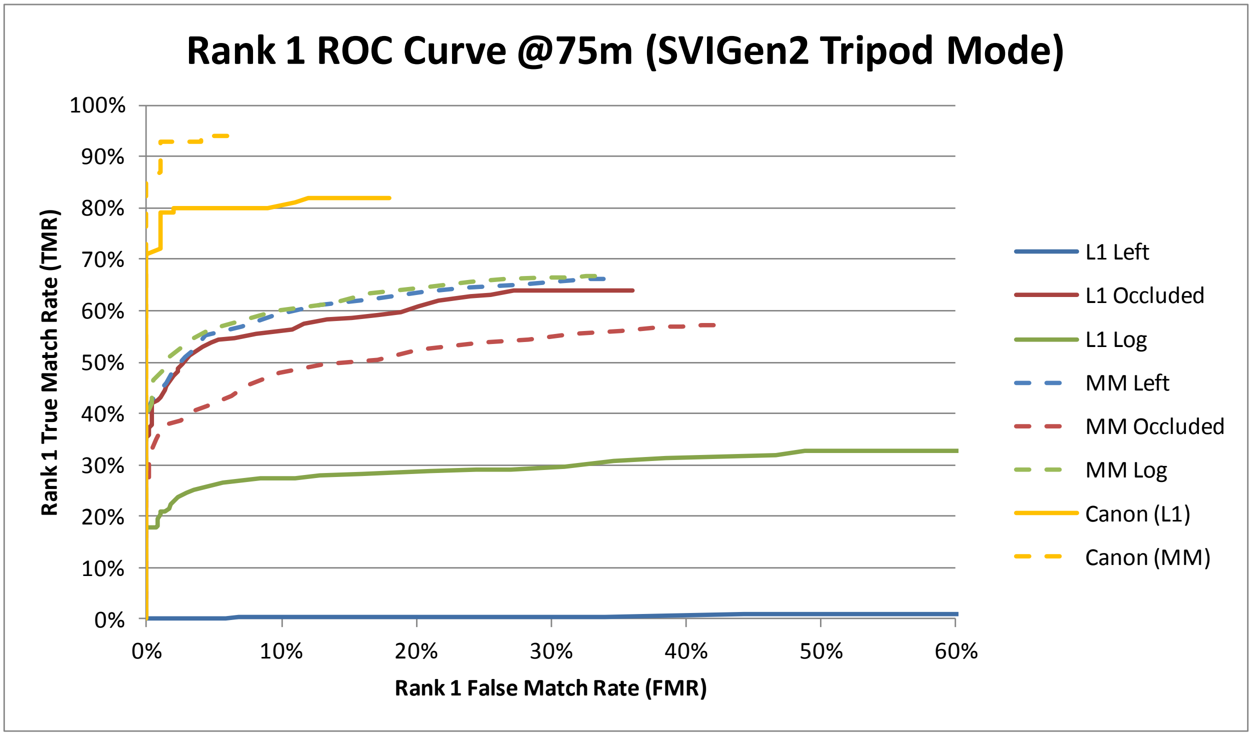


Figure 76: Rank 1 ROC Curve, 75m

In the rank 1 ROC curve, the threshold = 0 case is again the right most data point for a given plot. The values of TMR and FMR at the right most point are the same as what has been reported previously for SVI Gen2 Tripod Mode at 75m (see Figure 59). In addition, it should be noted that at threshold = 0, the TMR and FMR sum to 100% since no matches are excluded. However, as one moves from right to left, the TMR and FMR change with increasing threshold as some matches that would have been returned at rank 1 now fall below the threshold and are disqualified. In these specific cases, a submitted probe returns a null response, or "No Match Found." These rank 1 match rates are directly relevant to operational performance since they reflect real probability performance of receiving a TM or FM and take into account the rank position.

Using the rank 1 ROC curve, one can see how the system could be optimized based on a given end-user or operational use case's requirements regarding what kind of responses are acceptable. For example, the current SVI Gen2 with L1 using the Log Based image set has a relatively flat curve all the way down to FMR = ~10%. At this threshold setting, there would be few FMs returned at rank 1, but there would also be many "No Match Found" responses (~60%). As in previous analyses, the SVI Gen2 L1 Occluded performs better than Left or Log Based, and the SVI Gen2 MM matching runs are insensitivity to which image set is used and perform on par with the best L1 results.

7.10 SVI Gen1 T&E Conclusions

The T&E of the SVI Gen1 binoculars resulted in several key issues/observations relevant to the evaluation of the follow-on Gen2 device.[3] They are reproduced here (with annotations as needed) for reference and as a benchmark for determine how the SVI Gen2 may have evolved or improved. Additional discussions are included to address whether the Gen2 system addresses the item.

7.10.1 Gen1 Item #1

The Disparity Calculator failed to produce occluded images that were acceptable in quality to the L1 matcher. *In all subject cases, left and/or right standard images were determined by L1 to be the best quality and used as probes into the gallery. This is evidenced in the True Match Rates in Run 3 (Log Base, 0.8%) as compared to Runs 4 (All Left, 1.0%) and 5 (All Right, 0.7%). The subprocess that selects images for submission as probes is not working.*

This issue has been addressed. The SVI Gen2 system now includes a large portion of occluded images in its best quality probe sets for each subject. For example, for the SVI Gen2 Tripod Mode 50m Log Based image set 39% of the images were occluded, and 37% for the same collection at 125m. The probe image selection has been significantly improved, but there is room for further optimization of the L1 matcher (see Item #3 below).

7.10.2 Gen1 Item #2

There is a stark improvement in match performance produced by matching all occluded (Run 6, 27.4%) as compared to running all left (Run 4, 1.0%) and right (Run 5, 0.7%) images produced by the Disparity Calculator. *The background removal does improve match performance in this system, however; the current implementation does not seem to choose any occluded images.*

This observation is true for L1, but not for MM. The match performance for the Occluded image set is significantly improved over the Left and Right when using the L1 matcher (see Figure 59). However, when using the MM matcher the occluded image set is actually worse than the left and right at short distances and roughly equivalent at longer ranges (see Figure 63).

7.10.3 Gen1 Item #3

The significantly improved match performance of the MegaMatcher over the L1 matcher in Runs 3, 4, and 5 (Log Based, All Left, and All Right respectively) leads the test team to believe that some parameter(s) of the L1 matcher is incorrectly set. *The results of Runs 1, 2, 6, and 7 shows that the L1 and MegaMatcher are about equal in rank 1 True Accept Rates. In fact, the L1 is slightly better.*

This issue still remains. The L1 matcher is not optimized with respect to processing and selecting SVI images. Figure 70 shows that the L1 Occluded matching runs perform better than the L1 Log Based runs, as high as 30% better at some distances.

7.10.4 Gen1 Item #4

The Disparity Calculator produces occluded images that often contain partially or fully obscured faces. *This is observed qualitatively in examining resulting images, and is confirmed in the improvement in match performance when face finding is used as filter. The match performance between Runs 6 and 7 (All Occluded and Occluded with Faces, respectively) almost doubled, from 27.41% to 50.52%. The Disparity Calculator settings for automated processing require further adjustment or improvements.*

This issue still remains. Table 36 shows examples of partial and fully obscured faces from the occlusion process. However, it is difficult to determine the degree to which this is an issue. There is clearly a benefit provided to the L1 Log Based matching due to the inclusion of occluded images. One metric that speaks to this issue is the NMR when using the MM matcher (i.e., the number of subjects that could not be ingested by MM). At the optimal ranges of 50 – 100m this rate does not exceed 6%, which is reasonable. However, at 125m the NMR increased to 12.5%. There will always be a trade-off between aggressively removing background content and removing aspects of some subjects' faces. A parametric study of the Disparity Calculator occlusion variables as a function of matching run results would shed additional light on this topic.

8.0 CONCLUSIONS

In general, nine key conclusions were identified during the evaluation:

1. **The Gen2 system demonstrates a dramatically improved performance over the Gen1 device.** The hardware and software changes to the Gen2 have made an apparent significant positive effect on the TMR performance under both L1 and MM for the Occluded and Log Based image sets. For example, the L1 Occluded matching runs improved the TMR from 12.8% to 64.0% at the 75 m distance, while the MM Occluded matching runs improved from 8.0% to 57.2% at 75 m (see Figure 71).

2. **The Gen2 binoculars are a significant improvement over Gen1 in terms of functionality, but there are still issues that need addressing before becoming an operational product.** As discussed in Section 3.0 3DMOBILEID TECHNOLOGY ASSESSMENT, improvements are needed in image stabilization, lighting exposure, options for data transfer, ruggedization, and device housing.

3. **Based on the full system evaluation, the SVI Gen2 performs well and is on track to be a usable law enforcement device.** The full system evaluation is a more operationally-relevant evaluation method and better encapsulated the performance of the SVI binoculars. The SVI Gen2 system in Tripod Mode with the L1 matcher possessed a TMR of 59 – 68% for Log Based image sets in the optimal ranges of 50 – 100 m (see Figure 73). In the MM matching runs, the system produced a high TMR of 83% at 50 m with the Log Based image set (see Figure 74). The standard evaluation methods used in the majority of this report and in the Gen1 analysis likely underestimates the performance of the binoculars.

4. **The 3DMobileID may need to include more capabilities, such as video capture, before law enforcement is willing to adopt the system.** Based on practitioner engagement, and given constrained budget and operational requirements, agencies need systems that serve more than one role.

5. **Removing the background through the occlusion process improved the match performance of the SVI Gen2 system when using the L1 matcher.** The SVI Gen2 Tripod Mode L1 matching run using all the Left or Right image set had a TMR < 2%, while the same images after undergoing occlusion processing resulted in a high TMR of 64.6% at 65 m (see Figure 61). In Handheld Mode, the Occluded matching run resulted in a peak TMR of 55.8% at 75 m, with Left and Right matching runs producing a TMR < 2% (see Figure 66).

6. **Occluded images do not improve the performance of MM matching runs, and can sometimes hinder the performance of the system.** In Tripod Mode with the MM matcher, the TMRs of Log Based matching runs parallel those of the Left and Right matching runs. The Occluded matching runs perform worse than all others at target distances of 35 – 75 m and comparable at the longer ranges (see Figure 63). These results emphasize the fact that not all algorithms work the same and suggest that a background removal process may be algorithm dependent in its added benefits.

7. **Integration of the L1 matcher with the Disparity Calculator is incorrectly or suboptimally setup.** The Log Based matching runs should perform as well, if not better, than the Occluded matching runs. It should select the best images for submission as probes for a given subject. However, Figure 70 shows that the Tripod Mode L1 Occluded matching runs perform better than the L1 Log Based runs, as high as 30% better at some distances. Similarly, the Handheld L1 Occluded matching runs resulted in a peak TMR of 55.8% at 75 m, while the Log Based matching run resulted in a peak TMR of 29.7% at 75 m (see Figure 66).

8. **When braced on a tripod, the Tripod and Handheld Modes perform comparably.** This was true for both L1 and MM matchers, as depicted in Figure 68 and Figure 69, respectively. The faster shutter speed and shorter exposure time of the Handheld Mode did not affect the match performance at any distance. Note that the handheld images were taken with the device mounted on a tripod and not freely held by an operator, which could reduce match performances.

9. **SVI and future T&E efforts should conduct a parametric study of the effect of Disparity Calculator occlusion parameters on matching performance.** Further improvements to the occlusion image process and subsequent match performance may be realized by thoroughly exploring this parameter space.

APPENDIX A: WVU LONG-RANGE 3D FACE COLLECTION – PHASE II

Long-Range 3D Face Collection – Phase II
8/2018 - 12/2013

FINAL REPORT

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

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

This project was supported by Award No. 2010-IJ-CX-K024, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

Contents

1. Project Overview

The purpose of this data collection was to obtain data to enable the evaluation of a prototype binocular-based stereoscopic facial image acquisition system developed by StereoVision Imaging, Inc. (SVI), by comparing to data captured using similar COTS facial imaging hardware. In addition, human factors information was collected from operators performing the data collection to assess the operability of the prototype device. The original target number of participants for this collection was 100 based on initial evaluation of SVI image quality and hardware performance. Data collection took place between 8/19 and 11/25/2013 with 100 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 seven WVU staff members.

2. Data Collection

Data collection was performed on the WVU Evansdale Campus. The collection utilized existing equipment from FBI biometric collection projects as well as equipment provided by ManTech. The location for the collection was outside of the Engineering Sciences Building atrium and the Engineering Research Building. This provided unobstructed views from 35 meters to 125 meters for participant data collection. Data was collected from each device and assembled in a common data repository on a regular basis.

2.1 Imaging Devices

Data collection was performed using three different facial imaging devices.

1. SVI binoculars prototype
2. Digital SLR camera
    a. Outdoor: Canon 6D digital SLR camera with a Sigma Zoom Super Telephoto 300-800mm f/5.6 EX DG APO IF HSM Autofocus Lens
    b. Indoors: Canon 5D Mk II digital SLR camera with a Canon EF 70-200mm (f/2.8L, image stabilized) lens

Images of these devices are shown in Fig. 1.

Figure 1: Imaging Devices: prototype SVI stereoscopic binoculars (left), Canon 5D MkII with 800mm super-telephoto lens (right).

2.2. Collection Site

The following section describes the arrangement of the equipment used for the data collection.

2.2.1 Indoor Ground Truth Photo Capture

A Canon 5D Mark II DSLR camera and a Sigma EF 70-200mm f/2.8L IS II USM telephoto zoom lens were used for high-resolution ground truth image capture. Camera settings were as follows:

- White Balance: Tungsten
- ISO: 1000
- F/#: 1/10
- Exposure: 1/60 sec.
- Resolution: 5616x3744
- Horizontal/Vertical ppi: 72/72
- Bit Depth: 24

This camera was used to capture 5 different poses:-90 deg, -45 deg, 0 deg, 45 deg, 90 deg. A schematic view of the indoor photo collection is shown in Fig. 2.

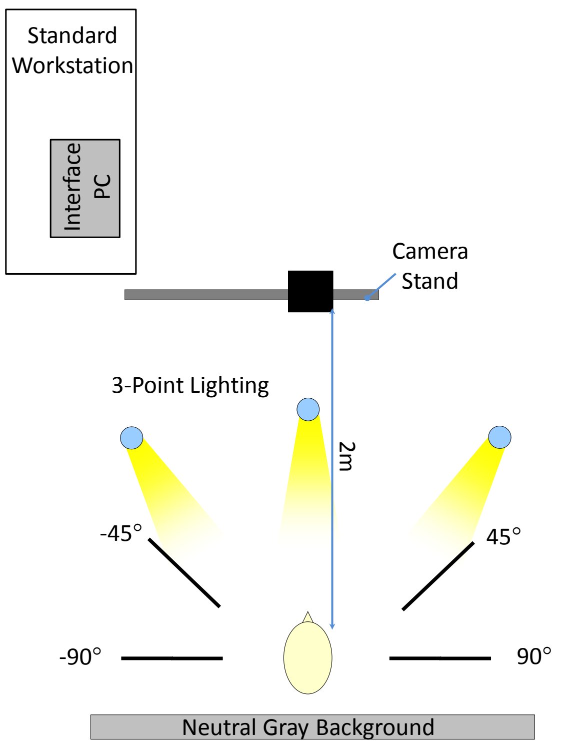


Figure 2: Photo station layout.

3-point lighting is used to meet standards outlined in ANSI/NIST–ITL 1-2007 Best Practice Recommendation for the Capture of Mugshots [1]. The lighting is comprised of one 250-watt

1. http://www.nist.gov/itl/ansi/upload/Approved-Std-20070427-2.pdf

fixture and dual 500-watt fixtures. The positioning of these sources with respect to the participant is slightly asymmetric and there is sufficient distance between the backdrop (neutral gray) and the participant to avoid shadows on the background. In addition, plastic diffusers in front of the reflector-mounted light bulbs are utilized to avoid "hot spots" on the face.

2.2.2 Outdoor Image Capture

This iteration of the SVI binoculars has auto-focusing and auto-exposure capabilities. Images were captured at distances of 35, 50, 65, 75, 90, 100 and 125 meters to survey the quality of images at varying distances from the SVI camera system. To accommodate these large distances, data collection was performed outdoors on the WVU Evansdale engineering campus. A schematic view of the collection setup is shown in Fig. 3.

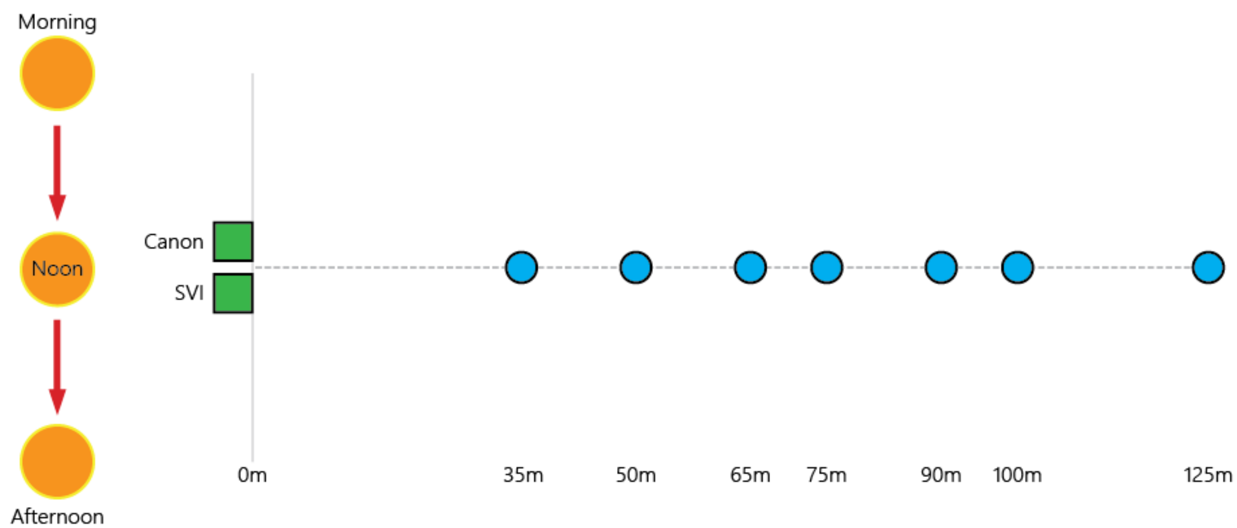


Figure 3: Outdoor collection setup.

The imaging devices were co-located to make imaging distances as equivalent as possible. Camera alignment was chosen to provide varied natural illumination on the faces throughout the day. By situating the cameras and image capture direction so that the sun was behind the collection hardware, facial illumination was most uniform during midday, with strong left or right illumination in the morning and afternoon. This was mainly the case for sunny days, with cloudy or overcast days resulting in uniform facial illumination. Since the Engineering Research Building blocked the light from the left side of the face, most strong illumination appears on the right side of the face in sunny conditions.

The SVI camera included a pre-set exposure setting called, 'Tripod Mode.' In this mode, the binoculars auto-corrected for exposure differently than when turned off. This led to challenges acquiring images in low-light conditions (dusk, cloudy, overcast, etc) with tripod mode set to "off." Due to time limitations and with the consent from ManTech Inc. images which normally would be collected with Tripod Mode *off*, could be collected with the mode *on* when necessary. This was to allow for a higher exposure during lower light conditions.

2.3 Data Types & Organization

The following data was collected from each participant:

- Indoor photos (image distance = 2m), low-compression JPEG format and camera raw (.cr2):
    - ground truth image of participant holding random ID number
    - ground truth image of participant holding white balance color card
    - one image of frontal (0 deg) pose*
    - one image 90 deg*
    - one image -90 deg*
    - one image 45 deg*
    - one image -45 deg*

    * some participants had two sets of these photos taken
- Outdoor photos/video
    - SVI binoculars
        - images captured at 35, 50, 65, 75, 90, 100, and 125 meters with 'Tripod Mode' *on*
        - images captured at 50, 75, and 100 meters with 'Tripod Mode' *off*
        - A left and right JPEG image at each distance
        - all images also in SVI proprietary VUR format
    - Canon Camera with 800mm lens
        - One image at each distance captured in camera raw CR2 and low-compression JPEG

The file structure for the dataset is as follows:

- Canon Indoor
    - RID
        - Original (Raw data: includes RID and Color Card photos)
        - SAP_50 (Cropped to SAP 50 Standard 3300 X 4400: RID and color card not included)
        - SAP_51 (Cropped to SAP 51 Standard 2400 X 3200: RID and color Card not included.
- Canon Outdoor (First 59 participants)
    - RID
        - Cropped (1024 X 1365)
            - 35
            - 50
            - 65
            - 75
            - 90
            - 100
            - 125
        - Moved (Contains whitespace at top so the AutoCropper could be used)
            - 35
            - 50
            - 65
            - 75
            - 90

            - 100
            - 125
        - Original (Raw Data)
            - 35
            - 50
            - 65
            - 75
            - 90
            - 100
            - 125
        - SAP_50 (3300 X 4400)
            - 35
            - 50
            - 65
            - 75
            - 90
            - 100
            - 125
        - SAP_51 (2400 X 3200)
            - 35
            - 50
            - 65
            - 75
            - 90
            - 100
            - 125
- Canon Outdoor (Last 41 Participants)
    - RID
        - Cropped (1024 X 1365)
            - 35
            - 50
            - 65
            - 75
            - 90
            - 100
            - 125
        - Original (Raw Data)
            - 35
            - 50
            - 65
            - 75
            - 90
            - 100
            - 125

- SVI
  - RID
    - 35
    - 50
    - 65
    - 75
    - 90
    - 100
    - 125

The reason for the change in structure approximately half way through the collection was due to changing the crop dimensions of the outdoor images as permitted by ManTech Inc.

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.

<u>2.4.1 Consent</u>

Greet the participant and provide the consent form. Explain each section of the consent form to include 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 photographs taken by different types of cameras, including a prototype system
- Participation is strictly voluntary; they may opt out of the process at any time.
- Inform the participant that they will be receiving a gift card upon completion of data collection and that if they choose to not complete the study they will not receive the gift card.

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

<u>2.4.2 Enrollment</u>

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 indoor photo station

2.4.3 Indoor Photos

1) Have the participant stand at the intersection of the lines on the ground in front of the camera, facing the camera. An overview of the area in which the participant will be standing is shown in Fig. 4.

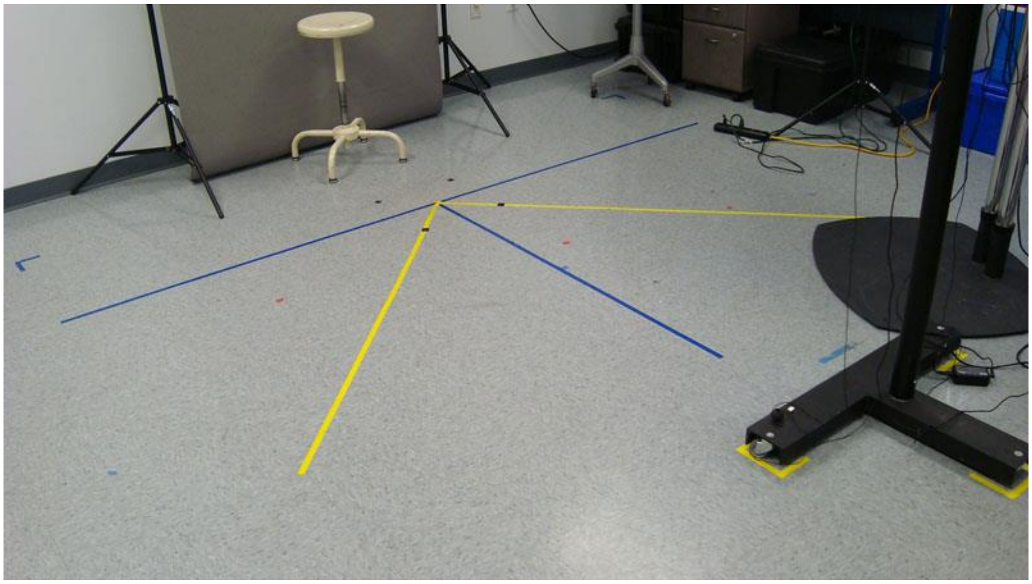


Figure 4: Pose angle indicator lines.

2) Turn on the Canon EOS 5D Mark II and adjust the camera height and angle such that the participant is framed in the picture as shown in Fig. 5. Have them hold the barcode up as shown; they are permitted to wear their glasses for this photograph and the white balance color card only. All further photos must be taken without glasses and, if applicable, hair kept behind the ears

Figure 5: Ground truth photograph.

3) Begin the photo capture by taking a ground truth photo. After capturing the Ground Truth photo and white balance color card photo, the participant will turn and face -90 deg towards the camera. They will then turn to align with -45 deg and so on, until they are facing 90 deg for the final photo. Foot placements for some of these shots are shown in Fig. 6.

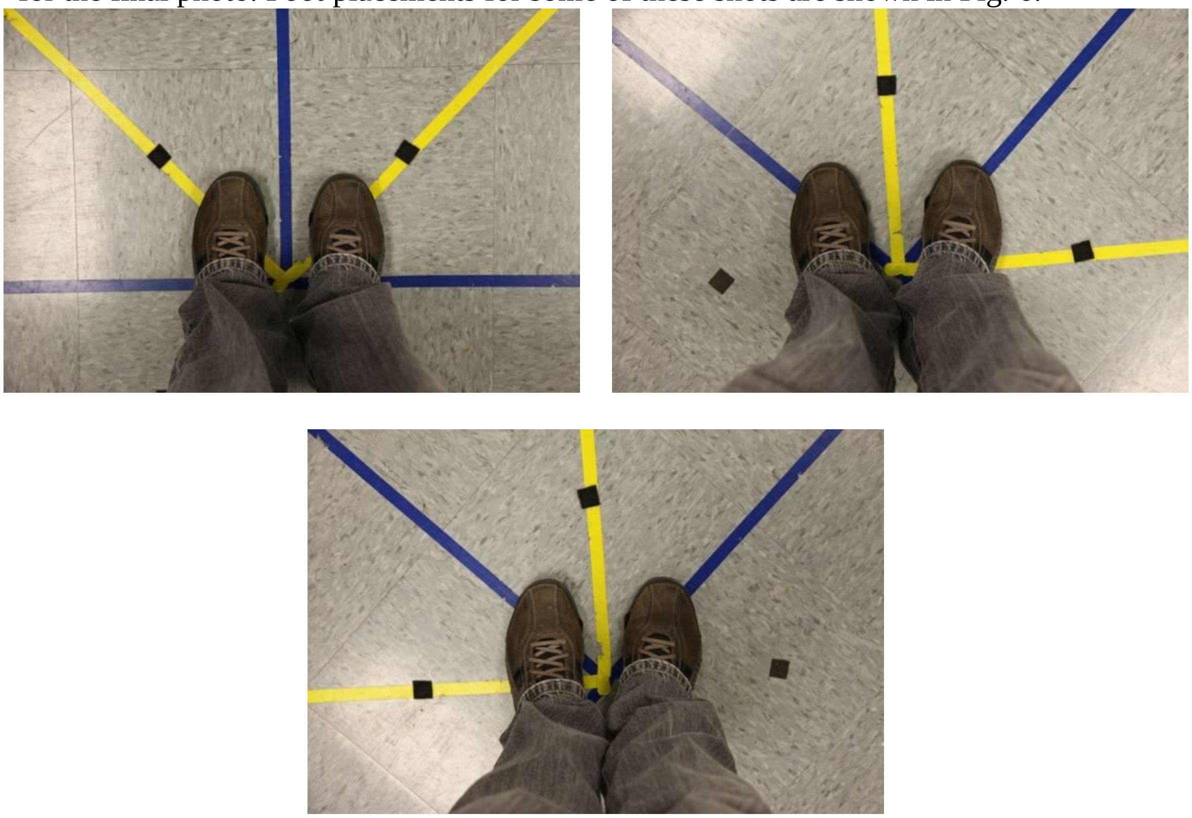


Figure 6: Proper foot placement for all pose angles.

2.4.4 Outdoor Image Capture

After completing the indoor photo session, the participant will proceed outdoors for the remainder of the collection. The outdoor equipment should be set up prior to the day's collection activity. It takes 10-15 mins to set up the equipment and take test shots to ensure proper sensor operation under the current outdoor conditions. The following equipment is used in the camera setup:

- StereoVision Imaging (SVI) camera with battery power supply and wireless dongle for communicating with the laptop computer
- Canon Mark II camera with 800mm lens
- 2 tripods
- Laptop computer for data transfer
- Location markers for each location (tape was used and applied one time at the beginning of the collection)

The collection hardware should be configured as follows:

1. Place the cameras on their respective tripods and ensure level with bubble indicators. The SVI camera should be on the right and the Canon camera on the left of the equipment setup, . The battery power supply should be sufficiently charged and plugged into the SVI camera.
2. Check that the Canon is set to automatic focus, full-auto operation (green square on selector knob).
3. The SVI collection software should be started and made sure to be connected to the camera. This is done by completing step 1 above, assuring that the Tripod Mode checkbox is checked and that the checkboxes for saving images as both '.jpg' and '.vur' are checked.
4. A test image should be captured with the SVI (with both the 'Tripod Mode' *on* and *off*) and Canon cameras to assure that images are able to be captured and that the images are clear and useful. *Note: taking photos with both Tripod Modes requires a restart of the application.*

After setup is complete, the collection procedure for each participant is as follows:

At Distance = 35 m

1. Collection guide walks with participant to 35 meter marking tape and instructs participant stand in position then records the lux value (light reflecting from the face of the participant).
2. Take the SVI Images
   a. Center the participant's face inside the reticule
   b. On the laptop computer, with 'Tripod Mode' *on* click the Capture Image button within the GUI. The images are finished being captured when the camera beeps once.
3. Take the Canon Image
   a. Align the participant's face in the center of the viewfinder and press the capture button

At Distance = 50 m

1. After completing the 35 meter location, the collection guide escorts the participant to 50 meters and repeats the 35 meter procedure.
2. Take the SVI Images
   a. Center the participant's face inside the reticule
   b. On the laptop computer, with 'Tripod Mode' *on* click the Capture Image button within the GUI. The images are finished being captured when the camera beeps once.
3. Take the Canon Image
   a. Align the participant's face in the center of the viewfinder and press the capture button

At Distance = 65 m

1. After completing the 50 meter location, the collection guide escorts the participant to 65 meters and repeats the procedure.
2. Take the SVI Images
   a. Center the participant's face inside the reticule

    b. On the laptop computer, with 'Tripod Mode' *on* click the Capture Image button within the GUI. The images are finished being captured when the camera beeps once.
3. Take the Canon Image
    a. Align the participant's face in the center of the viewfinder and press the capture button

At Distance = 75 m

1. After completing the 65 meter location, the collection guide escorts the participant to 75 meters and repeats the procedure.
2. Take the SVI Images
    a. Center the participant's face inside the reticule
    b. On the laptop computer, with 'Tripod Mode' *on* click the Capture Image button within the GUI. The images are finished being captured when the camera beeps once.
3. Take the Canon Image
    a. Align the participant's face in the center of the viewfinder and press the capture button

At Distance = 90 m

1. After completing the 75 meter location, the collection guide escorts the participant to 90 meters and repeats the procedure.
2. Take the SVI Images
    a. Center the participant's face inside the reticule
    b. On the laptop computer, with 'Tripod Mode' *on* click the Capture Image button within the GUI. The images are finished being captured when the camera beeps once.
3. Take the Canon Image
    a. Align the participant's face in the center of the viewfinder and press the capture button

At Distance = 100 m

1. After completing the 90 meter location, the collection guide escorts the participant to 100 meters and repeats the procedure.
2. Take the SVI Images
    a. Center the participant's face inside the reticule
    b. On the laptop computer, with 'Tripod Mode' *on* click the Capture Image button within the GUI. The images are finished being captured when the camera beeps once.
3. Take the Canon Image
    a. Align the participant's face in the center of the viewfinder and press the capture button

At Distance = 125 m

1. After completing the 100 meter location, the collection guide escorts the participant to 125 meters and repeats the procedure.

2. Take the SVI Images
    a. Center the participant's face inside the reticule
    b. On the laptop computer, with 'Tripod Mode' *on* click the Capture Image button within the GUI. The images are finished being captured when the camera beeps once.
3. Take the Canon Image
    a. Align the participant's face in the center of the viewfinder and press the capture button

Traveling back to camera station:

At Distance = 100 m

1. Computer operator restarts the SVI application
    a. Operator does **not** check the 'Tripod Mode' check box, but still checks the save file type checkboxes of '.jpg' and '.vur'. The operator then connects the SVI camera via the connect button in the GUI.
2. The collection guide escorts the participant back to the 100 meter mark.
3. Take the SVI Images
    a. Center the participant's face inside the reticule
    b. On the laptop computer, with 'Tripod Mode' *off* click the Capture Image button within the GUI. The images are finished being captured when the camera beeps once.

At Distance = 75 m

1. After completing the 100 meter location, the collection guide escorts the participant to 75 meters and repeats the procedure.
2. Take the SVI Images
    a. Center the participant's face inside the reticule
    b. On the laptop computer, with 'Tripod Mode' *off* click the Capture Image button within the GUI. The images are finished being captured when the camera beeps once.

At Distance = 50 m

1. After completing the 75 meter location, the collection guide escorts the participant to 50 meters and repeats the procedure.
2. Take the SVI Images
    a. Center the participant's face inside the reticule
    b. On the laptop computer, with 'Tripod Mode' *off* click the Capture Image button within the GUI. The images are finished being captured when the camera beeps once.

Consent forms are checked again at this point assuring all items are properly noted and correctly filled. The participant is then instructed to affirm they have received a gift card and the gift card is given to the participant.

2.4.5 Post-Processing

After completing the participant collection. Computer operator assures that all lux values are recorded in the lux table. Operator also assures that each participant has 40 image files from the SVI camera in total (which includes both JPEG and '.vur' files) and moves files into a folder designated for each participant. After all participants are complete for a given day, the Canon images were then added to the appropriate participant folders.

An automatic cropping tool was provided by Azimuth, Inc, Autocropper, to crop the images taken by the Canon camera to a uniform size and resolution. This was performed for both the indoor and outdoor photos. Cropping was performed on the outdoor photos to reduce their size to make them compatible with automated matching software. The procedure for cropping the images is as follows:

1. Open Autocropper and select 'open images.'
2. From here select the 'Canon' folder for the participant and select the first photo. The image will open in Autocropper and a red 'T' will appear on the screen.
3. Place this red 'T' so the crossbar is across the subject's eyes and the vertical bar is down the center of the nose.
4. Double click, and the image will automatically crop, save, and close.
5. Do this for all Canon images in the participant's directory.

The indoor ground truth photos were cropped to SAP 50 and 51 pixel sizes: 3300x4400 and 2400x3200 respectively. For the outdoor Canon photos, the participant may have been positioned in the image frame such that these images could not be cropped to SAP 50 size without first shifting the image position in Photoshop due to the position of the horizontal eye-marker line in the Autocropper tool. This shift often caused significant white space above the participant's head, which could lead to non-ideal behavior when the images were fed into automated matching software. To address this issue, outdoor Canon photos were cropped to a smaller size of 1024x1365 pixels (*NOTE:* This is the cropping dimension used for the outdoor Canon photos on the Phase I collection as well, and was performed using the Autocropper tool).

3. Collection Demographics

The charts on pages 16-20 provide information on cumulative participation in the data collection and a breakdown of ethnicity, age and gender. Figs. 7 and 8 provide weekly and cumulatve participation respectively. Fig. 9 indicates that Caucasians make up 79% of the participants, followed by Asian Indians (6%) and Asians, African Americans and Hispanics (all at 4%), and Africans (3%). This ethnicity distribution is consistent with the WVU student population. Fig. 10 indicates that the majority of participants were in the 20-29 age range, making up 85% of the total. Fig. 11 shows that male participation was greater than female for all ethnicities.

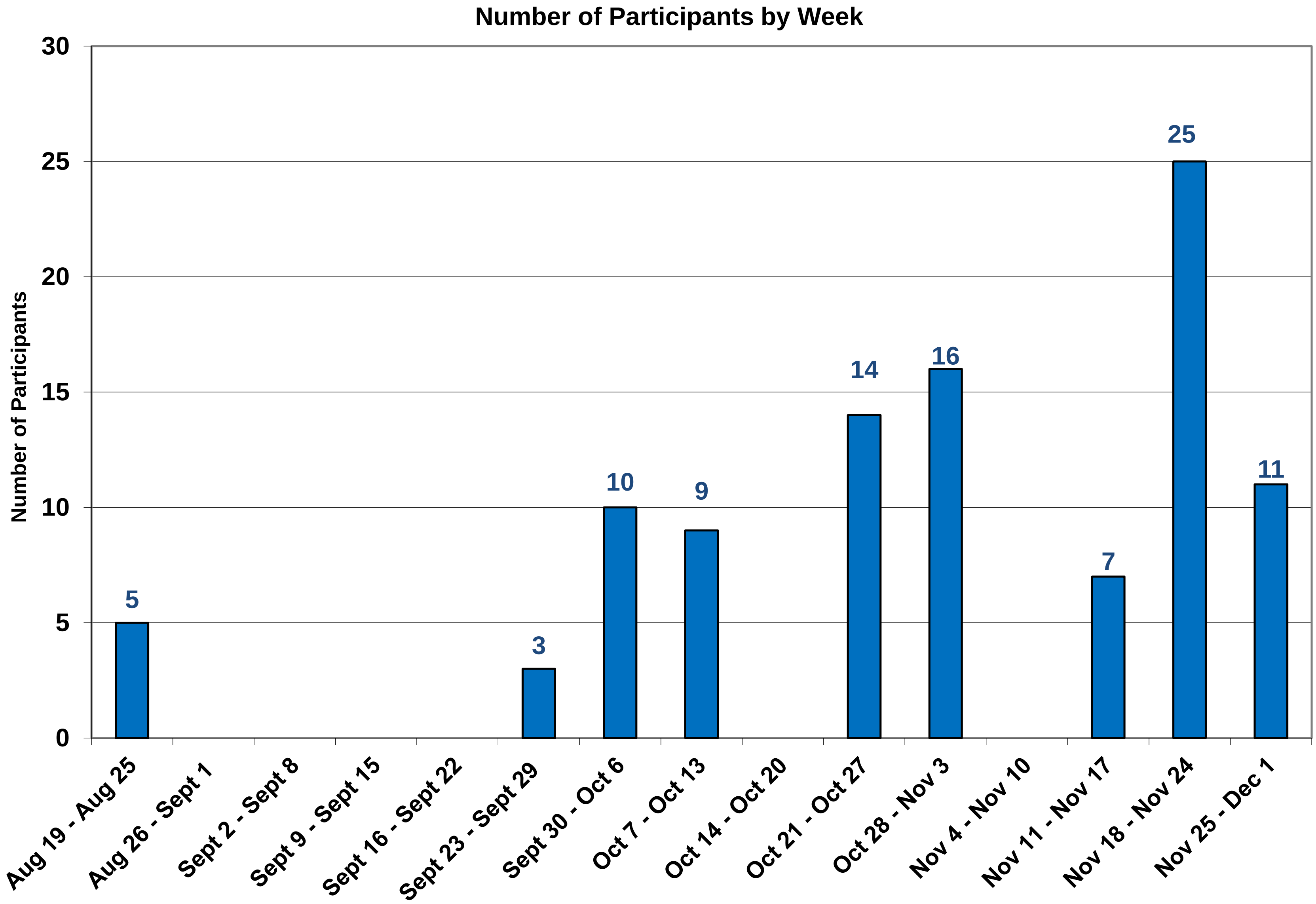


Figure 7: Number of participants by week.

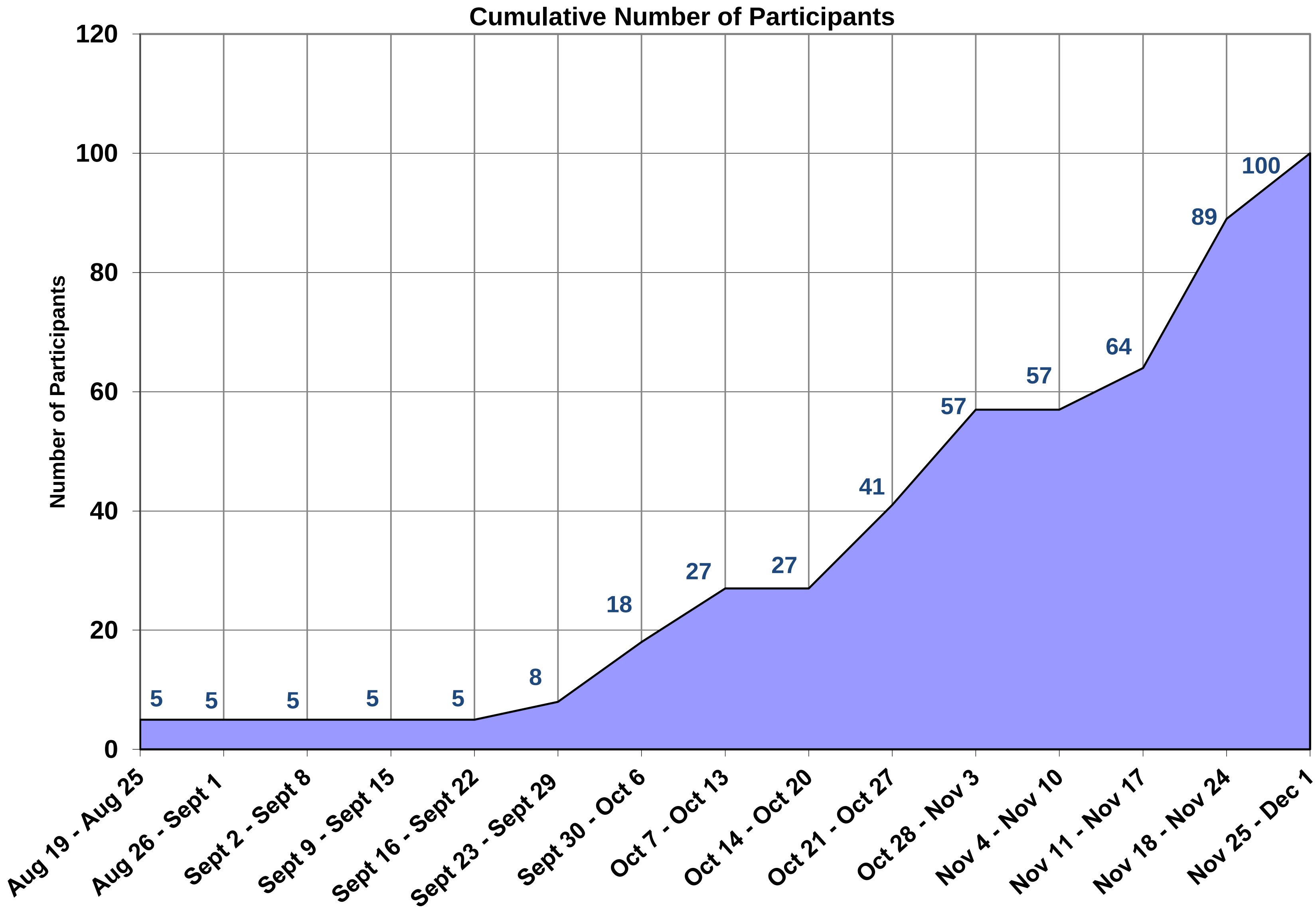


Figure 8: Cumulative participation.

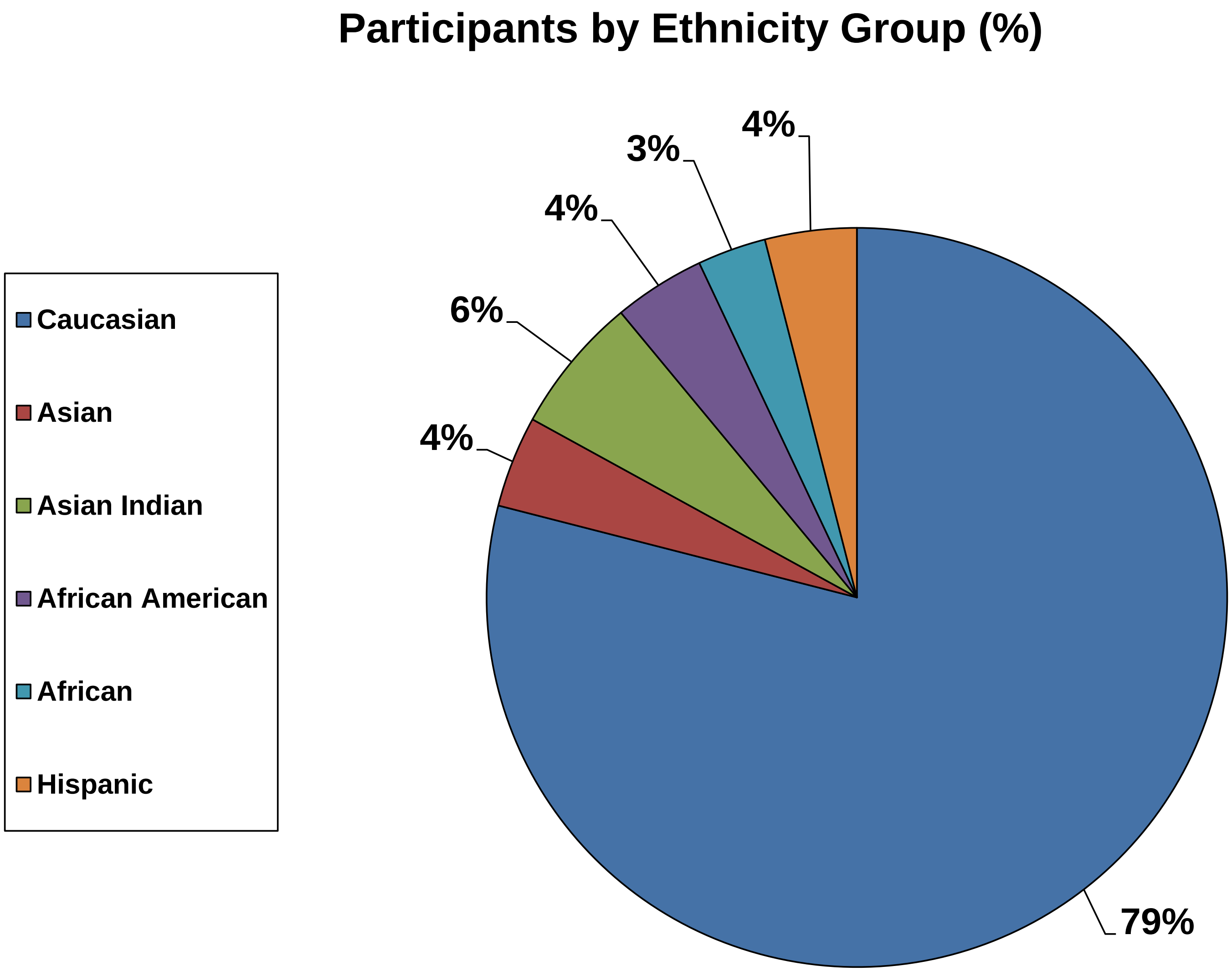


Figure 9: Participant ethnicity.

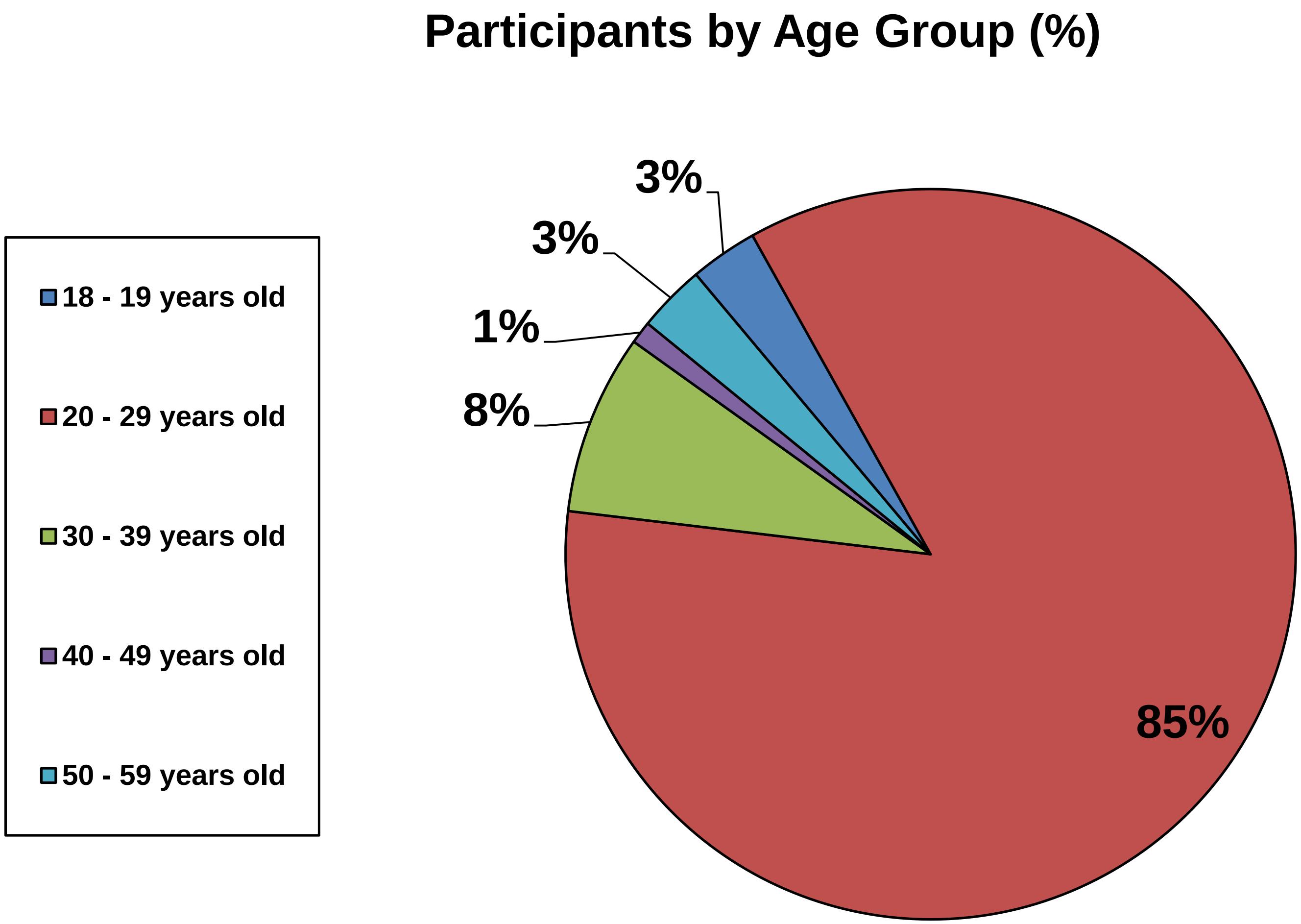


Figure 10: Participant age.

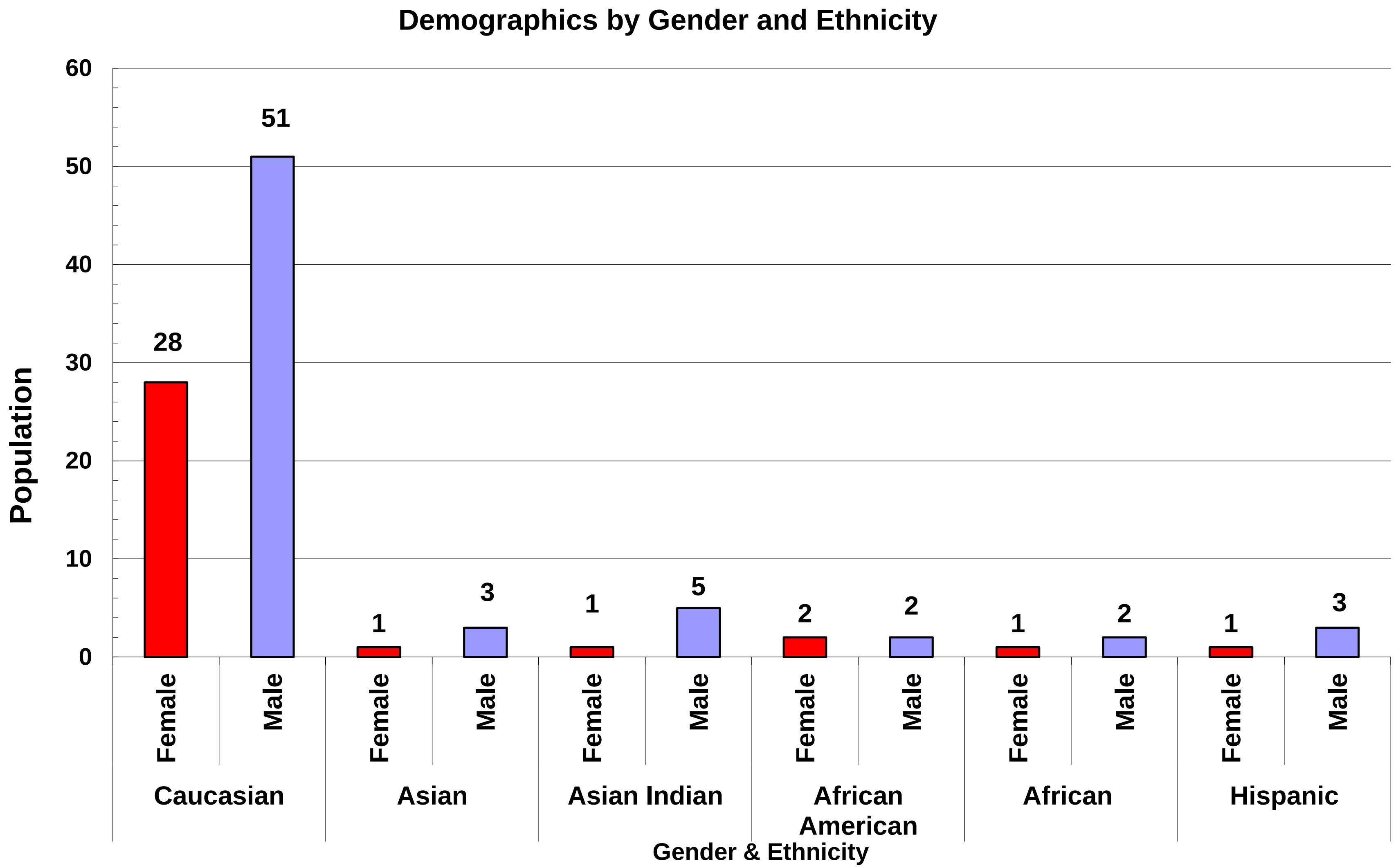


Figure 11: Breakdown of gender & ethnicity.

4. Damage Information

As previously mentioned the initial SVI prototype was damaged and replaced. The damaged occurred on October 9th, 2013 after the morning session of data collection during the clean-up procedure. This led to a two week delay in collection. Another delay also caused two days of down-time with the first prototype due to there being a problem with the wireless dongle connecting the SVI camera to the laptop. The SVI camera was replaced with another prototype and collection proceed.

5. Operator Feedback

The operators who performed the bulk of the data collection were asked to provide feedback on their experience using the SVI binoculars alongside other commercial image acquisition devices. They were to comment on the following aspects of their interaction with the various devices during the data collection process:

- What did you like about the SVI system?
- What were the biggest issues/challenges to operating the SVI system?
- What changes should be made to make the SVI system easier to use?

Anonymized, unedited responses from seven operators are provided below.

Operator 1

> Understanding that this system was in fact a prototype, several observations were concluded throughout the duration of the collection. There were favorable features with this system which made the process easier from the collection stand point. There were however nuances which required explicit care during collection to avoid faulty data or missing information. Collectively, the best feature was the auto-focusing portion of the system. When the system was in full operation with no error, participants could be fully collected via the outdoor equipment in as little as ten to fifteen minutes. While not functioning at all distances – most notably at 35 meters – the system itself avoided a great deal of operator error by including this feature in the system. The challenges of the collection were numerous; however, this required that those collecting data were very knowledgeable about common and frequent errors of the system. Initially, in the first prototype, wireless connection issues were prohibitively common. These issues often required an entire system restart (of both the computer and the camera) and even then was no guarantee of a successful connection. Keeping the battery pack fully charged for a full day of collection became more of a challenge as the weather became colder. The battery life significantly suffered in cold temperatures often requiring the collection to be put on hold for around thirty minutes or more since passive charging was not an option. Again, knowing that this collection was done with prototyping equipment, these issues were expected. When the camera was powered off, images left in the buffer were sent to the computer and saved, this also occurred when the camera would fail to focus or an error dialog box would appear on screen during collection. The biggest problem encountered with the system was the amount of contrast required for the images to capture. On many collection days, by as soon as 3 p.m., the camera would fail to capture an image due to poor

lighting from the setting sun. This was most notably seen in the *Tripod Mode* 'on' setting where the exposure was decreased, thus depending on greater ambient lighting. Minor issues included the reticule not being centered on the captured image, requiring the participant to need intentional misalignment to fully capture the face.

Operator 2

The main difference observed between the two versions of the system is the auto focus feature. In the old version, there was no auto focus. In order to capture the best data possible, the camera focus needed to be set to a designated distance. This required the subject to stand at 25, 50, 75 and 100m as well as 3m in front of and behind the designated distances. This increased the number of images to be captured and caused the duration of the collection to take up to 80 minutes per subject. With the new system, there was no need for the subject to stand at +/- 3m. The average duration per subject dropped down to about 20 minutes.

Another feature added to the newer version was the wireless functionality. The camera could connect to a computer via a wireless USB dongle. This feature posed new problems compared to the onboard memory storage built into the older version. On many occasions, the camera would disconnect from the workstation or it would send corrupted data either from a driver error or outside interference. The cause of many of these problems was not repeatable in some circumstances. From an operational standpoint the newer system was a large improvement from the previous version but there are still many issues that need to be addressed.

Operator 3

While I did not work in the previous collection where the SVI was also used, I was present during most times data was being collected for this one. The general set up was good, and was designed to really help the users get quick efficient data. Out of all the equipment used during the collection, the main issues arrived from the SVI camera – computer interface.

The SVI camera worked well when functioning properly. We would receive random camera errors, or dongle connection issues at times in the middle of collecting or when we first started the camera, which slowed things down extremely. We would have to cycle the power and application once or several times, until the camera would work. It is unknown why these errors would occur, since at times it would occur with no movement or change in the entire system. Even with these, the overwhelming largest issue was the exposure rate necessary for the camera when tripod mode was off. The extended exposure required a large amount of light and limited the times of day we could even collect data. Any overcast, early morning, or late afternoon times were almost certain to fail with this setting on the camera. Even with these errors though, the camera did perform well when it worked. It was very simple for users and easy to troubleshoot if there were any issues.

The software along with wireless usb dongle connection used to take images from the SVI, was a very helpful tool. It allowed administers to easily see the taken images, provide camera feedback, and give a useful interface for immediate data organization. As previously mentioned though, there were at times some connection issues as well as unexplained camera errors that could've been software based. The only other issue with the application was the displayed window relationship to the saving of the images. If a picture was taken while the application was snapped to the right side of the screen, only the left side camera picture would be saved. This required users to make sure that when taking photos the application was in full screen. These issues though were very minimal and did not affect time of participation or necessary debugging effort.

The Canon camera with Sigma lens was flawless. It was extremely user friendly, and even had automatic focus to help cut out user focusing error. No one in the entire group had any issues or errors with the camera for the entirety of the collection.

Overall the system set up was very efficient and was weighted towards usability, making it very simple and accommodating to the administers of the collection. All issues that ever occurred, mainly with the SVI camera-computer, with system were able to be fixed within the day at the most extreme case. That being said, the only area where improvement could make a large and noticeable difference would be in the SVI camera operation and computer interface. Eliminating or reducing these factors would help the overall efficiency of collecting data.

.

Operator 4

The SVI camera had some major changes from the last prototype that was used in the previous collection. One upgrade that I observed was the use of the wireless dongle to communicate with the software on the laptop. Another huge improvement from the last prototype consisted of not clicking a preset button at every distance where a picture was taken. These two changes made the collection much faster and easier. The Canon seemed to operate just about the same from what I remember from the last collection.

The SVI camera worked very well once it started working properly. Usually the first attempt at taking images for the day failed and it took several minutes to reset. When capturing the image failed in this manner, it produced two images that looked like white noise. First we would recycle the power and attempt to take the picture again with it able to focus on something and the same output was produced. When that didn't work, the whole computer had to be restarted and the dongle taken out and plugged in again. Most of the time, just one total reset of the setup worked, however there were a few occurrences where it had to be done more than once. When nearing the end of the collection, the weather proved to be a problem while it was overcast. It could be around 2:30pm and the handheld mode would not work because it kept giving the not enough light beep pattern. This forced us to use the Tripod Mode for the three pictures when the handheld mode should have been used.

The software used to take the images for the SVI worked great except for one flaw. I think it would be nice to be able to see both of the full images that were taken (Left and Right) at the same time in the GUI. The left picture was fine, however only the left portion of the right picture was shown on the screen. Other than this, I think it is very easy to use and navigate the software.

In conclusion, the improvements from the first prototype to the second prototype were excellent in my opinion. The system as a whole was much easier to use compared to the last collection that was done. By not clicking a preset button and keeping track of which one to press probably was the best improvement from the last prototype. This made a huge difference in the amount of time the collection took to complete.

APPENDIX B: ACRONYMS, ABBREVIATIONS, AND REFERENCES

B.1 Acronyms and Abbreviations

ACRONYM	DESCRIPTION
ABIS	Automated Biometric Identification System
CoE	Center of Excellence
DOJ	Department of Justice
FAR	False Accept Rate
FBI	Federal Bureau of Investigation
FM	False Match
FMR	False Match Rate at Rank 1
FRD	Facial Recognition at a Distance
GAR	Genuine Accept Rate
Gen1	First Generation
Gen2	Second Generation
Gen3	Third Generation
IOD	Intra-Ocular Distance
L1	L-1 Identity Solutions ABIS
MM	Neurotechnology MegaMatcher
NGI	Next Generation Identification
NIJ	National Institute of Justice
NLECTC	National Law Enforcement and Corrections Technology Center
NMR	Non-Match Rate
SDK	Software Development Kit
SSBT	Sensor, Surveillance, and Biometric Technologies
SVI	StereoVision Imaging, Inc.
T&E	Test and Evaluation
TM	True Match
TMR	True Match Rate at Rank 1
WVU	West Virginia University

B.2 References

[1] NIJ, "Award 2010-IJ-CX-K001 Image Stabilized Binoculars With Integrated 3-D Facial Recognition Imaging Capabilities," http://www.nij.gov/topics/technology/biometrics/projects.htm (Accessed March 31, 2014).

[2] Greg Steinthal, SVI; *Image Stabilized Binoculars with Integrated 3D Facial Recognition Imaging Capabilities*, Final Report for NIJ Award 2010-IJ-CX-K001 (June 2013).

[3] ManTech International Corporation and Azimuth, Inc; *T&E of the SVI Face Capture & Matching System (Final Report)* (November 6, 2012).

[4] Adam Vrankulj, BiometricUpdate.com; *NGI: A closer look at the FBI's billion-dollar biometric program*, http://www.biometricupdate.com/201311/ngi-a-closer-look-at-the-fbis-billion-dollar-biometric-program (Accessed April 1, 2014).

[5] NIST, *ANSI/NIST-ITL 1-2007 American National Standard for Information Systems – Data Format for the Interchange of Fingerprint, Facial, & Other Biometric Information – Part1*, http://www.nist.gov/itl/ansi/upload/Approved-Std-20070427-2.pdf (May 2007).

[6] NLECTC; *Sensor, Surveillance, and Biometric Technologies Center of Excellence;* https://www.justnet.org/our_centers/coes/sensor-tce.html (Accessed April 2, 2014).

[7] Sony, *Digital Recording Binoculars*, http://store.sony.com/digital-recording-binoculars-zid27-DEV50V/B/cat-27-catid-All-Digital-Recording-Binoculars (Accessed April 2, 2014).

[8] Renee Shipley, TopTenReviews.com; *3D Camera Review;* http://3d-camera-review.toptenreviews.com/ (Accessed April 2, 2014).

[9] SVI, *Second Generation Wireless 3DMobileID™ Face Recognition Binocular System User Manual, Revision 2.0* (July 8, 2013).

[10] Paul Schlyter, *Radiometry and photometry in astronomy,* http://stjarnhimlen.se/comp/radfaq.html (Accessed April 18, 2014).

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

[12] A. J. Mansfield and J. L. Wayman, National Physical Laboratory; *Best Practices in Testing and Reporting Performance of Biometric Devices;* http://www.npl.co.uk/upload/pdf/biometrics_bestprac_v2_1.pdf (August 2002).

[13] Manfred Bromba, *Biometrics FAQ*, http://www.bromba.com/faq/biofaqe.htm (Accessed April 24, 2014).