# innovatrics+000A

Innovatrics

Slap Fingerprint Segmentation Evaluation III

Last Updated: 25 June 2025

## Contents

# 1 Participation Information

## 1.1 Names and Dates

- **Organization Name:** Innovatrics
- **SlapSeg III Identifier:** innovatrics+000A
- **SlapSeg III API Version:** 1.2.0
- **Provided Marketing Name:** "Innovatrics segmentation"
- **Application Date:** 20 June 2025
- **First Submission Date:** 20 June 2025 (as version 000A)
- **Validation Date:** 24 June 2025
- **Completion Date:** 25 June 2025

## 1.2 Libraries

| Filename | MD5 Checksum | Size |
|---|---|---|
| libonnxruntime.so.1.18.2 | ef7ba8f9a656340b57fb98320c1f85ae | 23 MB |
| libslapsegiii_innovatrics_000A.so | 56fef30482df79671bb1503d3d2cc4e5 | 622 MB |

# 2 Tenprint Cards ("TwoInch" Data)

## 2.1 Segmentation Timing

All algorithms are run over a small fixed corpus of TwoInch images to estimate the total runtime of the evaluation. To be evaluated under SlapSeg III, algorithms **must** segment the timing corpus, on average, in under 1 500 milliseconds. This maximum reference time is documented in the SlapSeg III test plan, and is subject to change. Times are measured by running a single process on an isolated compute node equipped with an Intel Gold 6254 CPU (submissions received prior to February 2022 were timed with a Intel Xeon E5-4650 CPU).*=

Box plots of segmentation times are separated by slap orientation and capture technology in Figure 1. Tabular representations are enumerated in Table 1. Results are reported in milliseconds.

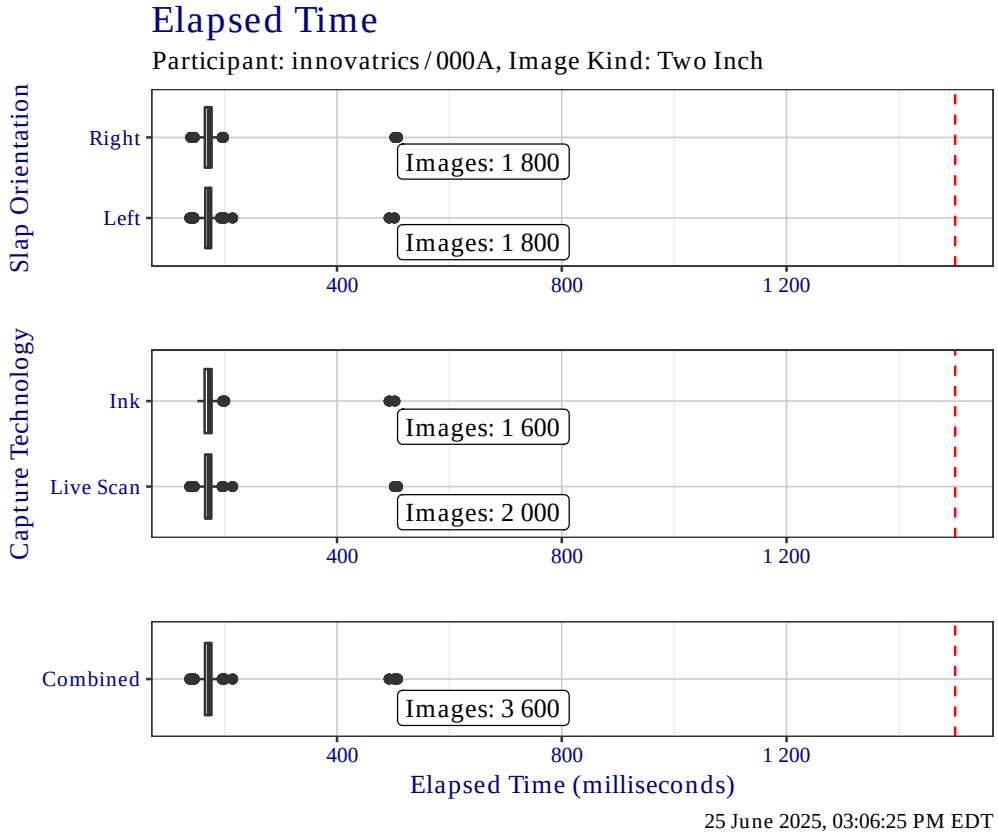


Figure 1: Box plots of elapsed time in milliseconds when segmenting the TwoInch timing test corpus, separated by slap orientation and capture technology.

Table 1: Elapsed time in milliseconds when segmenting the TwoInch timing test corpus, separated by slap orientation and capture technology.

| | Right | Left | Live Scan | Ink | Combined |
|---|---|---|---|---|---|
| Minimum | 140 | 138 | 138 | 152 | 138 |
| 25% | 165 | 166 | 165 | 164 | 165 |
| Median | 173 | 173 | 173 | 173 | 173 |
| 75% | 177 | 176 | 176 | 177 | 177 |
| Maximum | 508 | 502 | 508 | 503 | 508 |

## 2.2 Segmentation Centers and Dimensions

### 2.2.1 Segmentation Centers

The plots in this section show the distribution of segmentation position centers $(x, y)$ for TwoInch data. At the top of each figure is a combined plot for all finger positions of a given slap orientation. These figures are isolated in plots faceted at the bottom of the figure.

Plots of segmentation centers for the right hand TwoInch data are shown in Figure 2 and plots of segmentation centers for the left hand are shown in Figure 3. Blank lines that may appear in the plots are **not** rendering artifacts. Rather, they are indicative of image downsampling. Centers have been normalized to 500 pixels per inch.

Points in each plot are plotted with a semi-transparent opacity. This results in points of particular color appearing "darker" to indicate a higher frequency of the observed value, while "lighter" points indicate a lower observed frequency.

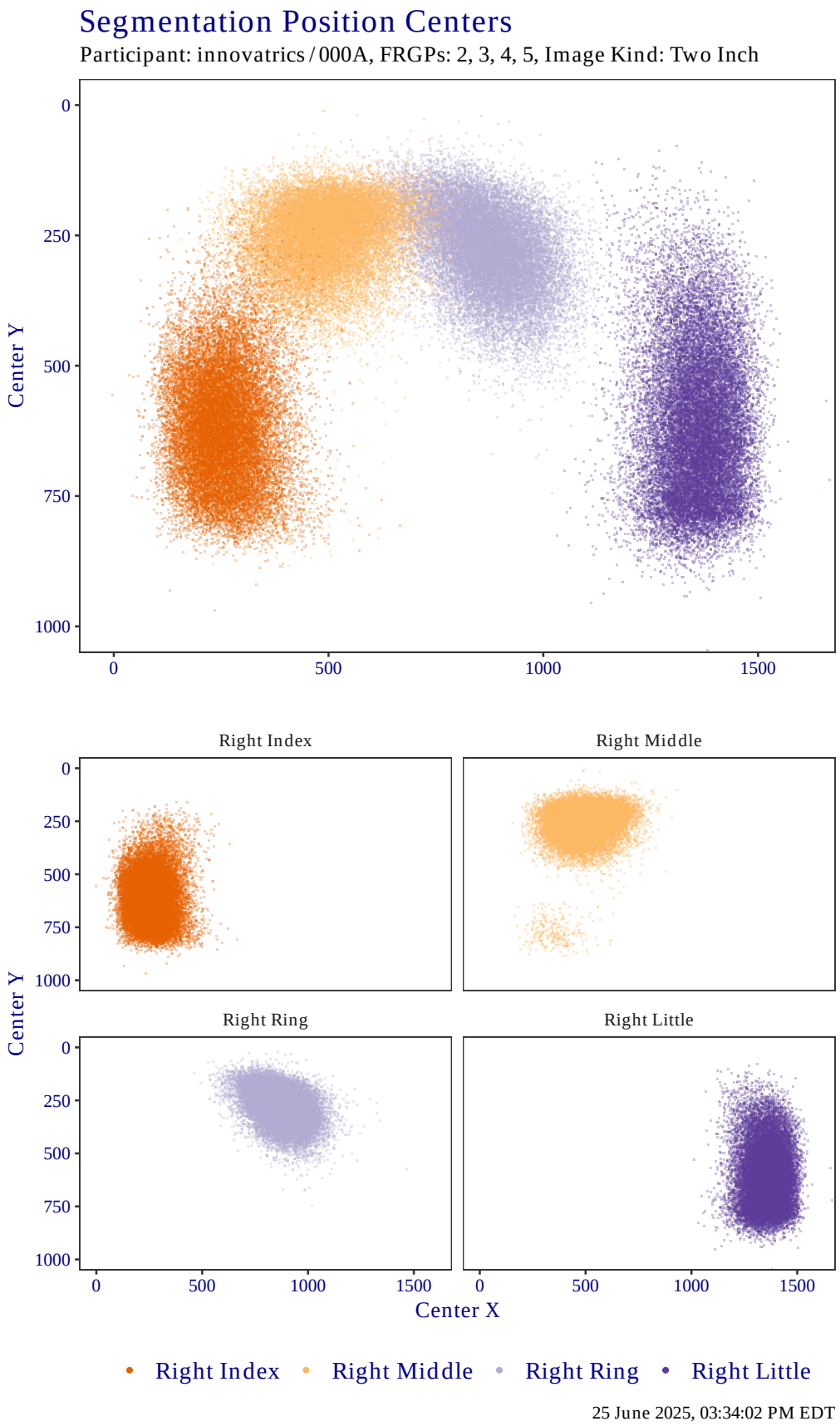


Figure 2: Segmentation centers for right hand TwoInch data.

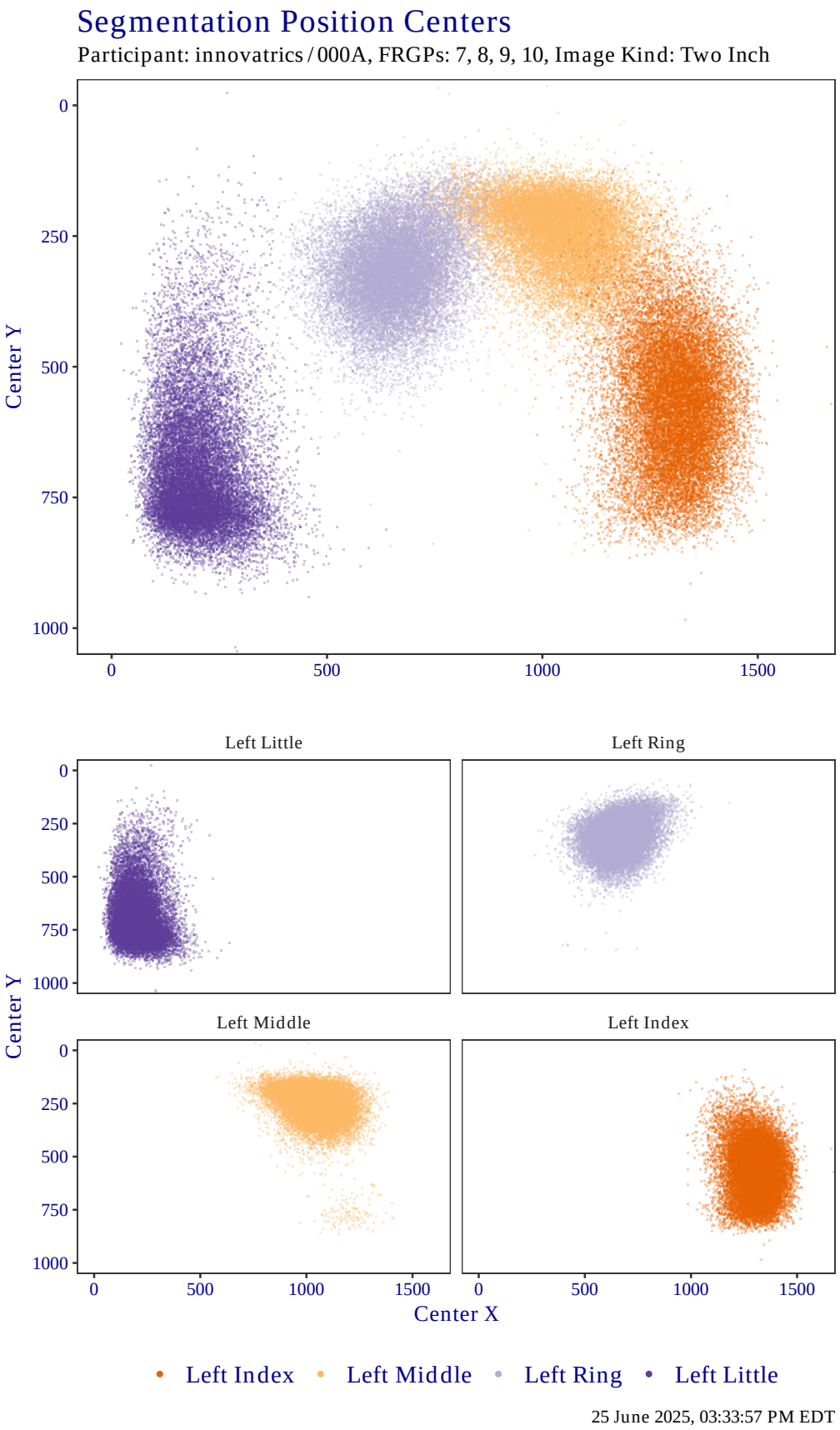


Figure 3: Segmentation centers for left hand TwoInch data.

### 2.2.2 Segmentation Dimensions

The plots in this section show the distribution of segmentation position widths and heights for TwoInch data. At the top of each figure is a combined plot for all finger positions of a given slap orientation. These figures are isolated in plots faceted at the bottom of the figure.

Plots of segmentation position dimensions for the right hand TwoInch data are shown in Figure 4 and the left hand in Figure 5. Blank lines that may appear in the plots are **not** rendering artifacts. Rather, they are indicative of image downsampling. Dimensions have been normalized to 500 pixels per inch.

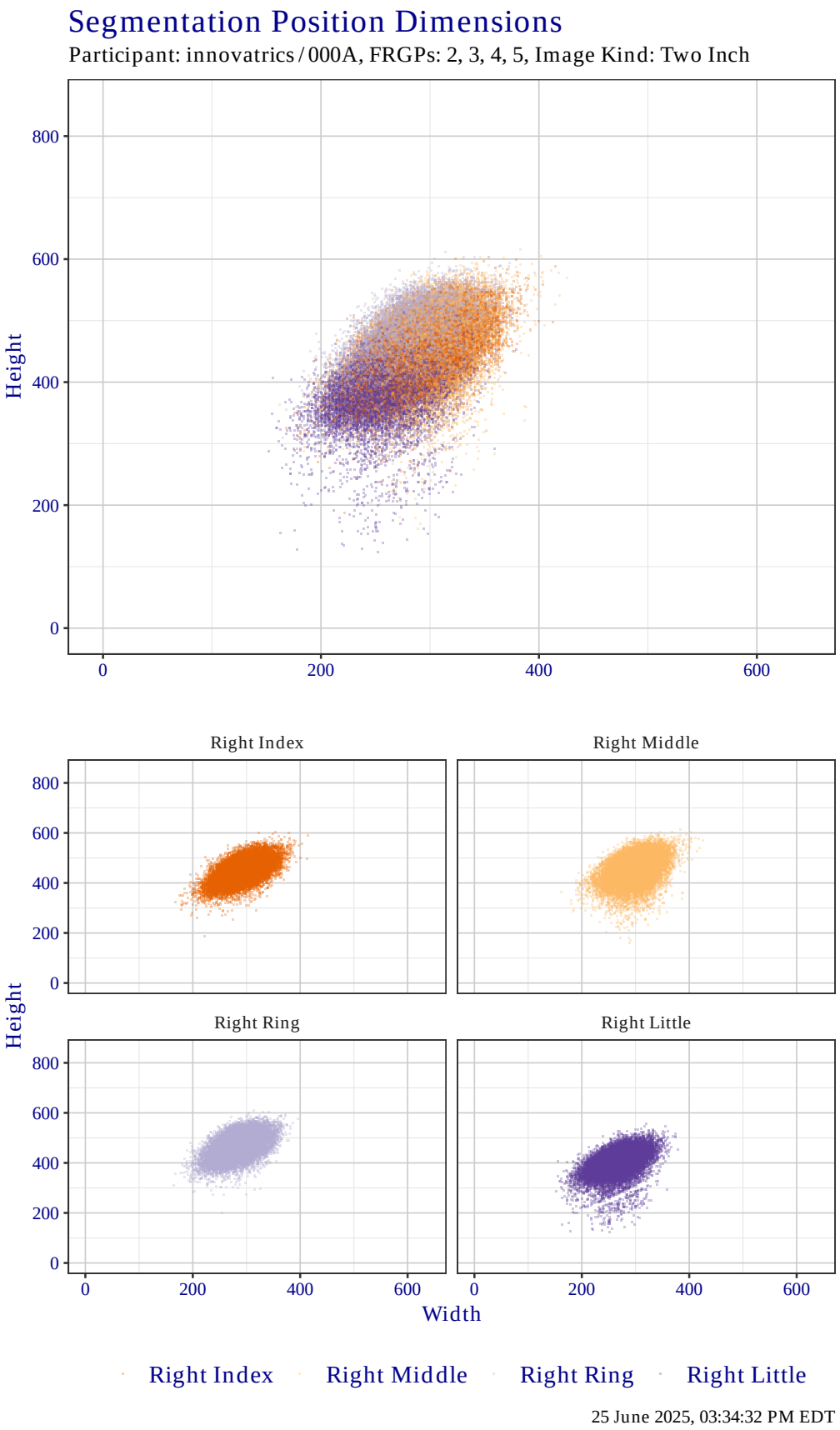


Figure 4: Segmentation position dimensions for right hand TwoInch data.

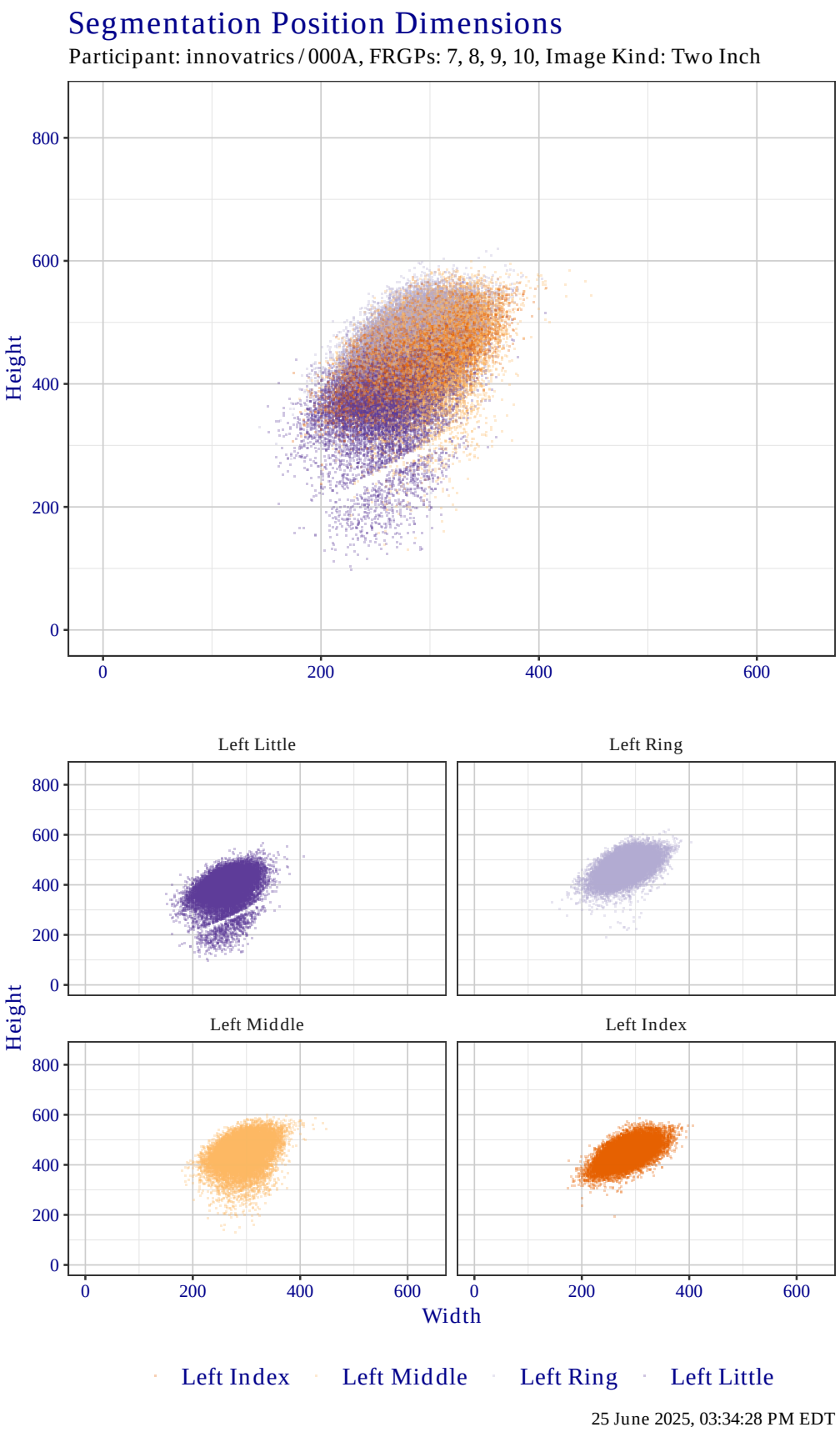


Figure 5: Segmentation position dimensions for left hand TwoInch data.

## 2.3 Detailed Segmentation Statistics

This section shows detailed results of segmentation of TwoInch data. Values in each table are the percentage that the variable in the left-most column was correctly segmented.

Each table has three columns of percentages. The *Standard Scoring* column shows the percentage of correctly-segmented positions based on the scoring metrics defined in the SlapSeg III scoring document. The *Ignoring Bottom Y* column shows how the percentage would change if the threshold for the *bottom Y* coordinate of the segmentation position was ignored. Similarly, the *Ignoring Bottom X and Y* columns shows how the percentage would change if only the top, left, and right sides of the segmentation position were considered. These two supplemental columns are included because it has traditionally been difficult to determine the exact location of the distal interphalangeal joint.

Table 2 shows how successful innovatrics+000A segmented fingers for each subject in the test corpus. Table 3 shows success for specific finger positions over the entire test corpus. Similarly, Table 4 shows success for segmenting the same finger position from both hands.

The remainder of the tables show success per subject when considering combinations of subsets of the fingers on each slap image. Table 5 shows success for combinations of all fingers, Table 6 for just the index and middle fingers, and Table 7 for all except the little finger.

Table 2: For each subject, the percentage that at least *Number of Fingers* fingers were correctly segmented, regardless of hand, for a maximum of eight correctly-segmented fingers. In *Standard Scoring*, scoring rules are followed exactly. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Number of Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| 1 | 100.0 | 100.0 | 100.0 |
| 2 | 99.9 | 99.9 | 99.9 |
| 3 | 99.4 | 99.5 | 99.6 |
| 4 | 98.5 | 98.6 | 98.9 |
| 5 | 95.6 | 95.7 | 95.7 |
| 6 | 94.8 | 95.0 | 95.2 |
| 7 | 90.2 | 91.2 | 92.0 |
| 8 | 74.8 | 78.3 | 80.9 |

Table 3: For all subjects, percentage that a particular friction ridge generalized position was correctly segmented. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Finger | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Index | 94.0 | 95.4 | 95.9 |
| Middle | 96.2 | 96.8 | 97.0 |
| Ring | 96.6 | 97.2 | 97.5 |
| Little | 95.6 | 96.3 | 97.8 |
| **Left** | | | |
| Index | 96.6 | 97.2 | 97.6 |
| Middle | 97.3 | 97.8 | 98.0 |
| Ring | 96.8 | 97.4 | 97.7 |
| Little | 95.8 | 96.2 | 96.8 |

Table 4: Percentage that a particular type of fingerprint was correctly segmented on *Either* or *Both* hands. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Index** | | | |
| Either | 98.9 | 99.0 | 99.1 |
| Both | 87.5 | 89.0 | 89.9 |
| **Middle** | | | |
| Either | 99.3 | 99.4 | 99.5 |
| Both | 90.6 | 91.5 | 91.8 |
| **Ring** | | | |
| Either | 99.2 | 99.4 | 99.5 |
| Both | 90.7 | 91.9 | 92.2 |
| **Little** | | | |
| Either | 99.2 | 99.3 | 99.5 |
| Both | 87.8 | 88.8 | 90.7 |

Table 5: Percentage of segmentation success by hand for combinations of all eight fingers of a TwoInch slap. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 100.0 | 100.0 | 100.0 |
| At Least Two | 99.7 | 99.8 | 99.9 |
| At Least Three | 97.1 | 97.6 | 98.0 |
| All Four | 85.7 | 88.5 | 90.4 |
| **Left** | | | |
| Any | 99.9 | 99.9 | 99.9 |
| At Least Two | 99.6 | 99.7 | 99.8 |
| At Least Three | 97.9 | 98.2 | 98.5 |
| All Four | 89.0 | 90.9 | 92.0 |

Table 6: Percentage of segmentation success by hand when only considering combinations of index and middle fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Either Index or Middle | 98.3 | 98.4 | 98.5 |
| Both Index and Middle | 91.9 | 93.8 | 94.4 |
| **Left** | | | |
| Either Index or Middle | 98.9 | 99.0 | 99.1 |
| Both Index and Middle | 95.0 | 96.0 | 96.5 |

Table 7: Percentage of segmentation success by hand when only considering combinations of index, middle, and ring fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 99.9 | 99.9 | 99.9 |
| At Least Two | 97.8 | 98.1 | 98.3 |
| All Three | 89.2 | 91.5 | 92.2 |
| **Left** | | | |
| Any | 99.8 | 99.8 | 99.9 |
| At Least Two | 98.5 | 98.7 | 98.8 |
| All Three | 92.4 | 93.9 | 94.6 |

## 2.4 Handling Troublesome Images

### 2.4.1 Capture Failures

Segmentation algorithms may refuse to process an image. This may happen for a technical reason (e.g., the algorithm cannot parse the image data), or for a practical reason (e.g., the hand in the image is placed incorrectly). These failure scenarios are the result of capturing improper image data. In these types of scenarios, it is important to examine the cause of the failure. With many live scan capture setups, segmentation is performed immediately after capture. If an algorithm can detect that it won't be able to segment an image due to a technical or practical issue, it can alert the operator to perform a recapture before the subject leaves.

The SlapSeg III API encourages algorithms to identify these failure reasons by specifying pre-defined *deficiencies* in the image. Algorithms should attempt segmentation even if an image deficiency is encountered if at all possible. Note that SlapSeg III *guarantees* well-formed image data, so failures to parse are **not** an indicator of the data provided.

Reasons for capture-type failures reported by innovatrics+000A are enumerated in Table 8. Note that for TwoInch data, images are expected to be rotated, so a capture failure of *Rotation Detected* is unacceptable.

Table 8: Count of self-reported capture-type failure reasoning.

| Failure Reason | Images |
|---|---|
| Request Recapture (Attempt) | 4 |

In situations where the algorithm feels that the presented image should be recaptured (Table 8), one or more image deficiencies must be identified. These deficiencies are enumerated in Table 9. At this point, NIST does not have a groundtruth of image deficiencies, but plans to update this table with the accuracy of deficiency observations in the future.

Table 9: Count of image deficiencies reported when requesting a recapture.

| Deficiency | Count |
|---|---|
| Incomplete | 4 |

#### 2.4.1.1 Recovery

When encountering a segmentation failure, SlapSeg III algorithms are encouraged to provide a *best-effort* segmentation when possible. In some cases, that best-effort may be correct, which reduces the amount of images that need to be manually adjudicated by an operator.The result of such best-effort segmentations are shown in Table 10.

Out of 4 recovery attemptsinnovatrics+000A attempted 3 segmentations of fingers and skipped 13 fingers. More information about skipped fingers can be found in Table 11.

Table 10: Results of best-effort segmentation when innovatrics+000A reported segmentation failure (3 best-effort attempts).

| Standard | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|

### 2.4.2 Segmentation Failures

Even if an algorithm accepts an image for processing, it can still fail to process one or more fingers from the image, regardless of if the algorithm requested a recapture and provided best-effort segmentation.

The SlapSeg III API allows algorithms to communicate reasons for failure to process these fingers. In some cases, the distal phalanx in question might not be present in the image due to amputation or being placed outside the platen's capture area. It is imperative that the segmentation algorithm correctly report this as failing to segment the correct friction ridge generalized position without disrupting the sequence of valid positions present in the image. This can help prompt an operator to recapture or record additional information about the subject.

In SlapSeg III, a number of images are missing fingers or otherwise have fingers that will not be able to be segmented. Reasons for segmentation failures reported by innovatrics+000A are enumerated in Table 11.

Table 11: Count of self-reported segmentation failure reasoning.

| Failure Reason | Fingers |
|---|---|
| Finger Not Found | 26 |
| Finger Not Found | 13 |
| Finger Found, but Can't Segment | 0 |
| Vendor Defined | 0 |

### 2.4.3 Identifying Missing Fingers

A small portion of the test corpus in SlapSeg III are missing fingers. Table 12 shows how successful innovatrics+000A was in correctly determining if a finger was missing. The *Missed* row shows when a segmentation position was returned for a missing finger. All possible failure reasons are enumerated, but are not considered *Correctly Identified* because the algorithm specified failure for a reason other than the finger not being found.

Table 12: Performance of innovatrics+000A at detecting fingers missing from an image.

| Result | Percentage |
|---|---|
| Missed | 59.4 |
| Correctly Identified | 40.6 |
| Other Failure: Finger Found, but Can't Segment | 0.0 |
| Other Failure: Vendor Defined | 0.0 |
| Other Failure: Segmentation Not Attempted | 0.0 |

### 2.4.4 Sequence Error

Sequence error occurs when a fingerprint is segmented from an image but assigned an incorrect finger position (e.g., segmenting a right middle finger but labeling it a right index finger). Table 13 shows cases in which a segmentation position was returned that matched a ground truth segmentation position for a different finger in the same image.

Table 13: Percentage of images in the dataset where one or more segmentation positions correctly matched an incorrect finger position within the same image, indicating sequence error.

| Hand | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| Left | 0.68 | 0.68 | 0.69 |
| Right | 1.20 | 1.20 | 1.20 |
| Combined | 0.96 | 0.96 | 0.96 |

## 2.5 Determining Orientation

An *optional* portion of the SlapSeg III API asked participants to determine the hand orientation of an image. Participants were provided the kind (e.g., Tenprint card) and capture technology (e.g., ink), and needed to determine whether the image was of the left or right hand.

**Overall Two Inch accuracy**: 99.8%

Table 14: Percentage of accuracy when determining hand orientation of a two inch image. The first column indicates the true hand orientation. Subsequent columns indicate the percentage of the time in which the indicated hand orientation was hypothesized.

| | Left | Right |
|---|---|---|
| Left | **99.8** | 0.2 |
| Right | 0.1 | **99.9** |

# 3 Identification Flats ("ThreeInch" Data)

## 3.1 Segmentation Timing

All algorithms are run over a small fixed corpus of ThreeInch images to estimate the total runtime of the evaluation. To be evaluated under SlapSeg III, algorithms **must** segment the timing corpus, on average, in under 1 500 milliseconds. This maximum reference time is documented in the SlapSeg III test plan, and is subject to change. Times are measured by running a single process on an isolated compute node equipped with an Intel Gold 6254 CPU (submissions received prior to February 2022 were timed with a Intel Xeon E5-4650 CPU).

Box plots of segmentation times are separated by hand in Figure 6, with tabular representations are enumerated in Table 15. Results are reported in milliseconds

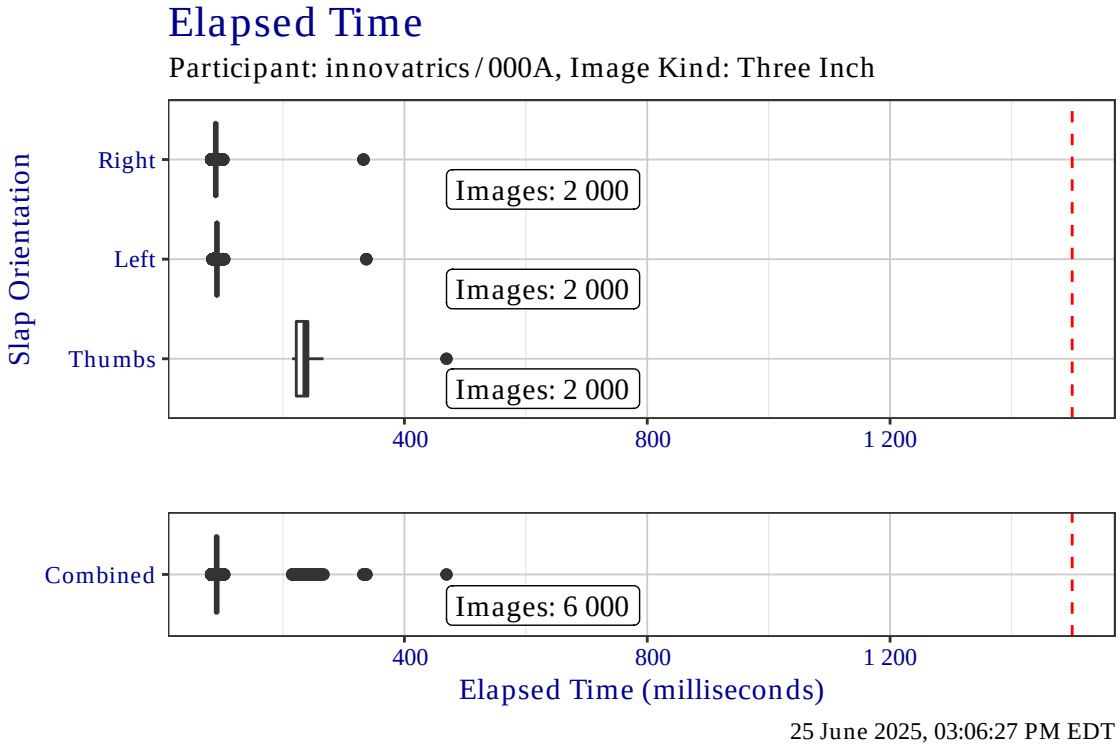


Figure 6: Box plots of elapsed time in milliseconds when segmenting the ThreeInch timing test corpus, separated by slap orientation.

Table 15: Elapsed time in milliseconds when segmenting the ThreeInch timing test corpus, separated by slap orientation.

| | Right | Left | Thumbs | Combined |
|---|---|---|---|---|
| Minimum | 81 | 84 | 215 | 81 |
| 25% | 89 | 91 | 222 | 89 |
| Median | 89 | 91 | 237 | 91 |
| 75% | 90 | 92 | 241 | 92 |
| Maximum | 333 | 337 | 469 | 469 |

## 3.2 Segmentation Centers and Dimensions

### 3.2.1 Segmentation Centers

The plots in this section show the distribution of segmentation position centers $(x, y)$ for ThreeInch data. At the top of each figure is a combined plot for all finger positions of a given hand orientation. These figures are isolated in plots faceted at the bottom of the figure.

Plots of segmentation centers for the right hand ThreeInch data are shown in Figure 7, for the left hand in Figure 8, and for thumbs in Figure 9. Blank lines that may appear in the plots are **not** rendering artifacts. Rather, they are indicative of image downsampling. Centers have been normalized to 500 pixels per inch.

Points in each plot are plotted with a semi-transparent opacity. This results in points of particular color appearing "darker" to indicate a higher frequency of the observed value, while "lighter" points indicate a lower observed frequency.

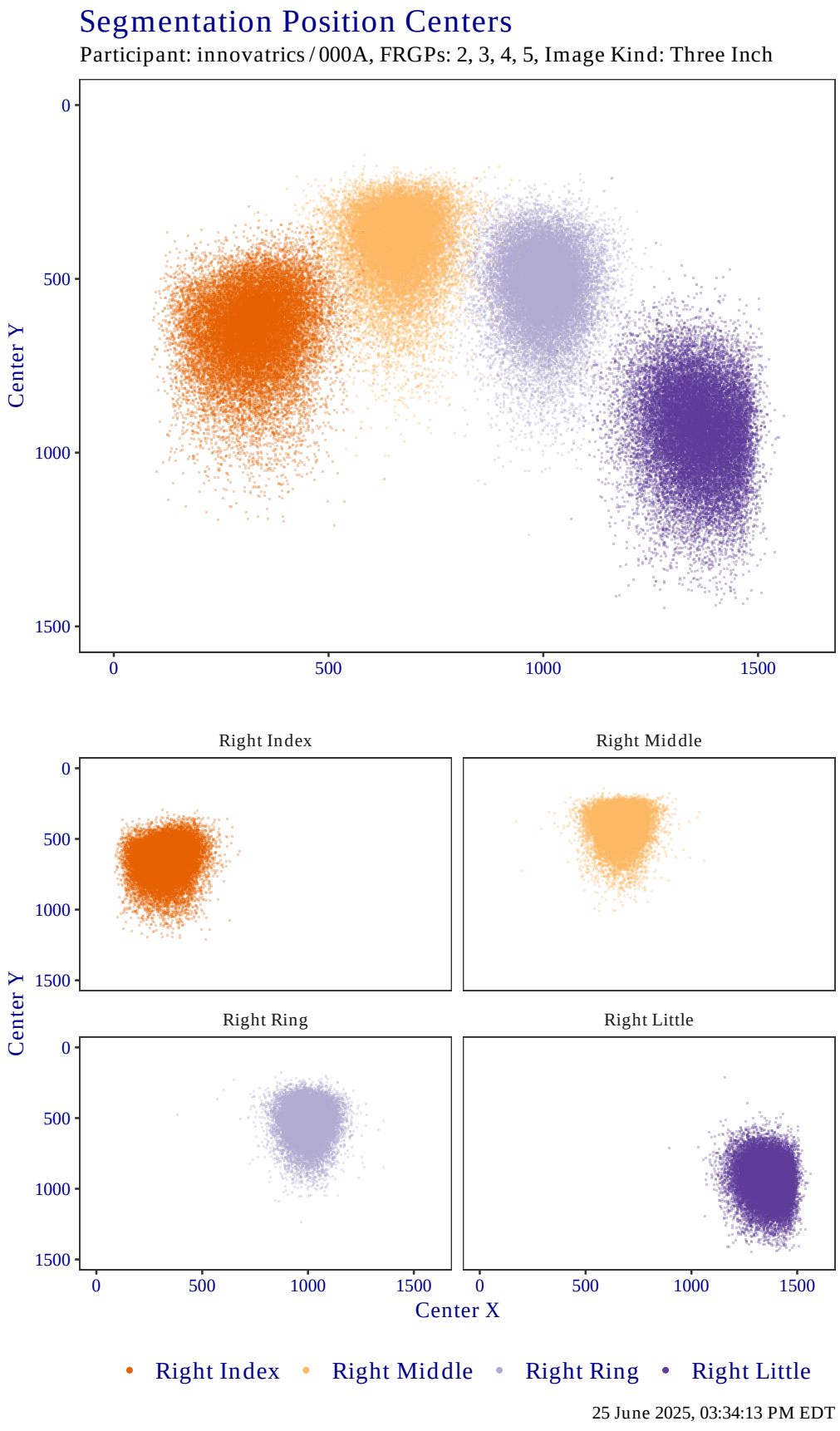


Figure 7: Segmentation centers for right hand ThreeInch data.

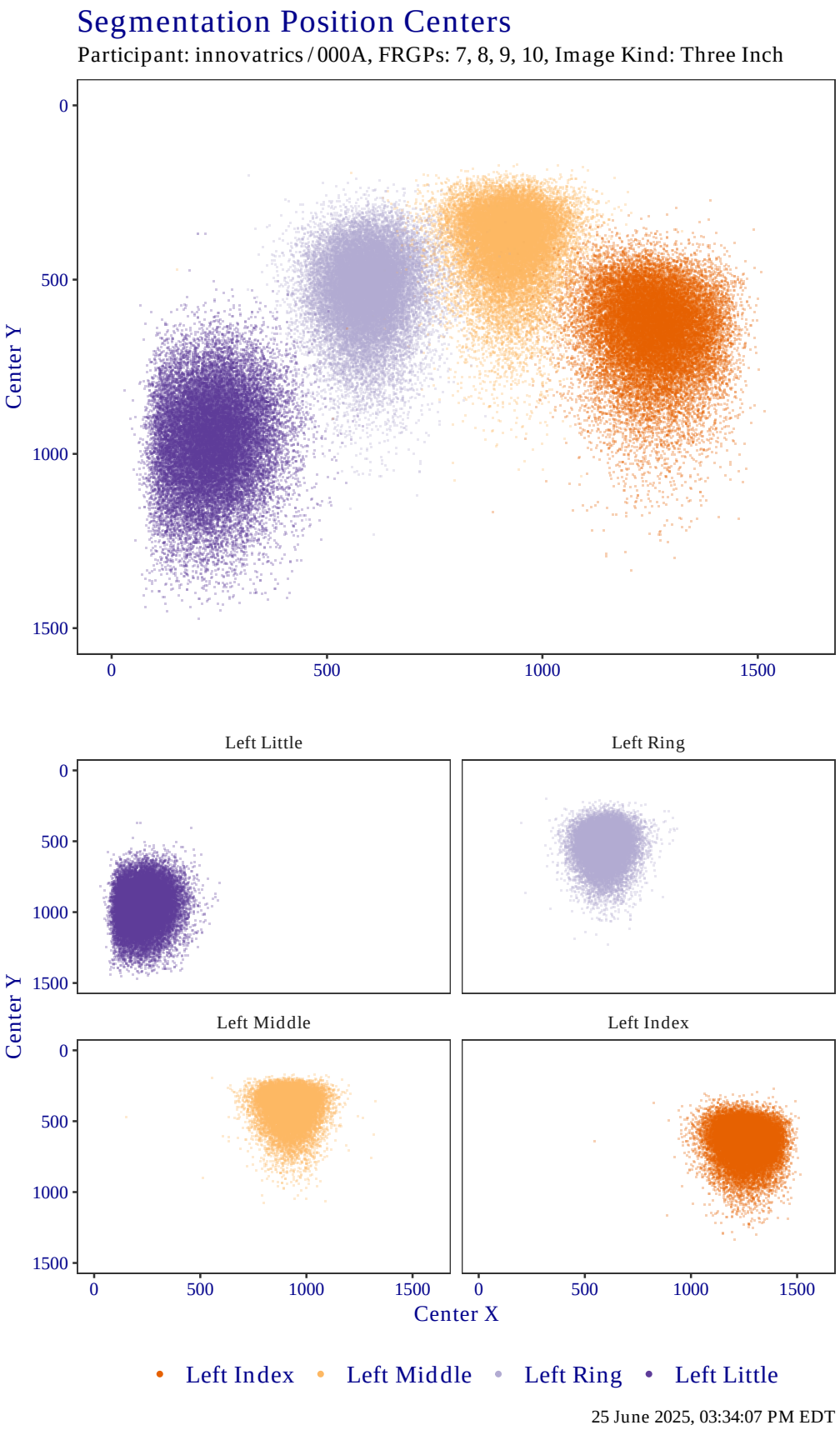


Figure 8: Segmentation centers for left hand ThreeInch data.

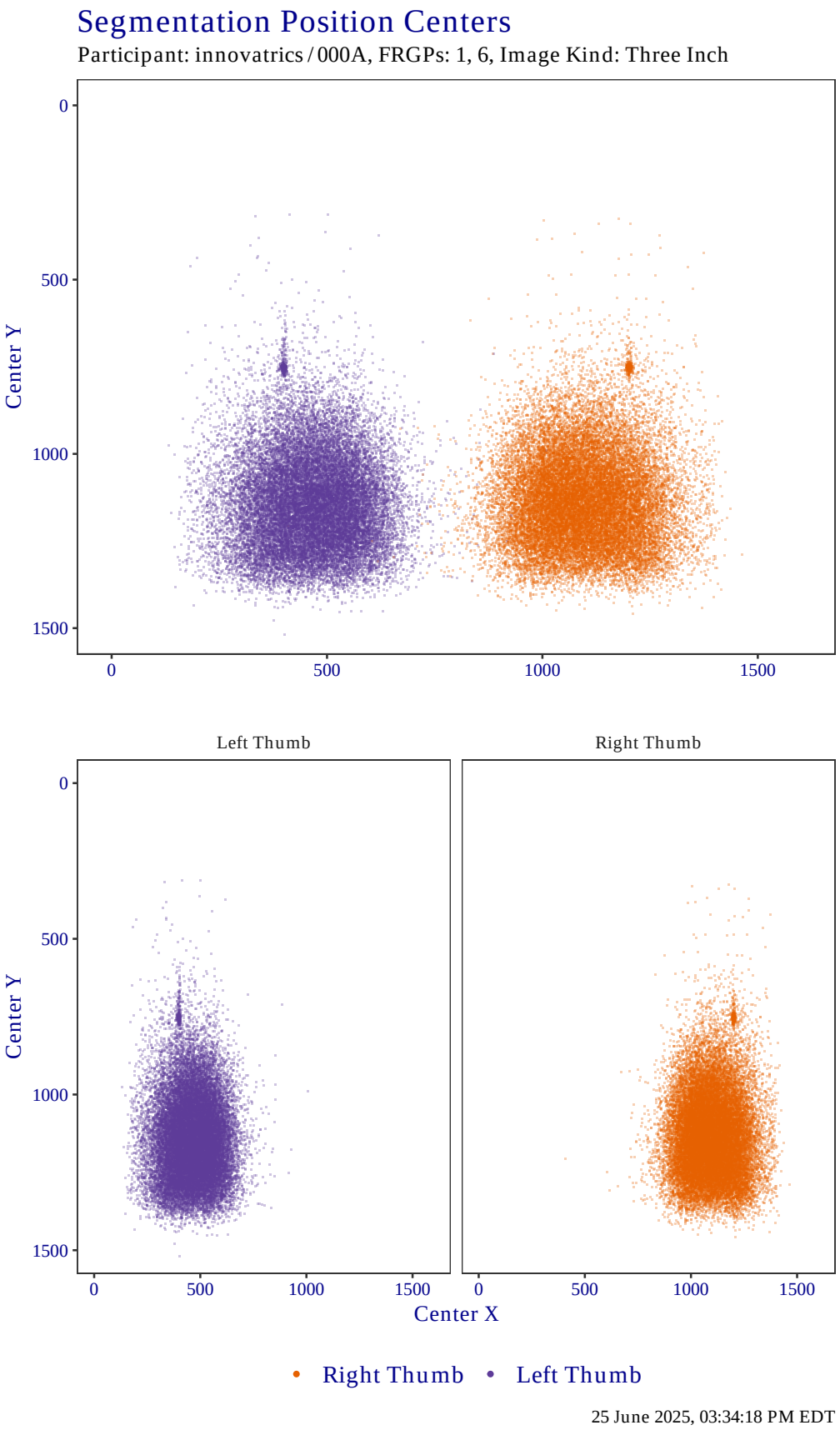


Figure 9: Segmentation centers for thumb ThreeInch data.

### 3.2.2 Segmentation Dimensions

The plots in this section show the distribution of segmentation position widths and heights for ThreeInch data. At the top of each figure is a combined plot for all finger positions of a given hand orientation. These figures are isolated in plots faceted at the bottom of the figure.

Plots of segmentation position dimensions for the right hand ThreeInch data are shown in Figure 11, for the left hand in Figure 10, and for thumbs in Figure 12. Blank lines that may appear in the plots are **not** rendering artifacts. Rather, they are indicative of image downsampling. Dimensions have been normalized to 500 pixels per inch.

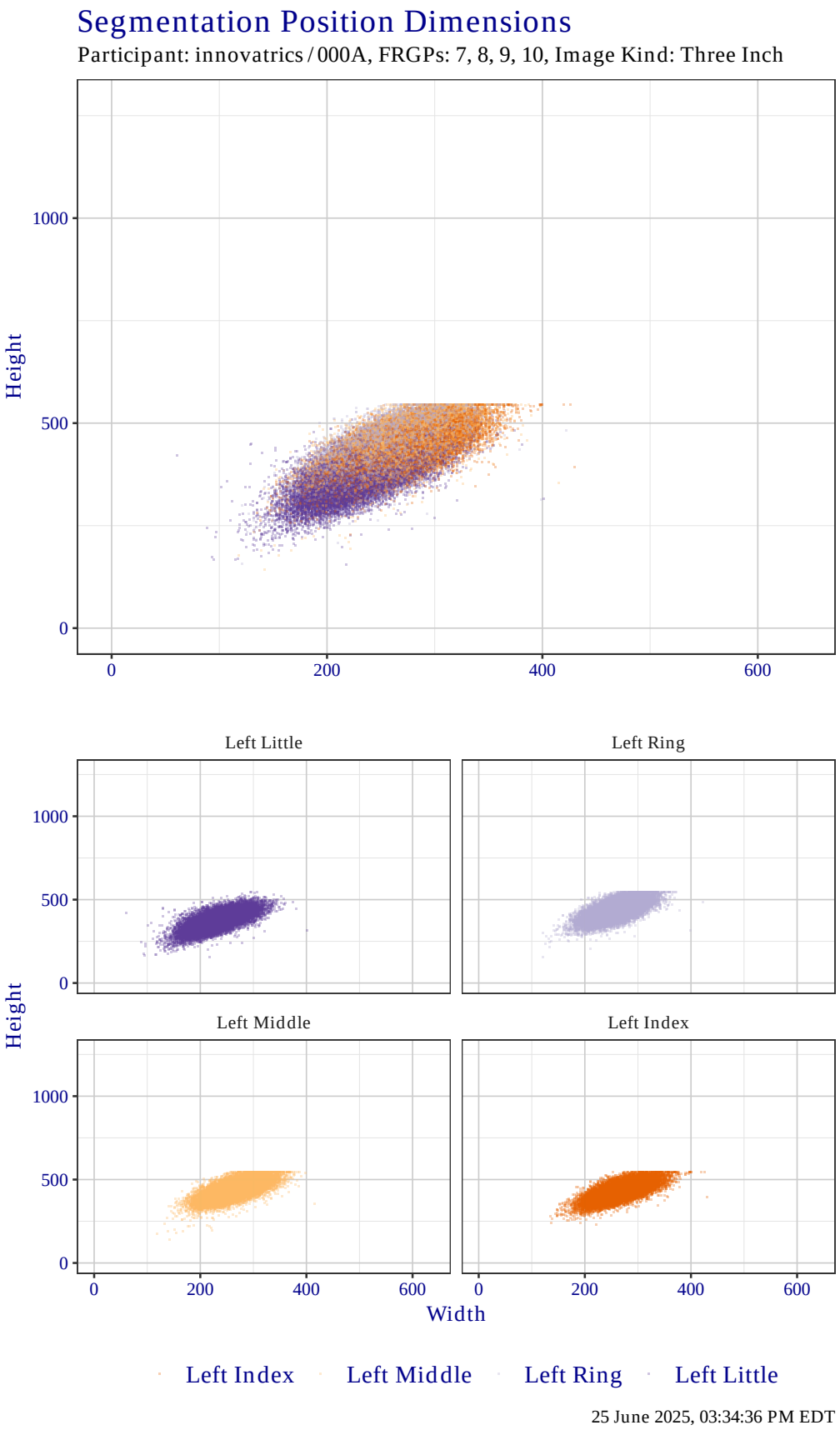


Figure 10: Segmentation position dimensions for left hand ThreeInch data.

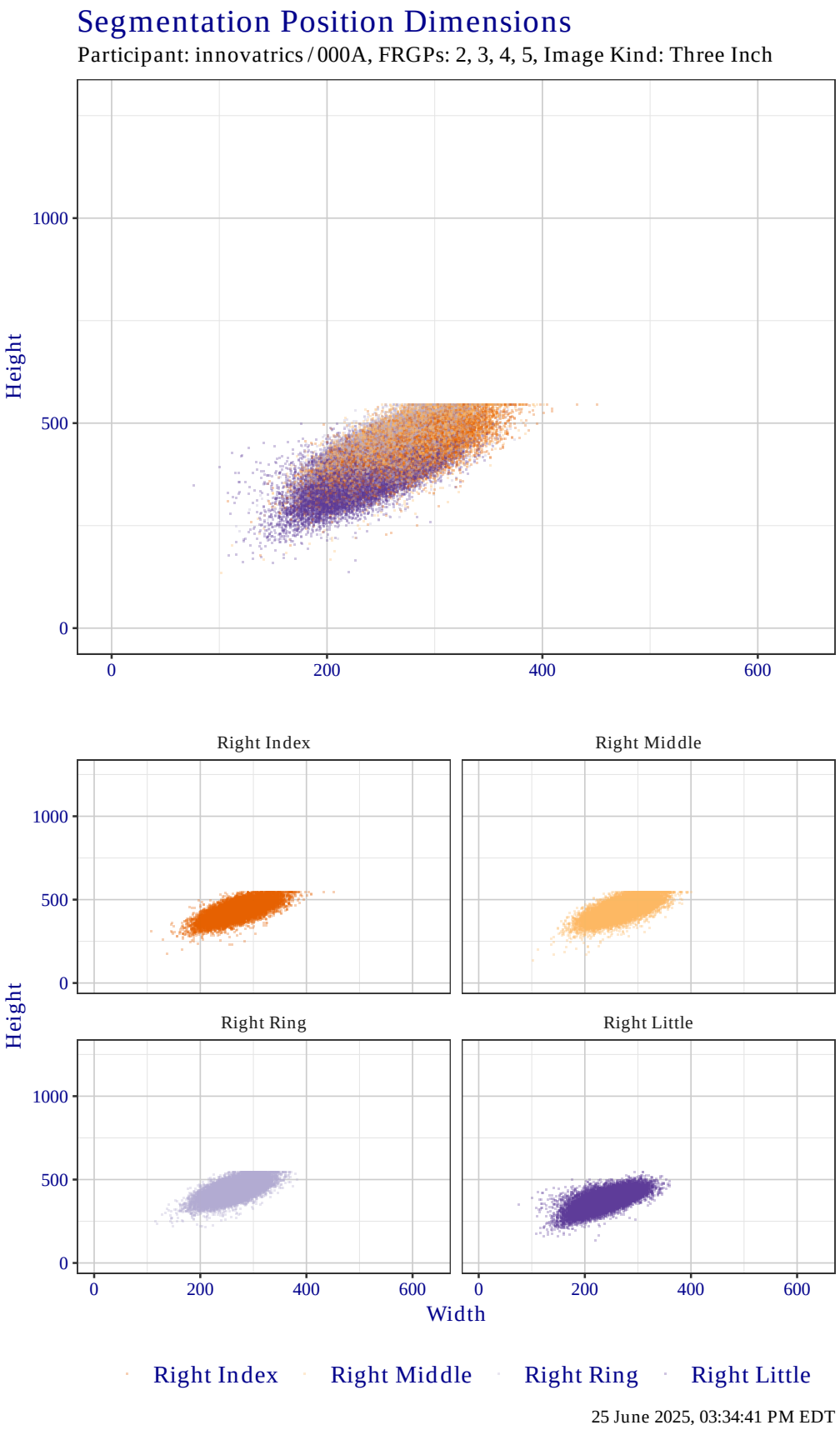


Figure 11: Segmentation position dimensions for right hand ThreeInch data.

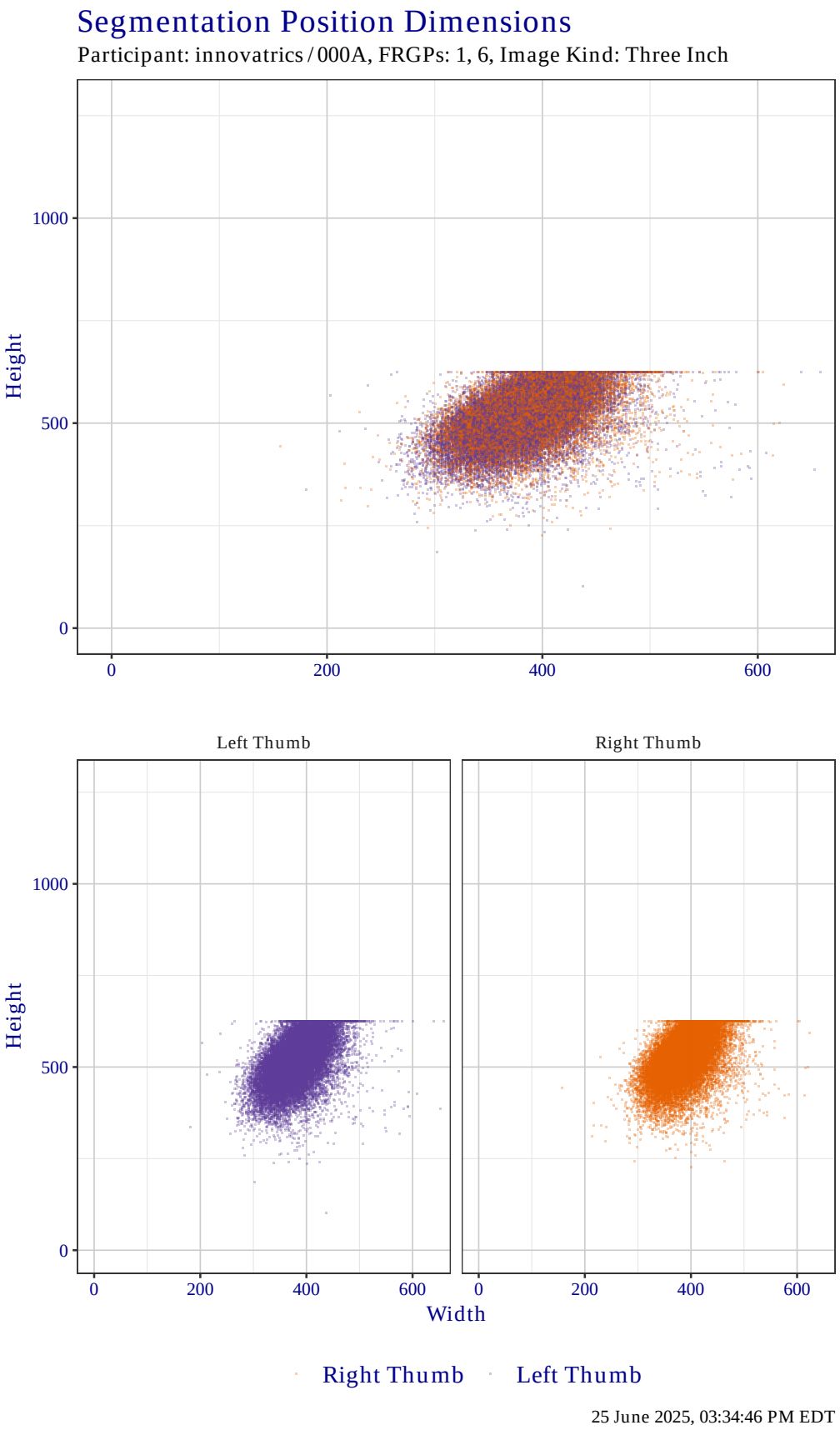


Figure 12: Segmentation position dimensions for thumb ThreeInch data.

## 3.3 Detailed Segmentation Statistics

This section shows detailed results of segmentation of ThreeInch data. Values in each table are the percentage that the variable in the left-most column was correctly segmented.

Each table has three columns of percentages. The *Standard Scoring* column shows the percentage of correctly-segmented positions based on the scoring metrics defined in the SlapSeg III scoring document. The *Ignoring Bottom Y* column shows how the percentage would change if the threshold for the *bottom Y* coordinate of the segmentation position was ignored. Similarly, the *Ignoring Bottom X and Y* columns shows how the percentage would change if only the top, left, and right sides of the segmentation position were considered. These two supplemental columns are included because it has traditionally been difficult to determine the exact location of the distal interphalangeal joint.

Table 16 shows how successful innovatrics+000A segmented fingers for each subject in the test corpus. Table 17 shows success for specific finger positions over the entire test corpus. Similarly, Table 18 shows success for segmenting the same finger position from both hands.

The remainder of the tables show success per subject when considering combinations of subsets of the fingers on each slap image. Table 19 shows success for combinations of all fingers, Table 20 for just the index and middle fingers, and Table 21 for all except the little finger.

Table 16: For each subject, the percentage that at least *Number of Fingers* fingers were correctly segmented, regardless of hand, for a maximum of eight correctly-segmented fingers. In *Standard Scoring*, scoring rules are followed exactly. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Number of Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| 1 | 99.9 | 99.9 | 99.9 |
| 2 | 99.5 | 99.5 | 99.6 |
| 3 | 98.6 | 98.6 | 98.6 |
| 4 | 98.3 | 98.3 | 98.4 |
| 5 | 95.9 | 95.9 | 95.9 |
| 6 | 95.9 | 95.9 | 95.9 |
| 7 | 95.9 | 95.9 | 95.9 |
| 8 | 95.5 | 95.5 | 95.6 |
| 9 | 93.7 | 93.8 | 94.3 |
| 10 | 84.0 | 85.0 | 87.4 |

Table 17: For all subjects, percentage that a particular friction ridge generalized position was correctly segmented. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Finger | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Thumb | 98.2 | 98.7 | 99.1 |
| Index | 99.2 | 99.2 | 99.3 |
| Middle | 98.6 | 98.6 | 98.9 |
| Ring | 97.4 | 97.4 | 98.0 |
| Little | 98.3 | 98.3 | 98.4 |
| **Left** | | | |
| Thumb | 98.2 | 98.8 | 99.2 |
| Index | 98.3 | 98.3 | 98.4 |
| Middle | 98.5 | 98.5 | 98.8 |
| Ring | 98.4 | 98.4 | 99.1 |
| Little | 98.6 | 98.6 | 98.7 |

Table 18: Percentage that a particular type of fingerprint was correctly segmented on *Either* or *Both* hands. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Thumb** | | | |
| Either | 99.7 | 99.8 | 99.9 |
| Both | 96.8 | 97.7 | 98.5 |
| **Index** | | | |
| Either | 99.9 | 99.9 | 99.9 |
| Both | 94.9 | 94.9 | 95.1 |
| **Middle** | | | |
| Either | 99.8 | 99.8 | 99.9 |
| Both | 94.6 | 94.6 | 95.2 |
| **Ring** | | | |
| Either | 99.7 | 99.8 | 99.9 |
| Both | 93.3 | 93.4 | 94.6 |
| **Little** | | | |
| Either | 99.9 | 99.9 | 99.9 |
| Both | 94.4 | 94.4 | 94.6 |

Table 19: Percentage of segmentation success by hand for combinations of all ten fingers of a ThreeInch slap. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 99.6 | 99.6 | 99.7 |
| At Least Two | 98.5 | 98.5 | 98.5 |
| At Least Three | 98.3 | 98.3 | 98.3 |
| At Least Four | 97.4 | 97.4 | 97.6 |
| All Five | 88.7 | 89.2 | 90.6 |
| **Left** | | | |
| Any | 99.8 | 99.8 | 99.8 |
| At Least Two | 98.5 | 98.5 | 98.5 |
| At Least Three | 98.3 | 98.3 | 98.4 |
| At Least Four | 97.4 | 97.5 | 97.7 |
| All Five | 88.7 | 89.3 | 90.6 |

Table 20: Percentage of segmentation success by hand when only considering combinations of index and middle fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are gnored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Either | 99.8 | 99.8 | 99.8 |
| Both | 98.0 | 98.1 | 98.5 |
| **Left** | | | |
| Either | 99.8 | 99.8 | 99.8 |
| Both | 96.9 | 97.0 | 97.4 |

Table 21: Percentage of segmentation success by hand when only considering combinations of index, middle, and ring fingers. In *Ignoring Bottom Y*, the bottom left and right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 99.9 | 99.9 | 99.9 |
| At Least Two | 99.5 | 99.5 | 99.6 |
| All Three | 95.8 | 95.9 | 96.8 |
| **Left** | | | |
| Any | 99.9 | 99.9 | 99.9 |
| At Least Two | 99.5 | 99.5 | 99.6 |
| All Three | 95.7 | 95.8 | 96.7 |

## 3.4 Handling Troublesome Images

### 3.4.1 Capture Failures

Segmentation algorithms may refuse to process an image. This may happen for a technical reason (e.g., the algorithm cannot parse the image data), or for a practical reason (e.g., the hand in the image is placed incorrectly). These failure scenarios are the result of capturing improper image data. In these types of scenarios, it is important to examine the cause of the failure. With many live scan capture setups, segmentation is performed immediately after capture. If an algorithm can detect that it won't be able to segment an image due to a technical or practical issue, it can alert the operator to perform a recapture before the subject leaves.

The SlapSeg III API encourages algorithms to identify these failure reasons by specifying pre-defined *deficiencies* in the image. Algorithms should attempt segmentation even if an image deficiency is encountered if at all possible. Note that SlapSeg III *guarantees* well-formed image data, so failures to parse are **not** an indicator of the data provided.

Reasons for capture-type failures reported by innovatrics+000A are enumerated in Table 22.

Table 22: Count of self-reported capture-type failure reasoning.

| Failure Reason | Images |
|---|---|
| Request Recapture (Attempt) | 36 |

In situations where the algorithm feels that the presented image should be recaptured (Table 22), one or more image deficiencies must be identified. These deficiencies are enumerated in Table 23. At this point, NIST does not have a groundtruth of image deficiencies, but plans to update this table with the accuracy of deficiency observations in the future.

Table 23: Count of image deficiencies reported when requesting a recapture.

| Deficiency | Count |
|---|---|
| Incomplete | 36 |

#### 3.4.1.1 Recovery

When encountering a segmentation failure, SlapSeg III algorithms are encouraged to provide a *best-effort* segmentation when possible. In some cases, that best-effort may be correct, which reduces the amount of images that need to be manually adjudicated by an operator.The result of such best-effort segmentations are shown in Table 24.

Out of 36 recovery attemptsinnovatrics+000A attempted 29 segmentations of fingers and skipped 63 fingers. More information about skipped fingers can be found in Table 25.

Table 24: Results of best-effort segmentation when innovatrics+000A reported segmentation failure (29 best-effort attempts).

| Standard | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|
| 65.5 | 65.5 | 65.5 |

### 3.4.2 Segmentation Failures

Even if an algorithm accepts an image for processing, it can still fail to process one or more fingers from the image, regardless of if the algorithm requested a recapture and provided best-effort segmentation.

The SlapSeg III API allows algorithms to communicate reasons for failure to process these fingers. In some cases, the distal phalanx in question might not be present in the image due to amputation or being placed outside the platen's capture area. It is imperative that the segmentation algorithm correctly report this as failing to segment the correct friction ridge generalized position without disrupting the sequence of valid positions present in the image. This can help prompt an operator to recapture or record additional information about the subject.

In SlapSeg III, a number of images are missing fingers or otherwise have fingers that will not be able to be segmented. Reasons for segmentation failures reported by innovatrics+000A are enumerated in Table 25.

Table 25: Count of self-reported segmentation failure reasoning.

| Failure Reason | Fingers |
|---|---|
| Finger Not Found | 140 |
| Finger Not Found | 63 |
| Finger Found, but Can't Segment | 0 |
| Vendor Defined | 0 |

### 3.4.3 Identifying Missing Fingers

A small portion of the test corpus in SlapSeg III are missing fingers. Table 26 shows how successful innovatrics+000A was in correctly determining if a finger was missing. The *Missed* row shows when a segmentation position was returned for a missing finger. All possible failure reasons are enumerated, but are not considered *Correctly Identified* because the algorithm specified failure for a reason other than the finger not being found.

Table 26: Performance of innovatrics+000A at detecting fingers missing from an image.

| Result | Percentage |
|---|---|
| Missed | 33.6 |
| Correctly Identified | 66.4 |
| Other Failure: Finger Found, but Can't Segment | 0.0 |
| Other Failure: Vendor Defined | 0.0 |
| Other Failure: Segmentation Not Attempted | 0.0 |

### 3.4.4 Sequence Error

Sequence error occurs when a fingerprint is segmented from an image but assigned an incorrect finger position (e.g., segmenting a right middle finger but labeling it a right index finger). Table 27 shows cases in which a segmentation position was returned that matched a ground truth segmentation position for a different finger in the same image.

Table 27: Percentage of images in the dataset where one or more segmentation positions correctly matched an incorrect finger position within the same image, indicating sequence error.

| Hand | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| Left | 0.07 | 0.07 | 0.07 |
| Right | 0.10 | 0.10 | 0.10 |
| Thumbs | 0.04 | 0.04 | 0.04 |
| Combined | 0.07 | 0.07 | 0.07 |

## 3.5 Determining Orientation

An *optional* portion of the SlapSeg III API asked participants to determine the hand orientation of an image. Participants were provided the kind (e.g., Identification Flat) and needed to determine whether the image was of the left hand, right hand, or thumbs.

**Overall Three Inch accuracy**: 80.5%

Table 28: Percentage of accuracy when determining hand orientation of a three inch image. The first column indicates the true hand orientation. Subsequent columns indicate the percentage of the time in which the indicated hand orientation was hypothesized.

| | Left | Right | Thumbs |
|---|---|---|---|
| Left | **99.1** | 0.9 | 0 |
| Right | 0.7 | **99.3** | 0 |
| Thumbs | 28.7 | 29 | **42.3** |

# 4 Upper Palm ("FiveInch" Data)

## 4.1 Segmentation Timing

All algorithms are run over a small fixed corpus of FiveInch images to estimate the total runtime of the evaluation. To be evaluated under SlapSeg III, algorithms **must** segment the timing corpus, on average, in under 1 500 milliseconds. This maximum reference time is documented in the SlapSeg III test plan, and is subject to change. Times are measured by running a single process on an isolated compute node equipped with an Intel Gold 6254 CPU (submissions received prior to February 2022 were timed with a Intel Xeon E5-4650 CPU).

Box plots of segmentation times are separated by slap orientation in Figure 13. Tabular representations are enumerated in Table 29. Results are reported in milliseconds.

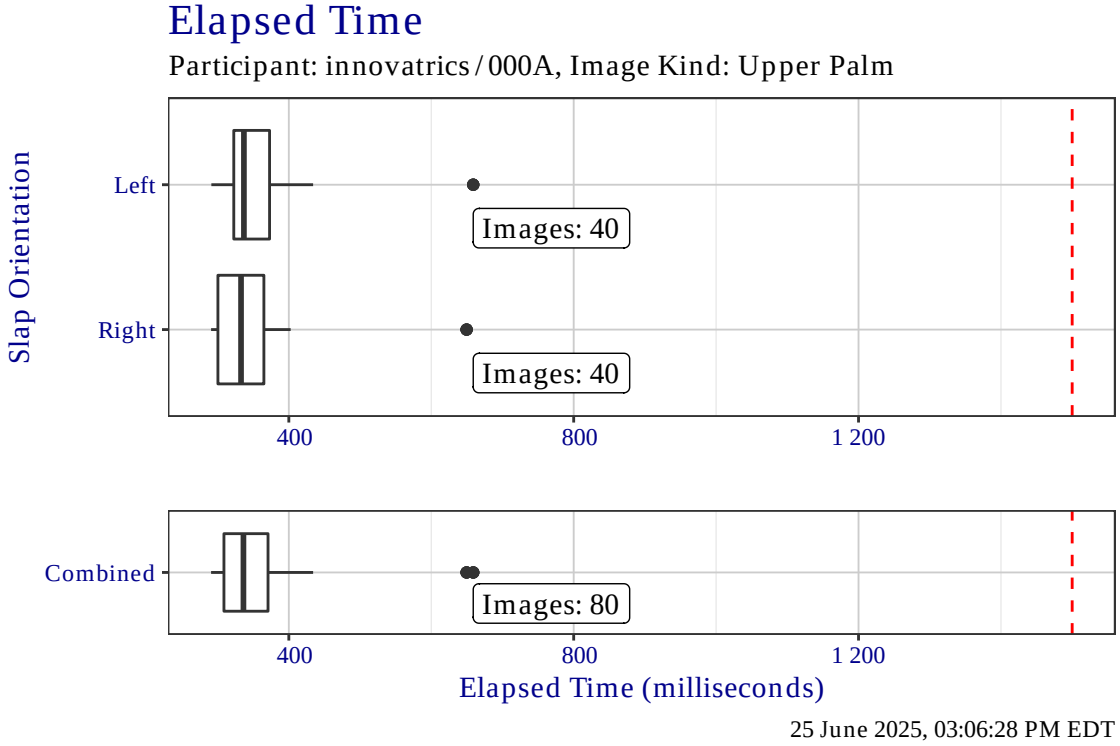


Figure 13: Box plots of elapsed time in milliseconds when segmenting the FiveInch timing test corpus, separated by slap orientation.

Table 29: Elapsed time in milliseconds when segmenting the FiveInch timing test corpus, separated by slap orientation.

| | Right | Left | Combined |
|---|---|---|---|
| Minimum | 291 | 291 | 291 |
| 25% | 300 | 323 | 309 |
| Median | 333 | 337 | 336 |
| 75% | 365 | 373 | 371 |
| Maximum | 650 | 659 | 659 |

## 4.2 Segmentation Centers and Dimensions

### 4.2.1 Segmentation Centers

The plots in this section show the distribution of segmentation position centers $(x, y)$ for FiveInch data. At the top of each figure is a combined plot for all finger positions of a given slap orientation. These figures are isolated in plots faceted at the bottom of the figure.

Plots of segmentation centers for the right hand FiveInch data are shown in Figure 14 and plots of segmentation centers for the left hand are shown in Figure 15. Blank lines that may appear in the plots are **not** rendering artifacts. Rather, they are indicative of image downsampling. Centers have been normalized to 500 pixels per inch.

Points in each plot are plotted with a semi-transparent opacity. This results in points of particular color appearing "darker" to indicate a higher frequency of the observed value, while "lighter" points indicate a lower observed frequency.

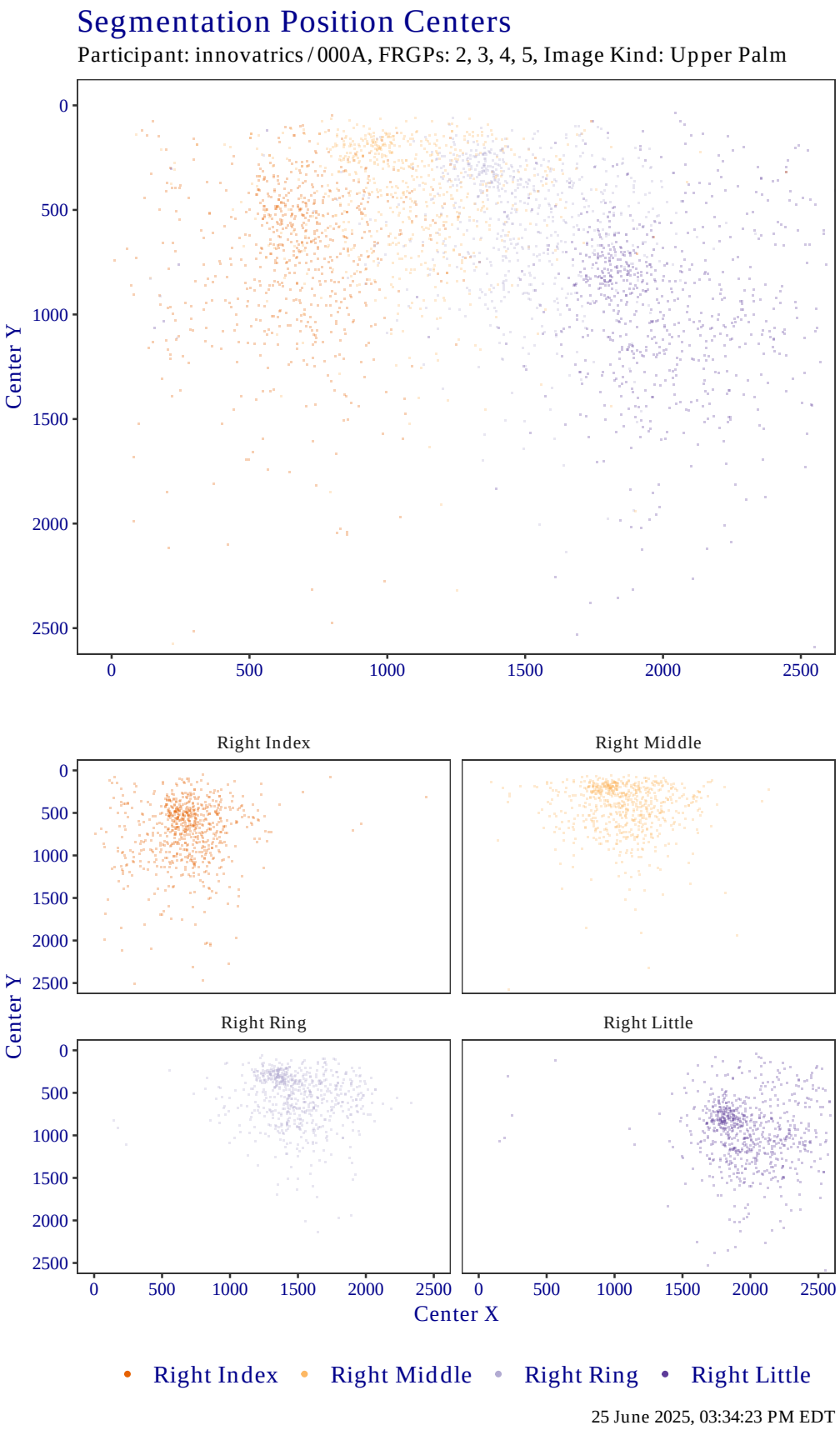


Figure 14: Segmentation centers for right hand FiveInch data.

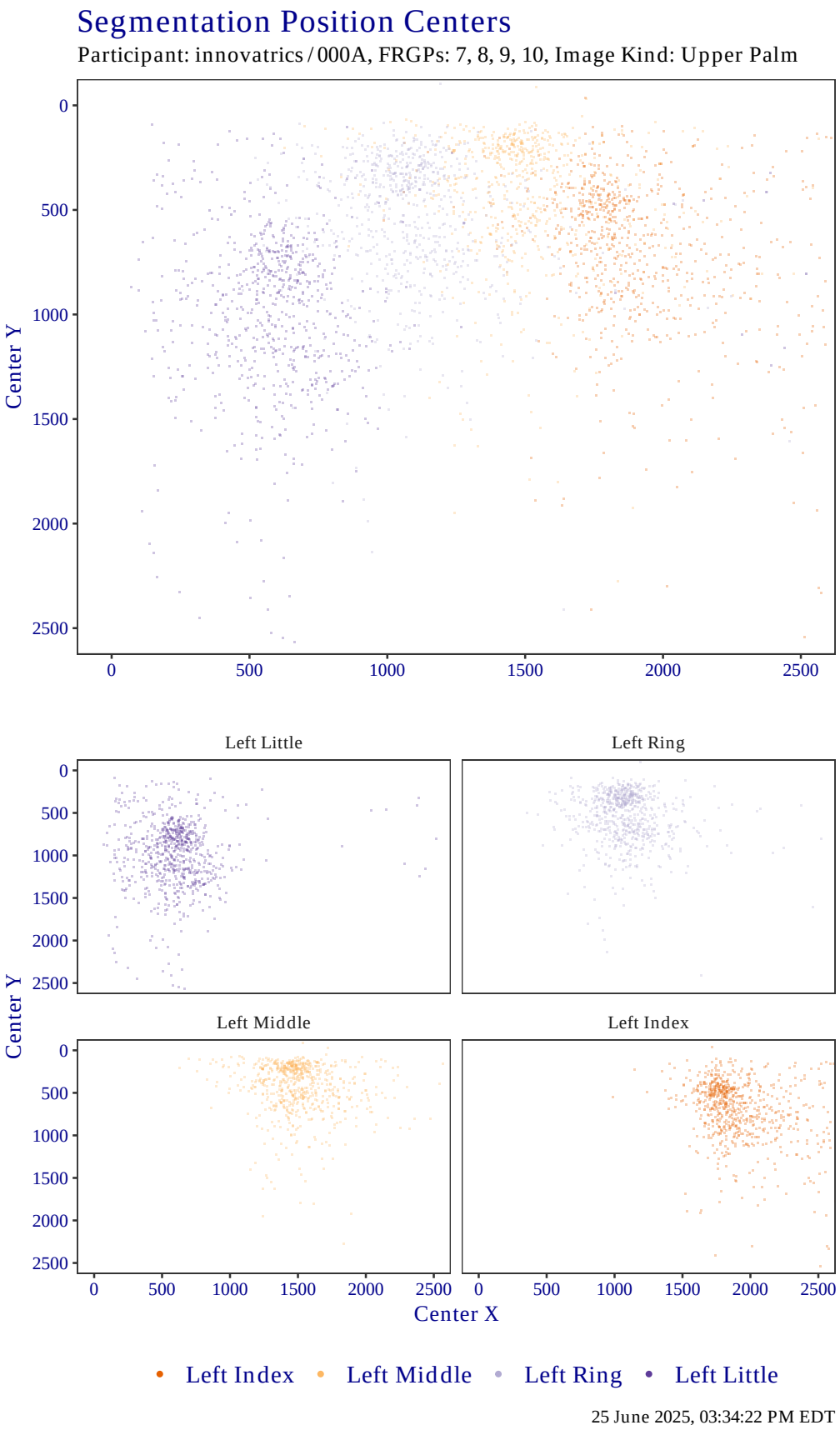


Figure 15: Segmentation centers for left hand FiveInch data.

### 4.2.2 Segmentation Dimensions

The plots in this section show the distribution of segmentation position widths and heights for FiveInch data. At the top of each figure is a combined plot for all finger positions of a given slap orientation. These figures are isolated in plots faceted at the bottom of the figure.

Plots of segmentation position dimensions for the right hand FiveInch data are shown in Figure 16 and the left hand in Figure 17. Blank lines that may appear in the plots are **not** rendering artifacts. Rather, they are indicative of image downsampling. Dimensions have been normalized to 500 pixels per inch.

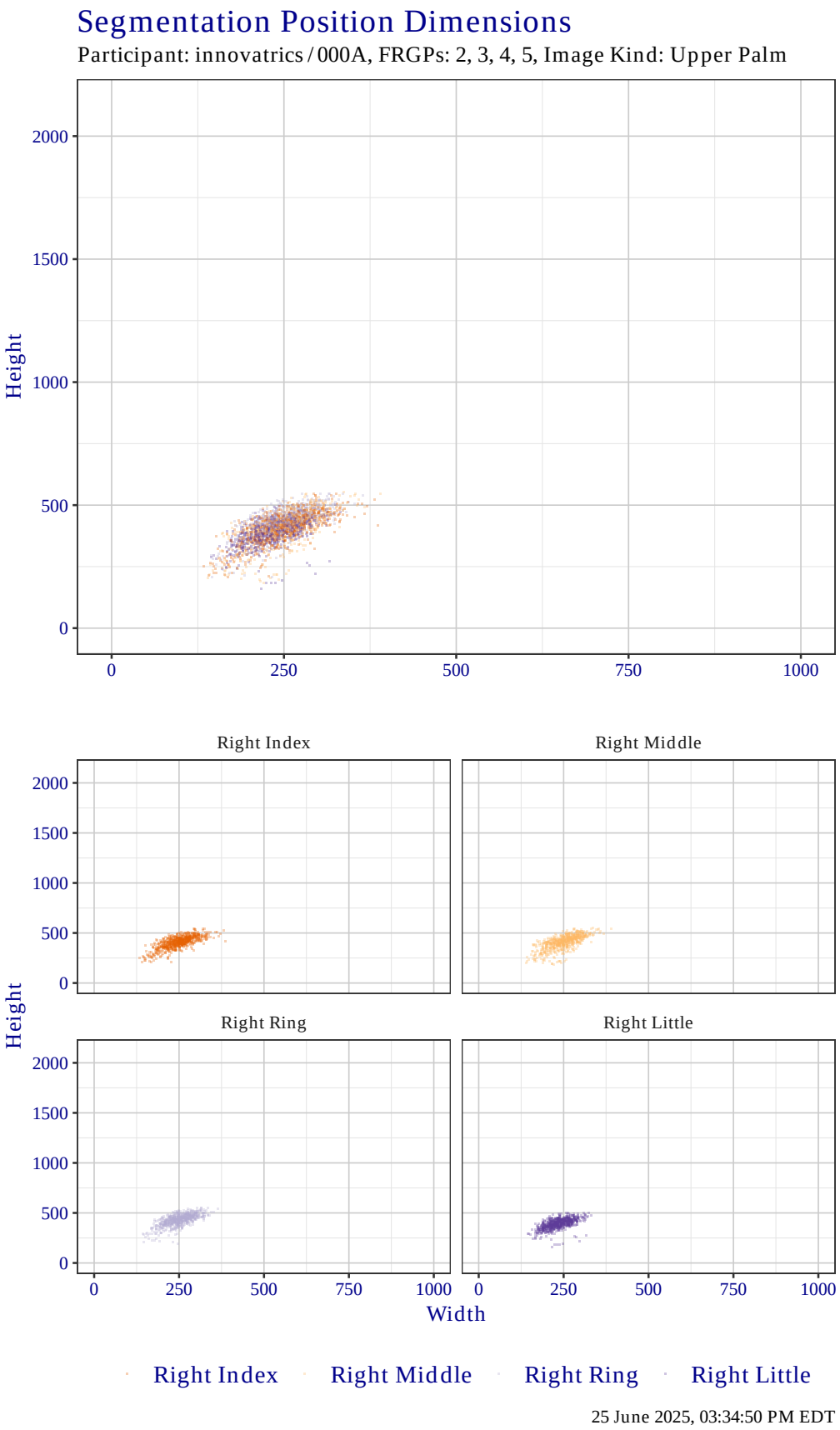


Figure 16: Segmentation position dimensions for right hand FiveInch data.

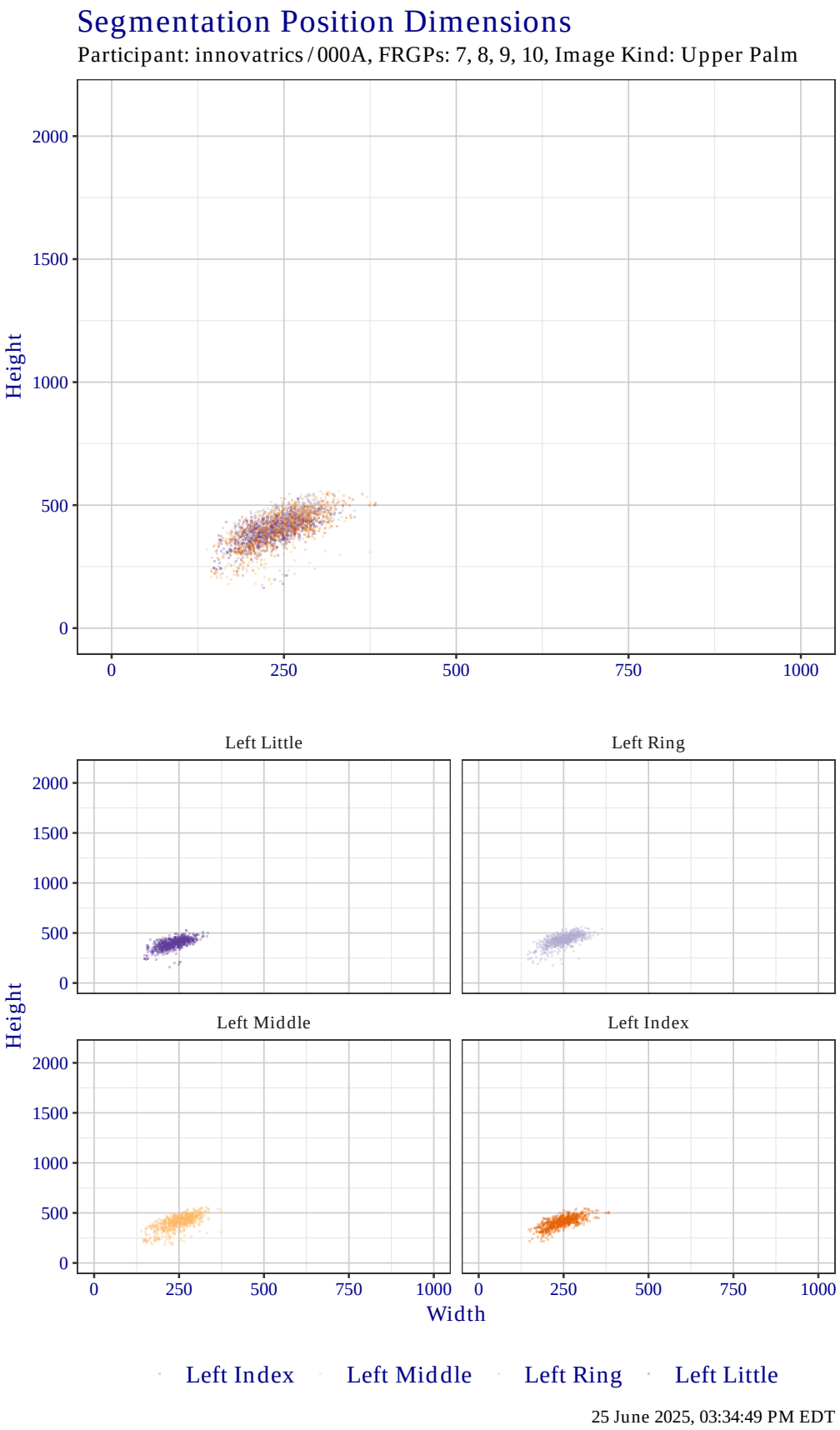


Figure 17: Segmentation position dimensions for left hand FiveInch data.

## 4.3 Detailed Segmentation Statistics

This section shows detailed results of segmentation of FiveInch data. Values in each table are the percentage that the variable in the left-most column was correctly segmented.

Each table has three columns of percentages. The *Standard Scoring* column shows the percentage of correctly-segmented positions based on the scoring metrics defined in the SlapSeg III scoring document. The *Ignoring Bottom Y* column shows how the percentage would change if the threshold for the *bottom Y* coordinate of the segmentation position was ignored. Similarly, the *Ignoring Bottom X and Y* columns shows how the percentage would change if only the top, left, and right sides of the segmentation position were considered. These two supplemental columns are included because it has traditionally been difficult to determine the exact location of the distal interphalangeal joint.

Table 30 shows how successful innovatrics+000A segmented fingers for each subject in the test corpus. Table 31 shows success for specific finger positions over the entire test corpus. Similarly, Table 32 shows success for segmenting the same finger position from both hands.

The remainder of the tables show success per subject when considering combinations of subsets of the fingers on each slap image. Table 33 shows success for combinations of all fingers, Table 34 for just the index and middle fingers, and Table 35 for all except the little finger.

Table 30: For each subject, the percentage that at least *Number of Fingers* fingers were correctly segmented, regardless of hand, for a maximum of eight correctly-segmented fingers. In *Standard Scoring*, scoring rules are followed exactly. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Number of Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| 1 | 99.6 | 99.6 | 99.7 |
| 2 | 99.1 | 99.1 | 99.1 |
| 3 | 96.6 | 96.7 | 96.7 |
| 4 | 92.5 | 92.6 | 92.9 |
| 5 | 85.4 | 85.8 | 85.8 |
| 6 | 79.8 | 79.8 | 80.2 |
| 7 | 70.0 | 70.1 | 70.6 |
| 8 | 52.4 | 53.2 | 54.4 |

Table 31: For all subjects, percentage that a particular friction ridge generalized position was correctly segmented. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Finger | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Index | 85.4 | 85.4 | 85.4 |
| Middle | 83.9 | 84.0 | 84.7 |
| Ring | 88.4 | 89.0 | 89.1 |
| Little | 88.2 | 88.3 | 88.6 |
| **Left** | | | |
| Index | 81.8 | 82.0 | 82.1 |
| Middle | 80.4 | 80.4 | 80.5 |
| Ring | 87.0 | 87.7 | 87.9 |
| Little | 85.7 | 85.7 | 86.6 |

Table 32: Percentage that a particular type of fingerprint was correctly segmented on *Either* or *Both* hands. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Index** | | | |
| Either | 93.1 | 93.1 | 93.1 |
| Both | 72.7 | 72.9 | 73.0 |
| **Middle** | | | |
| Either | 91.7 | 91.8 | 92.0 |
| Both | 71.3 | 71.3 | 71.9 |
| **Ring** | | | |
| Either | 95.1 | 95.5 | 95.5 |
| Both | 78.9 | 79.7 | 80.1 |
| **Little** | | | |
| Either | 96.6 | 96.6 | 96.7 |
| Both | 75.9 | 76.0 | 77.1 |

Table 33: Percentage of segmentation success by hand for combinations of all eight fingers of a FiveInch slap. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 98.7 | 98.7 | 98.8 |
| At Least Two | 94.0 | 94.0 | 94.0 |
| At Least Three | 84.2 | 84.2 | 84.3 |
| All Four | 69.0 | 69.8 | 70.6 |
| **Left** | | | |
| Any | 96.8 | 96.9 | 97.1 |
| At Least Two | 90.7 | 90.8 | 91.1 |
| At Least Three | 81.7 | 81.7 | 82.0 |
| All Four | 65.6 | 66.2 | 67.0 |

Table 34: Percentage of segmentation success by hand when only considering combinations of index and middle fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Either Index or Middle | 92.8 | 92.8 | 92.8 |
| Both Index and Middle | 76.5 | 76.6 | 77.3 |
| **Left** | | | |
| Either Index or Middle | 88.3 | 88.3 | 88.6 |
| Both Index and Middle | 73.9 | 74.0 | 74.0 |

Table 35: Percentage of segmentation success by hand when only considering combinations of index, middle, and ring fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 96.7 | 96.7 | 96.7 |
| At Least Two | 87.9 | 87.9 | 87.9 |
| All Three | 73.1 | 73.8 | 74.6 |
| **Left** | | | |
| Any | 94.3 | 94.6 | 94.7 |
| At Least Two | 83.8 | 83.8 | 84.0 |
| All Three | 71.1 | 71.6 | 71.9 |

## 4.4 Handling Troublesome Images

### 4.4.1 Capture Failures

Segmentation algorithms may refuse to process an image. This may happen for a technical reason (e.g., the algorithm cannot parse the image data), or for a practical reason (e.g., the hand in the image is placed incorrectly). These failure scenarios are the result of capturing improper image data. In these types of scenarios, it is important to examine the cause of the failure. With many live scan capture setups, segmentation is performed immediately after capture. If an algorithm can detect that it won't be able to segment an image due to a technical or practical issue, it can alert the operator to perform a recapture before the subject leaves.

The SlapSeg III API encourages algorithms to identify these failure reasons by specifying pre-defined *deficiencies* in the image. Algorithms should attempt segmentation even if an image deficiency is encountered if at all possible. Note that SlapSeg III *guarantees* well-formed image data, so failures to parse are **not** an indicator of the data provided.

Reasons for capture-type failures reported by innovatrics+000A are enumerated in Table 36.

Table 36: Count of self-reported capture-type failure reasoning.

| Failure Reason | Images |
|---|---|
| Request Recapture (Attempt) | 71 |

In situations where the algorithm feels that the presented image should be recaptured (Table 36), one or more image deficiencies must be identified. These deficiencies are enumerated in Table 37. At this point, NIST does not have a groundtruth of image deficiencies, but plans to update this table with the accuracy of deficiency observations in the future.

Table 37: Count of image deficiencies reported when requesting a recapture.

| Deficiency | Count |
|---|---|
| Incomplete | 71 |

#### 4.4.1.1 Recovery

When encountering a segmentation failure, SlapSeg III algorithms are encouraged to provide a *best-effort* segmentation when possible. In some cases, that best-effort may be correct, which reduces the amount of images that need to be manually adjudicated by an operator.The result of such best-effort segmentations are shown in Table 38.

Out of 71 recovery attemptsinnovatrics+000A attempted 47 segmentations of fingers and skipped 249 fingers. More information about skipped fingers can be found in Table 39.

Table 38: Results of best-effort segmentation when innovatrics+000A reported segmentation failure (47 best-effort attempts).

| Standard | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|
| 21.3 | 21.3 | 21.3 |

### 4.4.2 Segmentation Failures

Even if an algorithm accepts an image for processing, it can still fail to process one or more fingers from the image, regardless of if the algorithm requested a recapture and provided best-effort segmentation.

The SlapSeg III API allows algorithms to communicate reasons for failure to process these fingers. In some cases, the distal phalanx in question might not be present in the image due to amputation or being placed outside the platen's capture area. It is imperative that the segmentation algorithm correctly report this as failing to segment the correct friction ridge generalized position without disrupting the sequence of valid positions present in the image. This can help prompt an operator to recapture or record additional information about the subject.

In SlapSeg III, a number of images are missing fingers or otherwise have fingers that will not be able to be segmented. Reasons for segmentation failures reported by innovatrics+000A are enumerated in Table 39.

Table 39: Count of self-reported segmentation failure reasoning.

| Failure Reason | Fingers |
|---|---|
| Finger Not Found | 343 |
| Finger Not Found | 249 |
| Finger Found, but Can't Segment | 0 |
| Vendor Defined | 0 |

### 4.4.3 Identifying Missing Fingers

A small portion of the test corpus in SlapSeg III are missing fingers. Table 40 shows how successful innovatrics+000A was in correctly determining if a finger was missing. The *Missed* row shows when a segmentation position was returned for a missing finger. All possible failure reasons are enumerated, but are not considered *Correctly Identified* because the algorithm specified failure for a reason other than the finger not being found.

Table 40: Performance of innovatrics+000A at detecting fingers missing from an image.

| Result | Percentage |
|---|---|
| Missed | 51.5 |
| Correctly Identified | 48.5 |
| Other Failure: Finger Found, but Can't Segment | 0.0 |
| Other Failure: Vendor Defined | 0.0 |
| Other Failure: Segmentation Not Attempted | 0.0 |

### 4.4.4 Sequence Error

Sequence error occurs when a fingerprint is segmented from an image but assigned an incorrect finger position (e.g., segmenting a right middle finger but labeling it a right index finger). Table 41 shows cases in which a segmentation position was returned that matched a ground truth segmentation position for a different finger in the same image.

Table 41: Percentage of images in the dataset where one or more segmentation positions correctly matched an incorrect finger position within the same image, indicating sequence error.

| Hand | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| Left | 7.82 | 7.96 | 7.96 |
| Right | 6.78 | 6.78 | 7.05 |
| Combined | 7.30 | 7.37 | 7.50 |

## 4.5 Determining Orientation

An *optional* portion of the SlapSeg III API asked participants to determine the hand orientation of an image. Participants were provided the kind (e.g., upper palm) and needed to determine whether the image was of the left or right hand.

**Overall Upper Palm accuracy**: 96.6%

Table 42: Percentage of accuracy when determining hand orientation of an upper palm image. The first column indicates the true hand orientation. Subsequent columns indicate the percentage of the time in which the indicated hand orientation was hypothesized.

| | Left | Right |
|---|---|---|
| Left | **95.5** | 4.5 |
| Right | 2.4 | **97.6** |

# 5 Full Palm ("EightInch" Data)

## 5.1 Segmentation Timing

All algorithms are run over a small fixed corpus of EightInch images to estimate the total runtime of the evaluation. To be evaluated under SlapSeg III, algorithms **must** segment the timing corpus, on average, in under 1 500 milliseconds. This maximum reference time is documented in the SlapSeg III test plan, and is subject to change. Times are measured by running a single process on an isolated compute node equipped with an Intel Gold 6254 CPU (submissions received prior to February 2022 were timed with a Intel Xeon E5-4650 CPU).

Box plots of segmentation times are separated by slap orientation in Figure 18. Tabular representations are enumerated in Table 43. Results are reported in milliseconds.

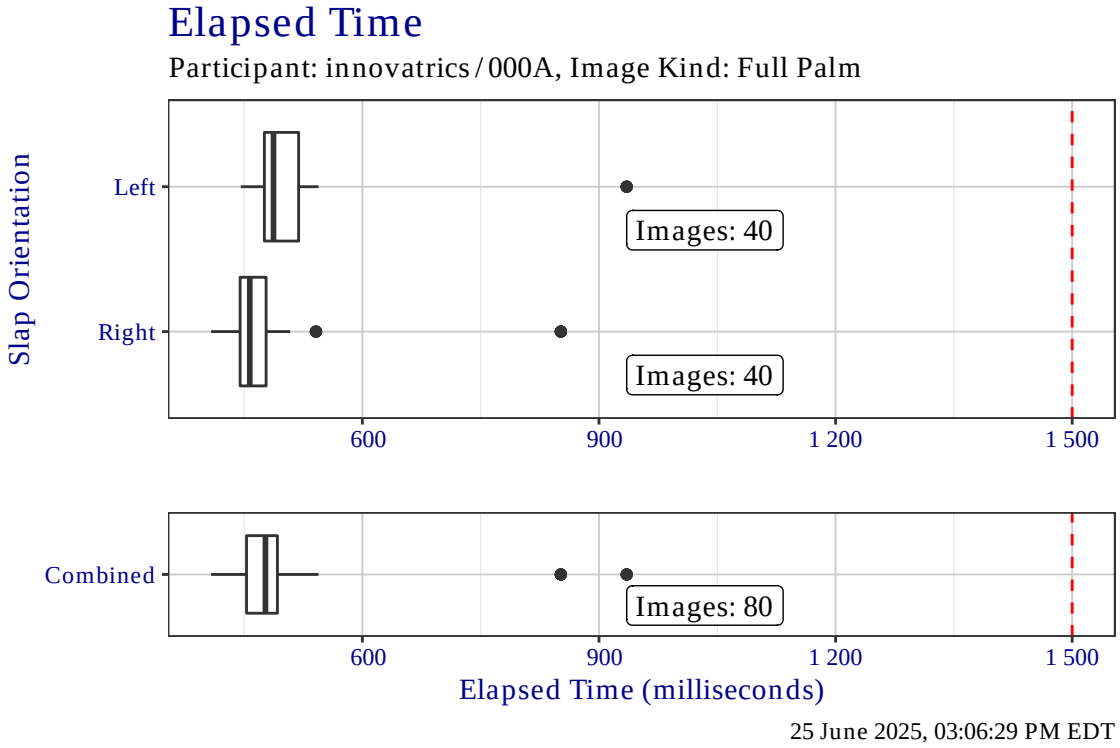


Figure 18: Box plots of elapsed time in milliseconds when segmenting the EightInch timing test corpus, separated by slap orientation.

Table 43: Elapsed time in milliseconds when segmenting the EightInch timing test corpus, separated by slap orientation and capture technology.

| | Right | Left | Combined |
|---|---|---|---|
| Minimum | 408 | 446 | 408 |
| 25% | 445 | 476 | 453 |
| Median | 457 | 487 | 477 |
| 75% | 478 | 519 | 492 |
| Maximum | 852 | 935 | 935 |

## 5.2 Segmentation Centers and Dimensions

### 5.2.1 Segmentation Centers

The plots in this section show the distribution of segmentation position centers $(x, y)$ for EightInch data. At the top of each figure is a combined plot for all finger positions of a given slap orientation. These figures are isolated in plots faceted at the bottom of the figure.

Plots of segmentation centers for the right hand EightInch data are shown in Figure 19 and plots of segmentation centers for the left hand are shown in Figure 20. Blank lines that may appear in the plots are **not** rendering artifacts. Rather, they are indicative of image downsampling. Centers have been normalized to 500 pixels per inch.

Points in each plot are plotted with a semi-transparent opacity. This results in points of particular color appearing "darker" to indicate a higher frequency of the observed value, while "lighter" points indicate a lower observed frequency.

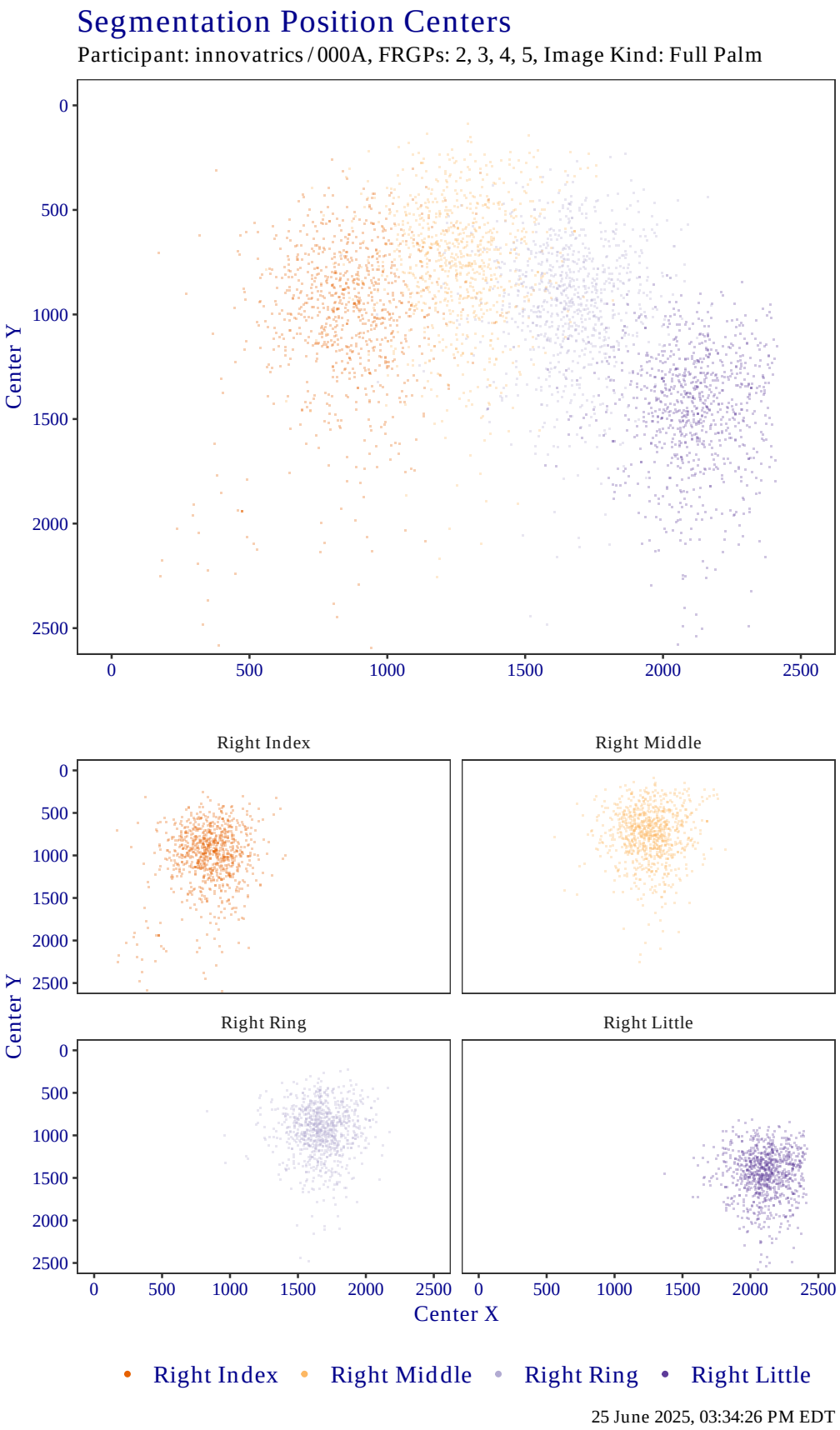


Figure 19: Segmentation centers for right hand EightInch data.

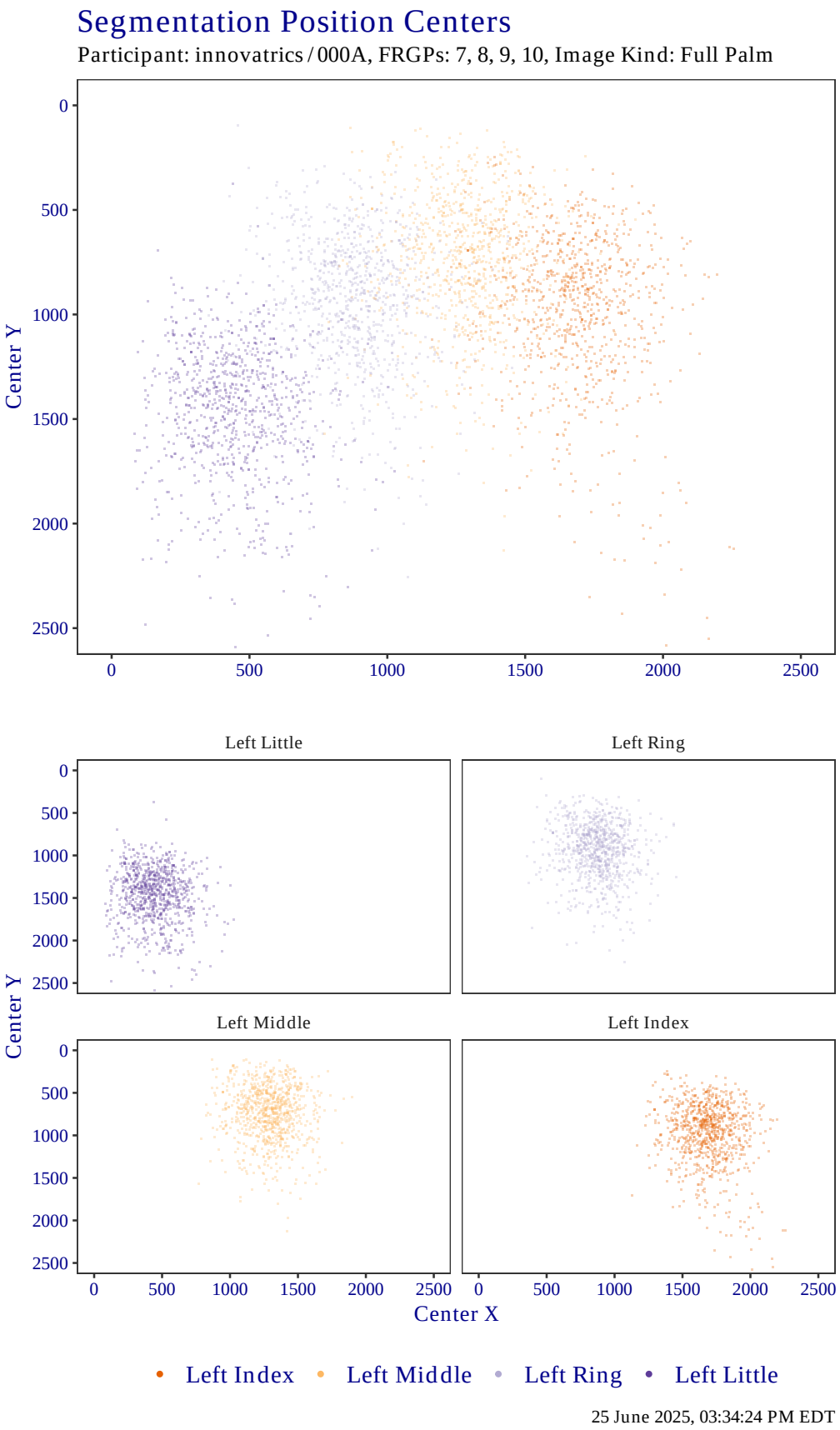


Figure 20: Segmentation centers for left hand EightInch data.

### 5.2.2 Segmentation Dimensions

The plots in this section show the distribution of segmentation position widths and heights for EightInch data. At the top of each figure is a combined plot for all finger positions of a given slap orientation. These figures are isolated in plots faceted at the bottom of the figure.

Plots of segmentation position dimensions for the right hand EightInch data are shown in Figure 21 and the left hand in Figure 22. Blank lines that may appear in the plots are **not** rendering artifacts. Rather, they are indicative of image downsampling. Dimensions have been normalized to 500 pixels per inch.

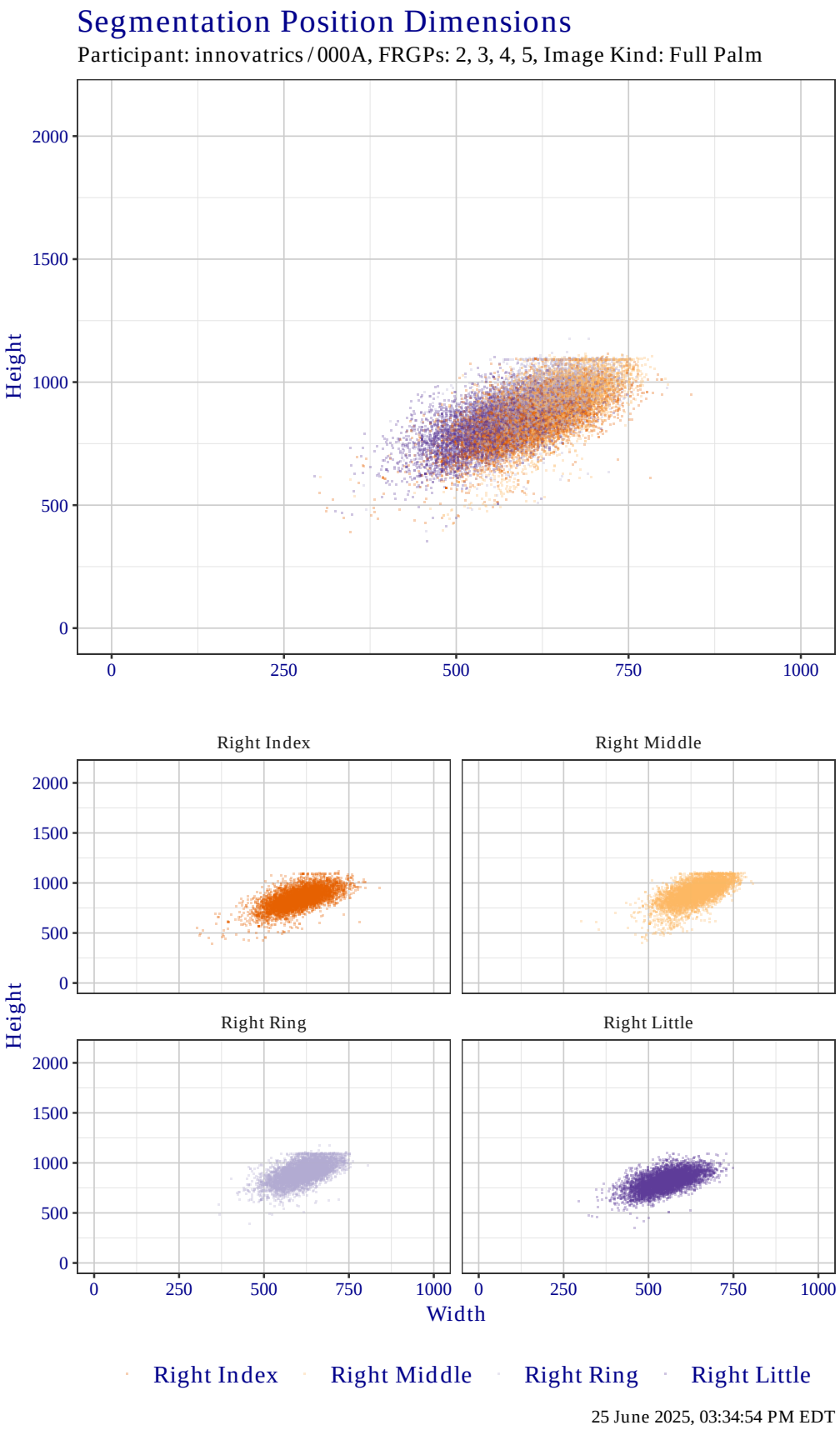


Figure 21: Segmentation position dimensions for right hand EightInch data.

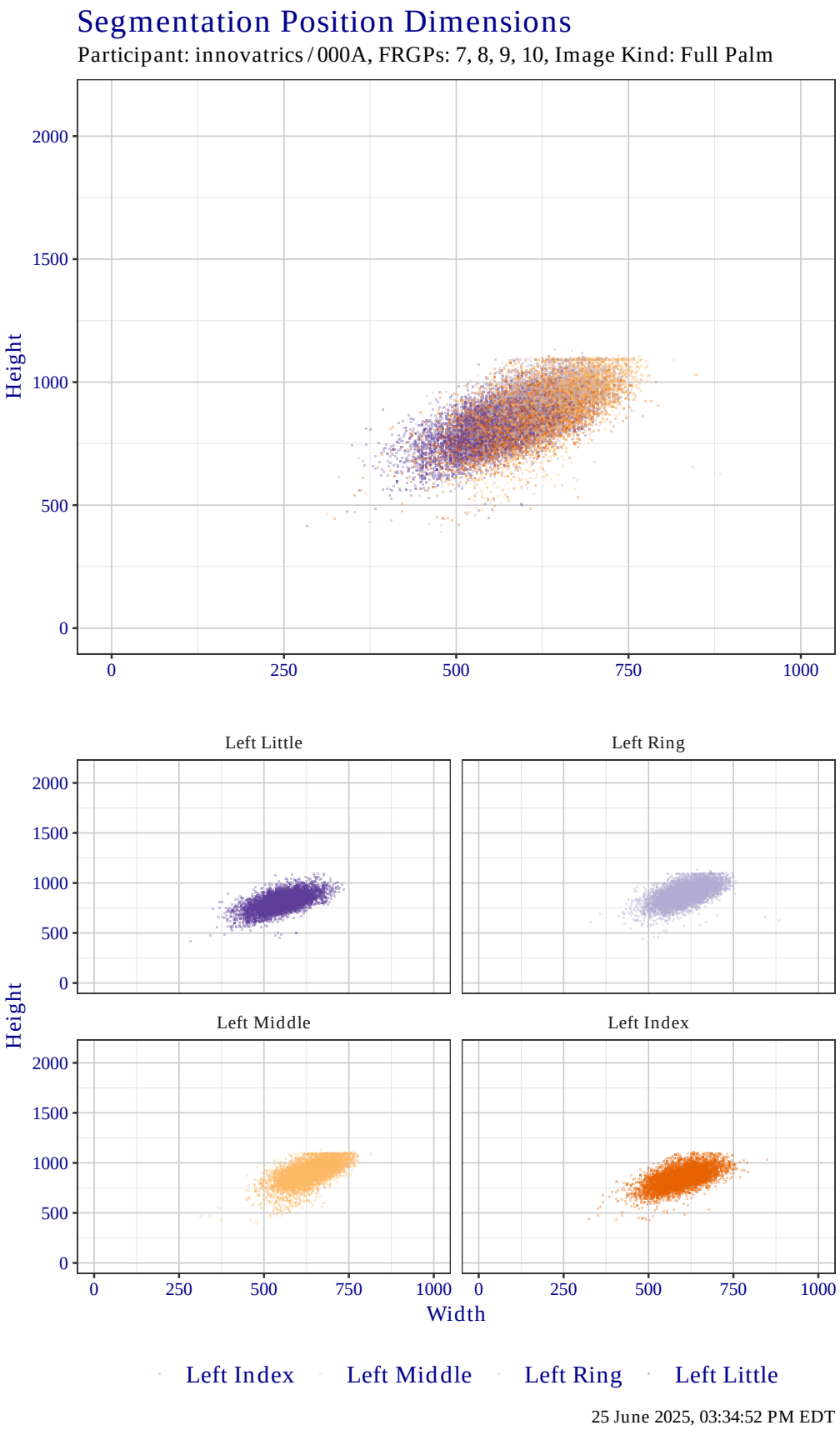


Figure 22: Segmentation position dimensions for left hand EightInch data.

## 5.3 Detailed Segmentation Statistics

**NOTE**: *The following segmentation statistics are based on a limited subset (approximately 15%) of the anticipated Full Palm dataset. This analysis will be updated as soon as NIST can obtain the remainder of the dataset.*

This section shows detailed results of segmentation of EightInch data. Values in each table are the percentage that the variable in the left-most column was correctly segmented.

Each table has three columns of percentages. The *Standard Scoring* column shows the percentage of correctly-segmented positions based on the scoring metrics defined in the SlapSeg III scoring document. The *Ignoring Bottom Y* column shows how the percentage would change if the threshold for the *bottom Y* coordinate of the segmentation position was ignored. Similarly, the *Ignoring Bottom X and Y* columns shows how the percentage would change if only the top, left, and right sides of the segmentation position were considered. These two supplemental columns are included because it has traditionally been difficult to determine the exact location of the distal interphalangeal joint.

Table 44 shows how successful innovatrics+000A segmented fingers for each subject in the test corpus. Table 45 shows success for specific finger positions over the entire test corpus. Similarly, Table 46 shows success for segmenting the same finger position from both hands.

The remainder of the tables show success per subject when considering combinations of subsets of the fingers on each slap image. Table 47 shows success for combinations of all fingers, Table 48 for just the index and middle fingers, and Table 49 for all except the little finger.

Table 44: For each subject, the percentage that at least *Number of Fingers* fingers were correctly segmented, regardless of hand, for a maximum of eight correctly-segmented fingers. In *Standard Scoring*, scoring rules are followed exactly. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Number of Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| 1 | 100.0 | 100.0 | 100.0 |
| 2 | 100.0 | 100.0 | 100.0 |
| 3 | 99.9 | 99.9 | 99.9 |
| 4 | 99.5 | 99.5 | 99.7 |
| 5 | 99.5 | 99.5 | 99.5 |
| 6 | 99.1 | 99.1 | 99.1 |
| 7 | 96.6 | 96.8 | 97.2 |
| 8 | 84.9 | 85.4 | 86.1 |

Table 45: For all subjects, percentage that a particular friction ridge generalized position was correctly segmented. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Finger | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Index | 94.5 | 94.6 | 94.7 |
| Middle | 97.7 | 97.8 | 98.0 |
| Ring | 98.3 | 98.5 | 98.5 |
| Little | 98.9 | 98.9 | 99.1 |
| **Left** | | | |
| Index | 96.0 | 96.1 | 96.1 |
| Middle | 97.5 | 97.5 | 97.7 |
| Ring | 98.2 | 98.3 | 98.7 |
| Little | 98.6 | 98.6 | 98.6 |

Table 46: Percentage that a particular type of fingerprint was correctly segmented on *Either* or *Both* hands. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Index** | | | |
| Either | 99.5 | 99.5 | 99.5 |
| Both | 90.9 | 91.1 | 91.3 |
| **Middle** | | | |
| Either | 99.3 | 99.3 | 99.3 |
| Both | 95.9 | 96.0 | 96.4 |
| **Ring** | | | |
| Either | 99.8 | 99.8 | 99.9 |
| Both | 96.7 | 97.0 | 97.4 |
| **Little** | | | |
| Either | 100.0 | 100.0 | 100.0 |
| Both | 97.5 | 97.5 | 97.7 |

Table 47: Percentage of segmentation success by hand for combinations of all eight fingers of a EightInch slap. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 99.9 | 99.9 | 99.9 |
| At Least Two | 99.3 | 99.3 | 99.3 |
| At Least Three | 98.5 | 98.6 | 98.9 |
| All Four | 91.6 | 92.0 | 92.3 |
| **Left** | | | |
| Any | 100.0 | 100.0 | 100.0 |
| At Least Two | 99.8 | 99.8 | 99.8 |
| At Least Three | 99.1 | 99.1 | 99.2 |
| All Four | 91.4 | 91.6 | 92.2 |

Table 48: Percentage of segmentation success by hand when only considering combinations of index and middle fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Either Index or Middle | 99.0 | 99.1 | 99.2 |
| Both Index and Middle | 93.2 | 93.3 | 93.6 |
| **Left** | | | |
| Either Index or Middle | 99.5 | 99.5 | 99.5 |
| Both Index and Middle | 93.9 | 94.0 | 94.3 |

Table 49: Percentage of segmentation success by hand when only considering combinations of index, middle, and ring fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 99.4 | 99.4 | 99.4 |
| At Least Two | 98.6 | 98.7 | 98.9 |
| All Three | 92.4 | 92.8 | 93.0 |
| **Left** | | | |
| Any | 99.8 | 99.8 | 99.8 |
| At Least Two | 99.3 | 99.3 | 99.4 |
| All Three | 92.5 | 92.8 | 93.3 |

## 5.4 Handling Troublesome Images

### 5.4.1 Capture Failures

Segmentation algorithms may refuse to process an image. This may happen for a technical reason (e.g., the algorithm cannot parse the image data), or for a practical reason (e.g., the hand in the image is placed incorrectly). These failure scenarios are the result of capturing improper image data. In these types of scenarios, it is important to examine the cause of the failure. With many live scan capture setups, segmentation is performed immediately after capture. If an algorithm can detect that it won't be able to segment an image due to a technical or practical issue, it can alert the operator to perform a recapture before the subject leaves.

The SlapSeg III API encourages algorithms to identify these failure reasons by specifying pre-defined *deficiencies* in the image. Algorithms should attempt segmentation even if an image deficiency is encountered if at all possible. Note that SlapSeg III *guarantees* well-formed image data, so failures to parse are **not** an indicator of the data provided.

Reasons for capture-type failures reported by innovatrics+000A are enumerated in Table 50.

Table 50: Count of self-reported capture-type failure reasoning.

| Failure Reason | Images |
|---|---|
| Request Recapture (Attempt) | 7 |

In situations where the algorithm feels that the presented image should be recaptured (Table 50), one or more image deficiencies must be identified. These deficiencies are enumerated in Table 51. At this point, NIST does not have a groundtruth of image deficiencies, but plans to update this table with the accuracy of deficiency observations in the future.

Table 51: Count of image deficiencies reported when requesting a recapture.

| Deficiency | Count |
|---|---|
| Incomplete | 7 |

#### 5.4.1.1 Recovery

When encountering a segmentation failure, SlapSeg III algorithms are encouraged to provide a *best-effort* segmentation when possible. In some cases, that best-effort may be correct, which reduces the amount of images that need to be manually adjudicated by an operator.The result of such best-effort segmentations are shown in Table 52.

Out of 7 recovery attemptsinnovatrics+000A attempted 6 segmentations of fingers and skipped 22 fingers. More information about skipped fingers can be found in Table 53.

Table 52: Results of best-effort segmentation when innovatrics+000A reported segmentation failure (6 best-effort attempts).

| Standard | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|
| 100.0 | 100.0 | 100.0 |

### 5.4.2 Segmentation Failures

Even if an algorithm accepts an image for processing, it can still fail to process one or more fingers from the image, regardless of if the algorithm requested a recapture and provided best-effort segmentation.

The SlapSeg III API allows algorithms to communicate reasons for failure to process these fingers. In some cases, the distal phalanx in question might not be present in the image due to amputation or being placed outside the platen's capture area. It is imperative that the segmentation algorithm correctly report this as failing to segment the correct friction ridge generalized position without disrupting the sequence of valid positions present in the image. This can help prompt an operator to recapture or record additional information about the subject.

In SlapSeg III, a number of images are missing fingers or otherwise have fingers that will not be able to be segmented. Reasons for segmentation failures reported by innovatrics+000A are enumerated in Table 53.

Table 53: Count of self-reported segmentation failure reasoning.

| Failure Reason | Fingers |
|---|---|
| Finger Not Found | 221 |
| Finger Not Found | 22 |
| Finger Found, but Can't Segment | 0 |
| Vendor Defined | 0 |

### 5.4.3 Identifying Missing Fingers

A small portion of the test corpus in SlapSeg III are missing fingers. Table 54 shows how successful innovatrics+000A was in correctly determining if a finger was missing. The *Missed* row shows when a segmentation position was returned for a missing finger. All possible failure reasons are enumerated, but are not considered *Correctly Identified* because the algorithm specified failure for a reason other than the finger not being found.

Table 54: Performance of innovatrics+000A at detecting fingers missing from an image.

| Result | Percentage |
|---|---|
| Missed | 0.0 |
| Correctly Identified | 100.0 |
| Other Failure: Finger Found, but Can't Segment | 0.0 |
| Other Failure: Vendor Defined | 0.0 |
| Other Failure: Segmentation Not Attempted | 0.0 |

### 5.4.4 Sequence Error

Sequence error occurs when a fingerprint is segmented from an image but assigned an incorrect finger position (e.g., segmenting a right middle finger but labeling it a right index finger). Table 55 shows cases in which a segmentation position was returned that matched a ground truth segmentation position for a different finger in the same image.

Table 55: Percentage of images in the dataset where one or more segmentation positions correctly matched an incorrect finger position within the same image, indicating sequence error.

| Hand | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| Left | 0.46 | 0.46 | 0.46 |
| Right | 0.34 | 0.34 | 0.34 |
| Combined | 0.40 | 0.40 | 0.40 |

## 5.5 Determining Orientation

An *optional* portion of the SlapSeg III API asked participants to determine the hand orientation of an image. Participants were provided the kind (e.g., full palm) and needed to determine whether the image was of the left or right hand.

**Overall Full Palm accuracy**: 96.5%

Table 56: Percentage of accuracy when determining hand orientation of an full palm image. The first column indicates the true hand orientation. Subsequent columns indicate the percentage of the time in which the indicated hand orientation was hypothesized.

| | Left | Right |
|---|---|---|
| Left | **94.2** | 5.8 |
| Right | 1.2 | **98.8** |

# A Tenprint Cards ("TwoInch" Data)

## A.1 Bootstrap Confidence for Segmentation Statistics

This section shows the same detailed results of segmentation of TwoInch data from Section 2.3, but with an added bootstrap confidence interval. For each observation, a bootstrap routine with 1 000 replicates was run, and a 95 % confidence interval extracted. The lower and upper confidence from that confidence interval are printed in each column within square brackets.

In Table 57, results are shown of how successful `innovatrics+000A` segmented fingers for each subject in the test corpus. Table 58 shows success for specific finger positions over the entire test corpus. Similarly, Table 59 shows success for segmenting the same finger position from both hands.

The remainder of the tables show success per subject when considering combinations of subsets of the fingers in each slap image. Table 60 shows success for combinations of all fingers, Table 62 for the all except the little finger, and Table 61 for just the index and middle fingers.

Table 57: For each subject, the percentage that at least *Number of Fingers* fingers were correctly segmented, regardless of hand, for a maximum of eight correctly-segmented fingers. In *Standard Scoring*, scoring rules are followed exactly. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Number of Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| 1 | 100.0 [99.9, 100.0] | 100.0 [99.9, 100.0] | 100.0 [99.9, 100.0] |
| 2 | 99.9 [99.8, 99.9] | 99.9 [99.8, 99.9] | 99.9 [99.9, 100.0] |
| 3 | 99.4 [99.3, 99.6] | 99.5 [99.4, 99.6] | 99.6 [99.5, 99.7] |
| 4 | 98.5 [98.3, 98.7] | 98.6 [98.4, 98.8] | 98.9 [98.7, 99.0] |
| 5 | 95.6 [95.3, 96.0] | 95.7 [95.3, 96.0] | 95.7 [95.4, 96.1] |
| 6 | 94.8 [94.4, 95.1] | 95.0 [94.6, 95.4] | 95.2 [94.9, 95.6] |
| 7 | 90.2 [89.6, 90.7] | 91.2 [90.7, 91.6] | 92.0 [91.5, 92.5] |
| 8 | 74.8 [74.1, 75.6] | 78.3 [77.6, 79.0] | 80.9 [80.2, 81.6] |

Table 58: For all subjects, Percentage that a particular friction ridge generalized position was correctly segmented. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Finger | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Index | 94.0 [93.7, 94.3] | 95.4 [95.2, 95.7] | 95.9 [95.6, 96.2] |
| Middle | 96.2 [96.0, 96.5] | 96.8 [96.6, 97.0] | 97.0 [96.8, 97.2] |
| Ring | 96.6 [96.4, 96.9] | 97.2 [97.0, 97.4] | 97.5 [97.2, 97.7] |
| Little | 95.6 [95.4, 95.9] | 96.3 [96.1, 96.6] | 97.8 [97.6, 98.0] |
| **Left** | | | |
| Index | 96.6 [96.4, 96.9] | 97.2 [96.9, 97.4] | 97.6 [97.4, 97.8] |
| Middle | 97.3 [97.1, 97.5] | 97.8 [97.6, 98.0] | 98.0 [97.8, 98.2] |
| Ring | 96.8 [96.5, 97.0] | 97.4 [97.2, 97.7] | 97.7 [97.5, 97.9] |
| Little | 95.8 [95.5, 96.0] | 96.2 [96.0, 96.5] | 96.8 [96.6, 97.1] |

Table 59: Percentage that a particular type of fingerprint was correctly segmented on *Either* or *Both* hands. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Index** | | | |
| Either | 98.9 [98.7, 99.1] | 99.0 [98.8, 99.2] | 99.1 [98.9, 99.2] |
| Both | 87.5 [86.9, 88.0] | 89.0 [88.5, 89.6] | 89.9 [89.4, 90.5] |
| **Middle** | | | |
| Either | 99.3 [99.1, 99.4] | 99.4 [99.2, 99.5] | 99.5 [99.4, 99.6] |
| Both | 90.6 [90.1, 91.1] | 91.5 [91.0, 92.0] | 91.8 [91.3, 92.3] |
| **Ring** | | | |
| Either | 99.2 [99.1, 99.4] | 99.4 [99.2, 99.5] | 99.5 [99.4, 99.6] |
| Both | 90.7 [90.2, 91.2] | 91.9 [91.4, 92.4] | 92.2 [91.8, 92.7] |
| **Little** | | | |
| Either | 99.2 [99.0, 99.3] | 99.3 [99.1, 99.4] | 99.5 [99.4, 99.7] |
| Both | 87.8 [87.2, 88.4] | 88.8 [88.2, 89.3] | 90.7 [90.1, 91.2] |

Table 60: Percentage of segmentation success by hand for combinations of all eight fingers of a TwoInch slap. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 100.0 [99.9, 100.0] | 100.0 [99.9, 100.0] | 100.0 [99.9, 100.0] |
| At Least Two | 99.7 [99.6, 99.7] | 99.8 [99.7, 99.8] | 99.9 [99.8, 99.8] |
| At Least Three | 97.1 [97.3, 97.6] | 97.6 [97.7, 98.0] | 98.0 [98.1, 98.3] |
| All Four | 85.7 [87.0, 87.6] | 88.5 [89.3, 89.9] | 90.4 [90.9, 91.4] |
| **Left** | | | |
| Any | 99.9 [99.9, 100.0] | 99.9 [99.9, 100.0] | 99.9 [99.9, 100.0] |
| At Least Two | 99.6 [99.6, 99.7] | 99.7 [99.7, 99.8] | 99.8 [99.8, 99.8] |
| At Least Three | 97.9 [97.3, 97.6] | 98.2 [97.7, 98.0] | 98.5 [98.1, 98.3] |
| All Four | 89.0 [87.0, 87.6] | 90.9 [89.3, 89.9] | 92.0 [90.9, 91.4] |

Table 61: Percentage of segmentation success by hand when only considering combinations of index and middle fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Either Index or Middle | 98.3 [98.5, 98.7] | 98.4 [98.6, 98.8] | 98.5 [98.7, 98.9] |
| Both Index and Middle | 91.9 [93.1, 93.6] | 93.8 [94.6, 95.0] | 94.4 [95.2, 95.6] |
| **Left** | | | |
| Either Index or Middle | 98.9 [98.5, 98.7] | 99.0 [98.6, 98.8] | 99.1 [98.7, 98.9] |
| Both Index and Middle | 95.0 [93.1, 93.6] | 96.0 [94.6, 95.0] | 96.5 [95.2, 95.6] |

Table 62: Percentage of segmentation success by hand when only considering combinations of index, middle, and ring fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 99.9 [99.8, 99.9] | 99.9 [99.8, 99.9] | 99.9 [99.9, 99.9] |
| At Least Two | 97.8 [98.0, 98.2] | 98.1 [98.2, 98.5] | 98.3 [98.4, 98.7] |
| All Three | 89.2 [90.4, 91.0] | 91.5 [92.4, 92.9] | 92.2 [93.1, 93.6] |
| **Left** | | | |
| Any | 99.8 [99.8, 99.9] | 99.8 [99.8, 99.9] | 99.9 [99.9, 99.9] |
| At Least Two | 98.5 [98.0, 98.2] | 98.7 [98.2, 98.5] | 98.8 [98.4, 98.7] |
| All Three | 92.4 [90.4, 91.0] | 93.9 [92.4, 92.9] | 94.6 [93.1, 93.6] |

## A.2 Jaccard Index

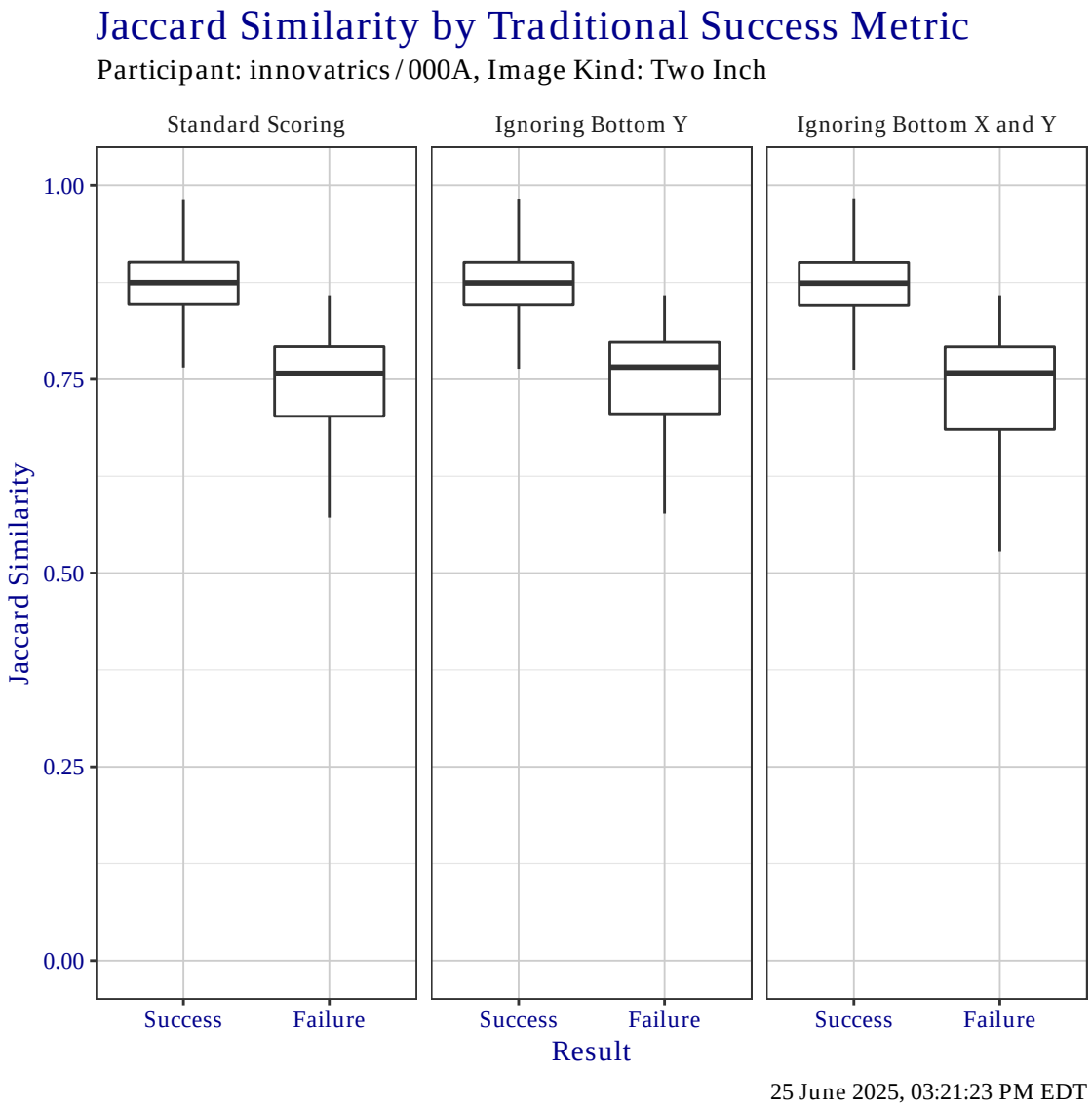


Figure 23: Boxplot of Jaccard similarity indices as compared to the traditional success metrics. Outliers have been removed for clarity.

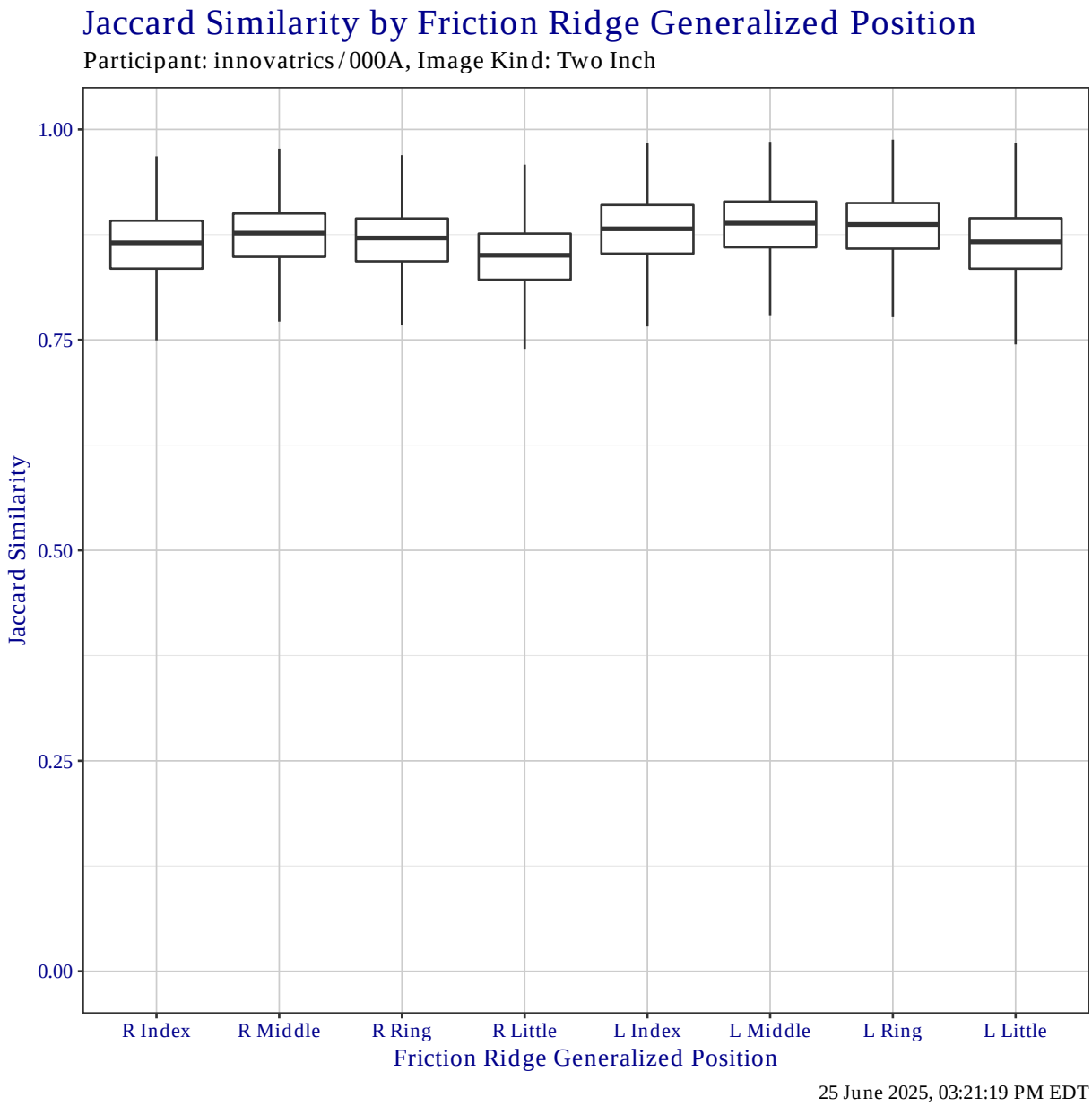


Figure 24: Boxplot of Jaccard similarity indices for each friction ridge generalized position. Outliers have been removed for clarity.

Table 63: For each subject, the percentage that at least *Number of Fingers* fingers were segmented with a Jaccard index in the indicated range.

| Number of Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| 1 | 100.0 | 100.0 | 100.0 | 99.9 | 79.7 | 11.7 | 0.3 |
| 2 | 100.0 | 100.0 | 99.9 | 99.5 | 57.2 | 1.6 | 0.0 |
| 3 | 99.9 | 99.9 | 99.7 | 98.5 | 35.3 | 0.2 | 0.0 |
| 4 | 99.8 | 99.7 | 99.2 | 96.9 | 17.9 | 0.0 | 0 |
| 5 | 95.8 | 95.8 | 95.8 | 94.3 | 6.6 | 0 | 0 |
| 6 | 95.8 | 95.8 | 95.7 | 90.6 | 1.9 | 0 | 0 |
| 7 | 94.3 | 94.3 | 93.9 | 80.5 | 0.4 | 0 | 0 |
| 8 | 94.0 | 93.7 | 89.9 | 56.4 | 0.0 | 0 | 0 |

Table 64: For all subjects, percentage that a particular friction ridge generalized position was segmented with a Jaccard index in the indicated range.

| Finger | 0-0.5 | 0.5-0.6 | 0.6-0.7 | 0.7-0.8 | 0.8-0.9 | 0.9-1.0 |
|---|---|---|---|---|---|---|
| **Right** | | | | | | |
| Index | 1.2 | 0.1 | 0.5 | 8.6 | 71.5 | 18.1 |
| Middle | 1.2 | 0.0 | 0.4 | 5.4 | 67.9 | 25.1 |
| Ring | 0.1 | 0.0 | 0.6 | 6.9 | 72.9 | 19.5 |
| Little | 0.1 | 0.1 | 0.7 | 12.6 | 77.8 | 8.7 |
| **Left** | | | | | | |
| Index | 0.7 | 0.1 | 0.4 | 4.3 | 61.2 | 33.3 |
| Middle | 0.7 | 0.1 | 0.5 | 4.2 | 55.8 | 38.7 |
| Ring | 0.1 | 0.1 | 0.8 | 5.2 | 56.8 | 37.0 |
| Little | 0.2 | 0.0 | 0.6 | 9.3 | 69.0 | 20.9 |

Table 65: Percentage of segmentation obtaining a Jaccard index in the indicated ranges, by hand, for combinations of all eight fingers of a TwoInch slap.

| Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| **Right** | | | | | | | |
| Any | 100.0 | 100.0 | 100.0 | 99.8 | 48.1 | 1.9 | 0.0 |
| At Least Two | 100.0 | 100.0 | 99.9 | 98.5 | 18.3 | 0.0 | 0.0 |
| At Least Three | 98.8 | 98.8 | 98.6 | 92.1 | 4.5 | 0.0 | 0.0 |
| All Four | 98.6 | 98.5 | 96.5 | 71.2 | 0.5 | 0.0 | 0.0 |
| **Left** | | | | | | | |
| Any | 100.0 | 100.0 | 100.0 | 99.8 | 67.0 | 9.7 | 0.2 |
| At Least Two | 99.9 | 99.9 | 99.9 | 98.8 | 39.5 | 1.3 | 0.0 |
| At Least Three | 99.2 | 99.2 | 99.1 | 95.0 | 18.4 | 0.1 | 0.0 |
| All Four | 99.0 | 98.8 | 96.7 | 79.1 | 5.0 | 0.0 | 0.0 |

Table 66: Percentage of segmentation obtaining a Jaccard index in the indicated ranges, by hand, for combinations of index and middle fingers of a TwoInch slap.

| Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| **Right** | | | | | | | |
| Either Index or Middle | 98.8 | 98.8 | 98.8 | 97.5 | 35.8 | 1.5 | 0.0 |
| Both Index and Middle | 98.7 | 98.7 | 97.9 | 85.1 | 7.5 | 0.0 | 0 |
| **Left** | | | | | | | |
| Either Index or Middle | 99.3 | 99.3 | 99.3 | 98.4 | 52.8 | 6.4 | 0.1 |
| Both Index and Middle | 99.2 | 99.1 | 98.3 | 90.6 | 19.2 | 0.4 | 0 |

Table 67: Percentage of segmentation obtaining a Jaccard index in the indicated ranges, by hand, for combinations of index, middle, and ring fingers of a TwoInch slap.

| Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| **Right** | | | | | | | |
| Any | 100.0 | 100.0 | 100.0 | 99.5 | 44.8 | 1.8 | 0.0 |
| At Least Two | 98.8 | 98.8 | 98.7 | 95.6 | 15.4 | 0.0 | 0.0 |
| All Three | 98.7 | 98.6 | 97.2 | 79.9 | 2.5 | 0 | 0 |
| **Left** | | | | | | | |
| Any | 100.0 | 100.0 | 99.9 | 99.5 | 63.3 | 8.9 | 0.2 |
| At Least Two | 99.3 | 99.2 | 99.1 | 97.0 | 33.9 | 1.0 | 0.0 |
| All Three | 99.2 | 98.9 | 97.4 | 86.3 | 11.8 | 0.1 | 0 |

# B Identification Flats ("ThreeInch" Data)

## B.1 Bootstrap Confidence for Segmentation Statistics

This section shows the same detailed results of segmentation of ThreeInch data from Section 3.3, but with an added bootstrap confidence interval. For each observation, a bootstrap routine with 1 000 replicates was run, and a 95 % confidence interval extracted. The lower and upper confidence from that confidence interval are printed in each column within square brackets.

In Table 68, results are shown of how successful `innovatrics+000A` segmented fingers for each subject in the test corpus. Table 69 shows success for specific finger positions over the entire test corpus. Similarly, Table 70 shows success for segmenting the same finger position from both hands.

The remainder of the tables show success per subject when considering combinations of subsets of the fingers in each slap image. Table 71 shows success for combinations of all fingers, Table 73 for the all except the little finger, and Table 72 for just the index and middle fingers.

Table 68: For each subject, the percentage that at least *Number of Fingers* fingers were correctly segmented, regardless of hand, for a maximum of eight correctly-segmented fingers. In *Standard Scoring*, scoring rules are followed exactly. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Number of Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---:|---|---|---|
| 1 | 99.9 [99.9, 99.9] | 99.9 [99.9, 100.0] | 99.9 [99.9, 100.0] |
| 2 | 99.5 [99.5, 99.6] | 99.5 [99.5, 99.6] | 99.6 [99.5, 99.6] |
| 3 | 98.6 [98.4, 98.7] | 98.6 [98.4, 98.7] | 98.6 [98.4, 98.7] |
| 4 | 98.3 [98.2, 98.5] | 98.3 [98.2, 98.5] | 98.4 [98.2, 98.5] |
| 5 | 95.9 [95.7, 96.2] | 95.9 [95.7, 96.2] | 95.9 [95.7, 96.2] |
| 6 | 95.9 [95.7, 96.2] | 95.9 [95.7, 96.2] | 95.9 [95.7, 96.2] |
| 7 | 95.9 [95.6, 96.1] | 95.9 [95.6, 96.1] | 95.9 [95.6, 96.1] |
| 8 | 95.5 [95.2, 95.8] | 95.5 [95.2, 95.8] | 95.6 [95.3, 95.9] |
| 9 | 93.7 [93.4, 93.9] | 93.8 [93.5, 94.1] | 94.3 [94.1, 94.6] |
| 10 | 84.0 [83.6, 84.4] | 85.0 [84.6, 85.4] | 87.4 [87.0, 87.8] |

Table 69: For all subjects, Percentage that a particular friction ridge generalized position was correctly segmented. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Finger | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Thumb | 98.2 [98.0, 98.3] | 98.7 [98.5, 98.8] | 99.1 [99.0, 99.2] |
| Index | 99.2 [99.1, 99.3] | 99.2 [99.1, 99.3] | 99.3 [99.2, 99.4] |
| Middle | 98.6 [98.5, 98.7] | 98.6 [98.5, 98.8] | 98.9 [98.8, 99.1] |
| Ring | 97.4 [97.2, 97.6] | 97.4 [97.2, 97.6] | 98.0 [97.9, 98.2] |
| Little | 98.3 [98.1, 98.5] | 98.3 [98.1, 98.5] | 98.4 [98.2, 98.5] |
| **Left** | | | |
| Thumb | 98.2 [98.1, 98.4] | 98.8 [98.6, 98.9] | 99.2 [99.1, 99.3] |
| Index | 98.3 [98.1, 98.4] | 98.3 [98.1, 98.4] | 98.4 [98.2, 98.5] |
| Middle | 98.5 [98.3, 98.6] | 98.5 [98.4, 98.7] | 98.8 [98.7, 99.0] |
| Ring | 98.4 [98.2, 98.5] | 98.4 [98.3, 98.6] | 99.1 [98.9, 99.2] |
| Little | 98.6 [98.5, 98.8] | 98.6 [98.5, 98.8] | 98.7 [98.6, 98.9] |

Table 70: Percentage that a particular type of fingerprint was correctly segmented on *Either* or *Both* hands. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Thumb** | | | |
| Either | 99.7 [99.6, 99.8] | 99.8 [99.7, 99.8] | 99.9 [99.8, 99.9] |
| Both | 96.8 [96.6, 97.0] | 97.7 [97.6, 97.9] | 98.5 [98.4, 98.7] |
| **Index** | | | |
| Either | 99.9 [99.8, 99.9] | 99.9 [99.8, 99.9] | 99.9 [99.8, 99.9] |
| Both | 94.9 [94.6, 95.2] | 94.9 [94.7, 95.2] | 95.1 [94.9, 95.4] |
| **Middle** | | | |
| Either | 99.8 [99.8, 99.9] | 99.8 [99.8, 99.9] | 99.9 [99.8, 99.9] |
| Both | 94.6 [94.3, 94.9] | 94.6 [94.3, 94.9] | 95.2 [95.0, 95.5] |
| **Ring** | | | |
| Either | 99.7 [99.7, 99.8] | 99.8 [99.7, 99.8] | 99.9 [99.8, 99.9] |
| Both | 93.3 [93.0, 93.7] | 93.4 [93.1, 93.8] | 94.6 [94.3, 94.9] |
| **Little** | | | |
| Either | 99.9 [99.8, 99.9] | 99.9 [99.8, 99.9] | 99.9 [99.8, 99.9] |
| Both | 94.4 [94.1, 94.7] | 94.4 [94.1, 94.7] | 94.6 [94.3, 94.9] |

Table 71: Percentage of segmentation success by hand for combinations of all ten fingers of a ThreeInch slap. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 99.6 [99.7, 99.8] | 99.6 [99.7, 99.8] | 99.7 [99.7, 99.8] |
| At Least Two | 98.5 [98.4, 98.6] | 98.5 [98.4, 98.6] | 98.5 [98.4, 98.6] |
| At Least Three | 98.3 [98.2, 98.4] | 98.3 [98.2, 98.4] | 98.3 [98.2, 98.5] |
| At Least Four | 97.4 [97.3, 97.6] | 97.4 [97.3, 97.6] | 97.6 [97.5, 97.7] |
| All Five | 88.7 [88.4, 89.0] | 89.2 [89.0, 89.5] | 90.6 [90.3, 90.8] |
| **Left** | | | |
| Any | 99.8 [99.7, 99.8] | 99.8 [99.7, 99.8] | 99.8 [99.7, 99.8] |
| At Least Two | 98.5 [98.4, 98.6] | 98.5 [98.4, 98.6] | 98.5 [98.4, 98.6] |
| At Least Three | 98.3 [98.2, 98.4] | 98.3 [98.2, 98.4] | 98.4 [98.2, 98.5] |
| At Least Four | 97.4 [97.3, 97.6] | 97.5 [97.3, 97.6] | 97.7 [97.5, 97.7] |
| All Five | 88.7 [88.4, 89.0] | 89.3 [89.0, 89.5] | 90.6 [90.3, 90.8] |

Table 72: Percentage of segmentation success by hand when only considering combinations of index and middle fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Either Index or Middle | 99.8 [99.8, 99.8] | 99.8 [99.8, 99.8] | 99.8 [99.8, 99.8] |
| Both Index and Middle | 98.0 [97.4, 97.6] | 98.1 [97.4, 97.7] | 98.5 [97.8, 98.1] |
| **Left** | | | |
| Either Index or Middle | 99.8 [99.8, 99.8] | 99.8 [99.8, 99.8] | 99.8 [99.8, 99.8] |
| Both Index and Middle | 96.9 [97.4, 97.6] | 97.0 [97.4, 97.7] | 97.4 [97.8, 98.1] |

Table 73: Percentage of segmentation success by hand when only considering combinations of index, middle, and ring fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 99.9 [99.9, 99.9] | 99.9 [99.9, 99.9] | 99.9 [99.9, 99.9] |
| At Least Two | 99.5 [99.4, 99.5] | 99.5 [99.4, 99.6] | 99.6 [99.5, 99.6] |
| All Three | 95.8 [95.6, 95.9] | 95.9 [95.7, 96.0] | 96.8 [96.6, 96.9] |
| **Left** | | | |
| Any | 99.9 [99.9, 99.9] | 99.9 [99.9, 99.9] | 99.9 [99.9, 99.9] |
| At Least Two | 99.5 [99.4, 99.5] | 99.5 [99.4, 99.6] | 99.6 [99.5, 99.6] |
| All Three | 95.7 [95.6, 95.9] | 95.8 [95.7, 96.0] | 96.7 [96.6, 96.9] |

## B.2 Jaccard Index

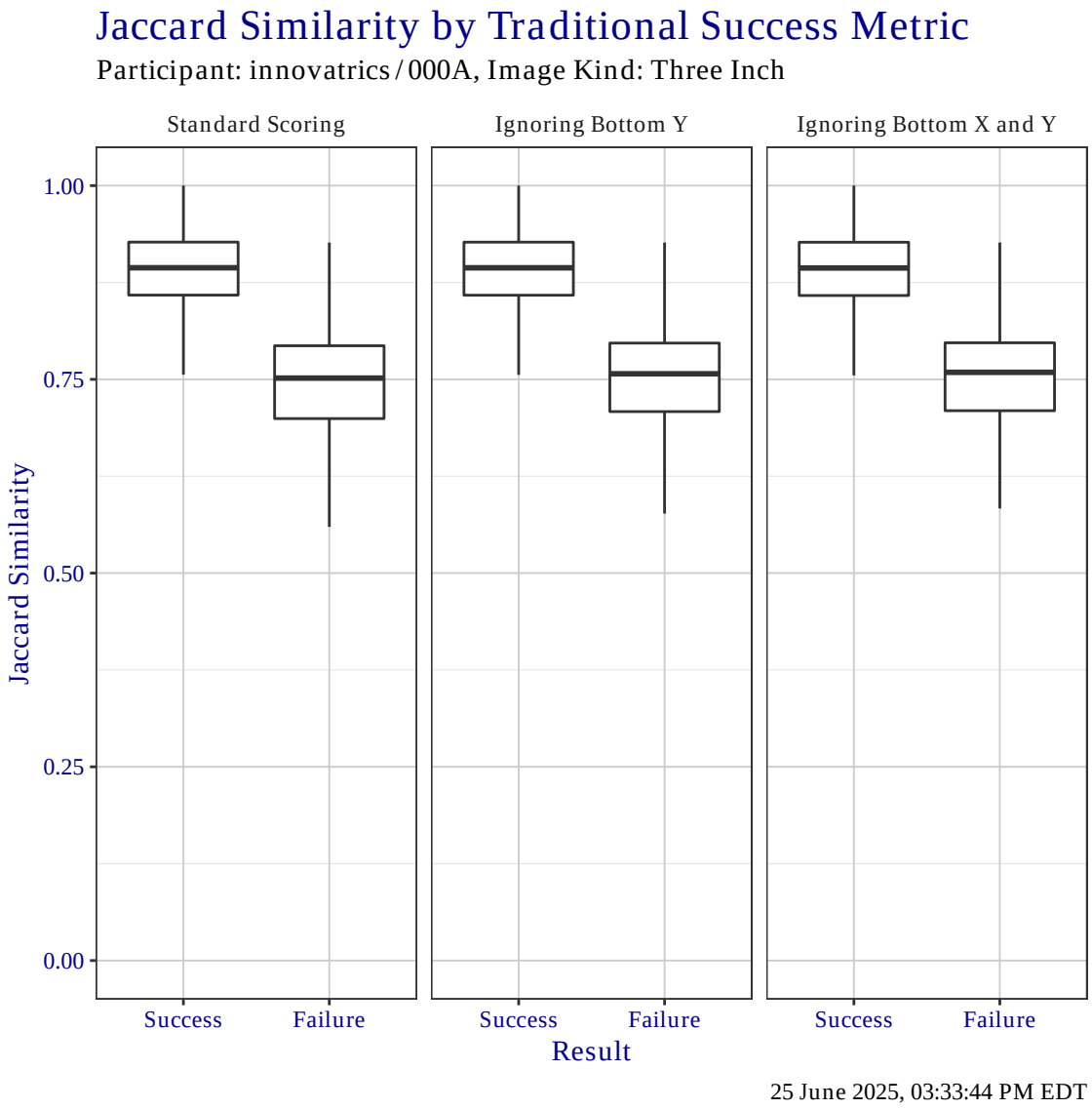


Figure 25: Boxplot of Jaccard similarity indices as compared to the traditional success metrics. Outliers have been removed for clarity.

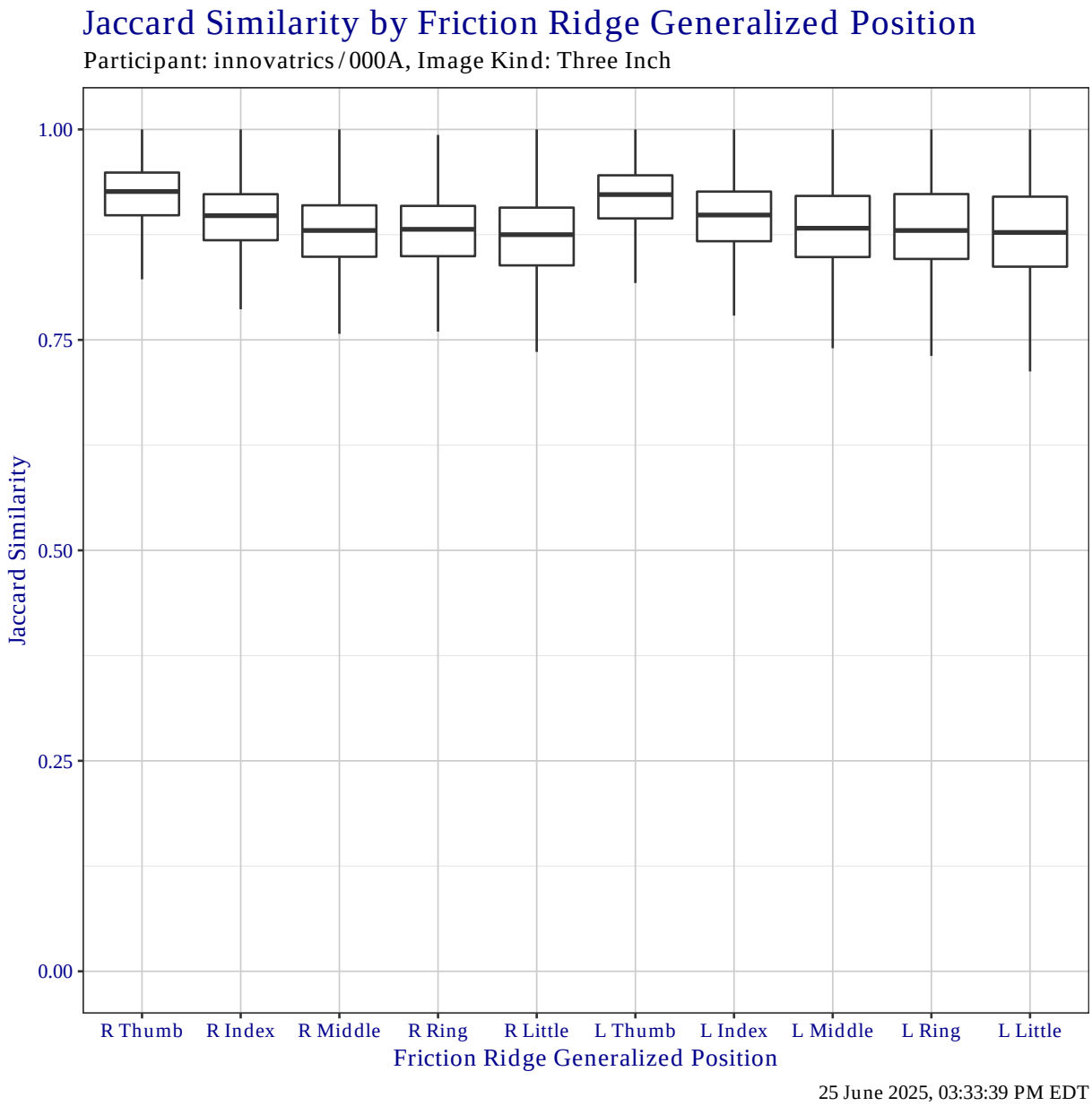


Figure 26: Boxplot of Jaccard similarity indices for each friction ridge generalized position. Outliers have been removed for clarity.

Table 74: For each subject, the percentage that at least *Number of Fingers* fingers were segmented with a Jaccard index in the indicated range.

| Number of Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| 1 | 100.0 | 100.0 | 100.0 | 99.9 | 97.0 | 58.8 | 6.2 |
| 2 | 100.0 | 100.0 | 99.9 | 99.6 | 90.7 | 28.7 | 0.3 |
| 3 | 98.6 | 98.6 | 98.6 | 98.4 | 77.2 | 10.9 | 0.0 |
| 4 | 98.5 | 98.5 | 98.4 | 98.0 | 62.4 | 3.9 | 0.0 |
| 5 | 95.9 | 95.9 | 95.9 | 95.6 | 46.2 | 1.1 | 0.0 |
| 6 | 95.9 | 95.9 | 95.9 | 95.0 | 30.9 | 0.2 | 0 |
| 7 | 95.9 | 95.9 | 95.9 | 93.5 | 17.7 | 0.0 | 0 |
| 8 | 95.9 | 95.9 | 95.8 | 90.3 | 8.7 | 0 | 0 |
| 9 | 95.8 | 95.8 | 95.3 | 82.9 | 3.6 | 0 | 0 |
| 10 | 95.4 | 95.0 | 92.0 | 64.0 | 0.9 | 0 | 0 |

Table 75: For all subjects, percentage that a particular friction ridge generalized position was segmented with a Jaccard index in the indicated range.

| Finger | 0-0.5 | 0.5-0.6 | 0.6-0.7 | 0.7-0.8 | 0.8-0.9 | 0.9-1.0 |
|---|---|---|---|---|---|---|
| **Right** | | | | | | |
| Thumb | 0.1 | 0.1 | 0.4 | 1.9 | 23.8 | 73.7 |
| Index | 0.2 | 0.0 | 0.2 | 2.9 | 49.2 | 47.5 |
| Middle | 0.1 | 0.0 | 0.3 | 5.2 | 62.1 | 32.3 |
| Ring | 0.1 | 0.1 | 0.5 | 6.1 | 60.5 | 32.7 |
| Little | 0.1 | 0.0 | 0.5 | 9.2 | 60.1 | 30.1 |
| **Left** | | | | | | |
| Thumb | 0.2 | 0.1 | 0.5 | 2.1 | 26.1 | 71.0 |
| Index | 0.1 | 0.0 | 0.2 | 3.5 | 47.7 | 48.5 |
| Middle | 0.1 | 0.0 | 0.4 | 6.3 | 56.0 | 37.2 |
| Ring | 0.1 | 0.1 | 0.4 | 6.0 | 56.1 | 37.3 |
| Little | 0.1 | 0.1 | 0.6 | 9.4 | 53.6 | 36.2 |

Table 76: Percentage of segmentation obtaining a Jaccard index in the indicated ranges, by hand, for combinations of all ten fingers of a ThreeInch slap.

| Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| **Right** | | | | | | | |
| Any | 100.0 | 99.9 | 99.9 | 99.7 | 89.4 | 34.4 | 2.7 |
| At Least Two | 98.5 | 98.5 | 98.5 | 97.9 | 60.0 | 6.8 | 0.1 |
| At Least Three | 98.5 | 98.5 | 98.4 | 96.5 | 36.5 | 2.0 | 0.0 |
| At Least Four | 98.4 | 98.4 | 98.2 | 92.6 | 19.2 | 0.5 | 0.0 |
| All Five | 94.8 | 94.6 | 93.1 | 76.6 | 6.6 | 0.1 | 0.0 |
| **Left** | | | | | | | |
| Any | 100.0 | 100.0 | 99.9 | 99.8 | 89.0 | 41.1 | 3.7 |
| At Least Two | 98.5 | 98.5 | 98.5 | 98.0 | 60.5 | 13.4 | 0.1 |
| At Least Three | 98.5 | 98.5 | 98.4 | 96.3 | 40.6 | 4.6 | 0.0 |
| At Least Four | 98.4 | 98.4 | 98.2 | 91.7 | 25.3 | 1.1 | 0.0 |
| All Five | 94.7 | 94.5 | 92.8 | 75.3 | 10.1 | 0.1 | 0.0 |

Table 77: Percentage of segmentation obtaining a Jaccard index in the indicated ranges, by hand, for combinations of index and middle fingers of a ThreeInch slap.

| Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| **Right** | | | | | | | |
| Either Index or Middle | 99.9 | 99.9 | 99.9 | 98.6 | 56.9 | 10.7 | 0.6 |
| Both Index and Middle | 99.8 | 99.8 | 99.4 | 92.5 | 23.0 | 1.5 | 0.0 |
| **Left** | | | | | | | |
| Either Index or Middle | 100.0 | 100.0 | 99.9 | 98.6 | 58.4 | 16.8 | 1.1 |
| Both Index and Middle | 99.9 | 99.8 | 99.4 | 91.0 | 27.3 | 3.3 | 0.0 |

Table 78: Percentage of segmentation obtaining a Jaccard index in the indicated ranges, by hand, for combinations of index, middle, and ring fingers of a ThreeInch slap.

| Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| **Right** | | | | | | | |
| Any | 99.9 | 99.9 | 99.9 | 99.2 | 63.6 | 12.9 | 0.8 |
| At Least Two | 99.9 | 99.9 | 99.8 | 97.0 | 34.5 | 3.1 | 0.1 |
| All Three | 99.8 | 99.7 | 98.8 | 88.2 | 14.5 | 0.6 | 0.0 |
| **Left** | | | | | | | |
| Any | 100.0 | 100.0 | 100.0 | 99.3 | 63.6 | 22.5 | 1.8 |
| At Least Two | 99.9 | 99.9 | 99.9 | 96.6 | 38.6 | 7.5 | 0.1 |
| All Three | 99.8 | 99.7 | 98.8 | 87.1 | 20.9 | 1.5 | 0 |

# C Upper Palm ("FiveInch" Data)

## C.1 Bootstrap Confidence for Segmentation Statistics

This section shows the same detailed results of segmentation of FiveInch data from Section 4.3, but with an added bootstrap confidence interval. For each observation, a bootstrap routine with 1 000 replicates was run, and a 95 % confidence interval extracted. The lower and upper confidence from that confidence interval are printed in each column within square brackets.

In Table 79, results are shown of how successful `innovatrics+000A` segmented fingers for each subject in the test corpus. Table 80 shows success for specific finger positions over the entire test corpus. Similarly, Table 81 shows success for segmenting the same finger position from both hands.

The remainder of the tables show success per subject when considering combinations of subsets of the fingers in each slap image. Table 82 shows success for combinations of all fingers, Table 84 for the all except the little finger, and Table 83 for just the index and middle fingers.

Table 79: For each subject, the percentage that at least *Number of Fingers* fingers were correctly segmented, regardless of hand, for a maximum of eight correctly-segmented fingers. In *Standard Scoring*, scoring rules are followed exactly. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Number of Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| 1 | 99.6 [99.1, 100.0] | 99.6 [99.1, 100.0] | 99.7 [99.3, 100.0] |
| 2 | 99.1 [98.3, 99.7] | 99.1 [98.3, 99.7] | 99.1 [98.3, 99.7] |
| 3 | 96.6 [95.3, 97.8] | 96.7 [95.4, 97.9] | 96.7 [95.4, 97.9] |
| 4 | 92.5 [90.6, 94.3] | 92.6 [90.6, 94.5] | 92.9 [90.9, 94.9] |
| 5 | 85.4 [82.7, 87.7] | 85.8 [83.3, 88.3] | 85.8 [83.3, 88.4] |
| 6 | 79.8 [76.9, 82.6] | 79.8 [76.8, 82.7] | 80.2 [77.6, 83.0] |
| 7 | 70.0 [66.7, 73.4] | 70.1 [66.5, 73.3] | 70.6 [67.2, 73.8] |
| 8 | 52.4 [49.1, 56.3] | 53.2 [49.5, 56.8] | 54.4 [50.7, 57.7] |

Table 80: For all subjects, Percentage that a particular friction ridge generalized position was correctly segmented. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Finger | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Index | 85.4 [82.8, 87.9] | 85.4 [82.8, 88.0] | 85.4 [82.6, 87.9] |
| Middle | 83.9 [81.1, 86.6] | 84.0 [81.5, 86.6] | 84.7 [82.1, 87.4] |
| Ring | 88.4 [86.0, 90.7] | 89.0 [86.6, 91.1] | 89.1 [87.0, 91.2] |
| Little | 88.2 [85.9, 90.6] | 88.3 [86.0, 90.6] | 88.6 [86.0, 90.8] |
| **Left** | | | |
| Index | 81.8 [78.9, 84.6] | 82.0 [79.4, 84.7] | 82.1 [79.4, 84.7] |
| Middle | 80.4 [77.5, 83.4] | 80.4 [77.5, 83.2] | 80.5 [77.7, 83.2] |
| Ring | 87.0 [84.5, 89.5] | 87.7 [85.3, 89.9] | 87.9 [85.7, 90.3] |
| Little | 85.7 [83.0, 88.2] | 85.7 [83.0, 88.1] | 86.6 [84.4, 89.0] |

Table 81: Percentage that a particular type of fingerprint was correctly segmented on *Either* or *Both* hands. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Index** | | | |
| Either | 93.1 [91.2, 94.7] | 93.1 [91.4, 94.9] | 93.1 [91.3, 94.7] |
| Both | 72.7 [69.3, 75.9] | 72.9 [69.7, 75.9] | 73.0 [69.8, 76.2] |
| **Middle** | | | |
| Either | 91.7 [89.9, 93.5] | 91.8 [89.9, 93.8] | 92.0 [89.9, 93.8] |
| Both | 71.3 [68.2, 74.3] | 71.3 [68.2, 74.4] | 71.9 [68.6, 75.1] |
| **Ring** | | | |
| Either | 95.1 [93.5, 96.6] | 95.5 [93.9, 97.0] | 95.5 [93.9, 97.0] |
| Both | 78.9 [76.0, 81.6] | 79.7 [76.7, 82.5] | 80.1 [77.3, 82.9] |
| **Little** | | | |
| Either | 96.6 [95.3, 97.8] | 96.6 [95.3, 97.9] | 96.7 [95.3, 97.9] |
| Both | 75.9 [72.5, 78.9] | 76.0 [73.0, 79.2] | 77.1 [73.9, 79.8] |

Table 82: Percentage of segmentation success by hand for combinations of all eight fingers of a FiveInch slap. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 98.7 [97.0, 98.5] | 98.7 [97.0, 98.5] | 98.8 [97.2, 98.7] |
| At Least Two | 94.0 [91.0, 93.6] | 94.0 [90.8, 93.8] | 94.0 [91.2, 93.9] |
| At Least Three | 84.2 [80.9, 84.8] | 84.2 [81.0, 84.8] | 84.3 [81.2, 85.0] |
| All Four | 69.0 [64.8, 69.5] | 69.8 [65.6, 70.5] | 70.6 [66.1, 71.1] |
| **Left** | | | |
| Any | 96.8 [97.0, 98.5] | 96.9 [97.0, 98.5] | 97.1 [97.2, 98.7] |
| At Least Two | 90.7 [91.0, 93.6] | 90.8 [90.8, 93.8] | 91.1 [91.2, 93.9] |
| At Least Three | 81.7 [80.9, 84.8] | 81.7 [81.0, 84.8] | 82.0 [81.2, 85.0] |
| All Four | 65.6 [64.8, 69.5] | 66.2 [65.6, 70.5] | 67.0 [66.1, 71.1] |

Table 83: Percentage of segmentation success by hand when only considering combinations of index and middle fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Either Index or Middle | 92.8 [89.0, 92.2] | 92.8 [89.2, 92.0] | 92.8 [89.1, 92.1] |
| Both Index and Middle | 76.5 [73.0, 77.4] | 76.6 [73.0, 77.4] | 77.3 [73.4, 77.7] |
| **Left** | | | |
| Either Index or Middle | 88.3 [89.0, 92.2] | 88.3 [89.2, 92.0] | 88.6 [89.1, 92.1] |
| Both Index and Middle | 73.9 [73.0, 77.4] | 74.0 [73.0, 77.4] | 74.0 [73.4, 77.7] |

Table 84: Percentage of segmentation success by hand when only considering combinations of index, middle, and ring fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 96.7 [94.4, 96.5] | 96.7 [94.6, 96.6] | 96.7 [94.6, 96.7] |
| At Least Two | 87.9 [84.2, 87.6] | 87.9 [84.0, 87.5] | 87.9 [84.1, 87.6] |
| All Three | 73.1 [69.9, 74.2] | 73.8 [70.5, 74.8] | 74.6 [70.9, 75.4] |
| **Left** | | | |
| Any | 94.3 [94.4, 96.5] | 94.6 [94.6, 96.6] | 94.7 [94.6, 96.7] |
| At Least Two | 83.8 [84.2, 87.6] | 83.8 [84.0, 87.5] | 84.0 [84.1, 87.6] |
| All Three | 71.1 [69.9, 74.2] | 71.6 [70.5, 74.8] | 71.9 [70.9, 75.4] |

## C.2 Jaccard Index

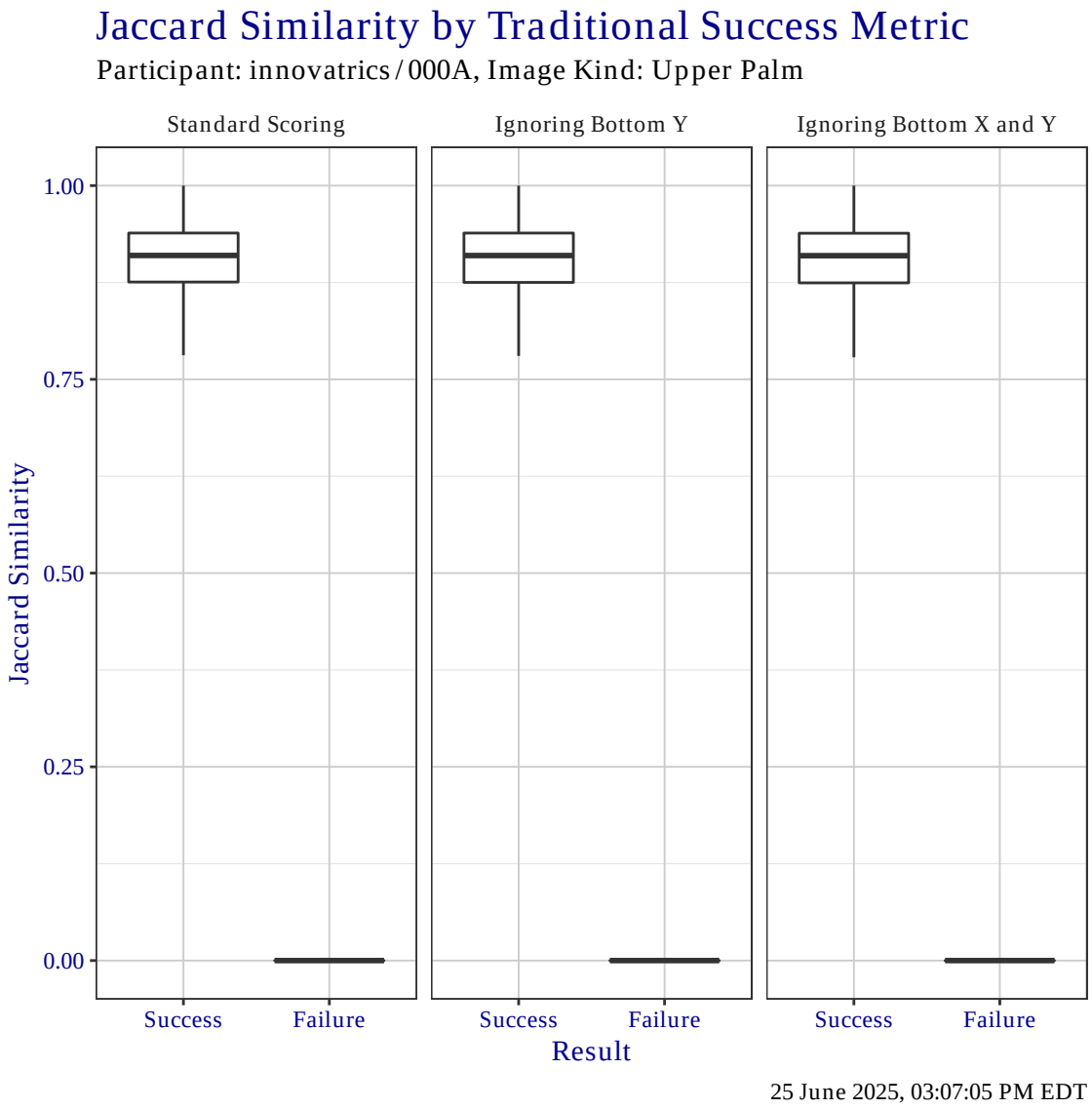


Figure 27: Boxplot of Jaccard similarity indices as compared to the traditional success metrics. Outliers have been removed for clarity.

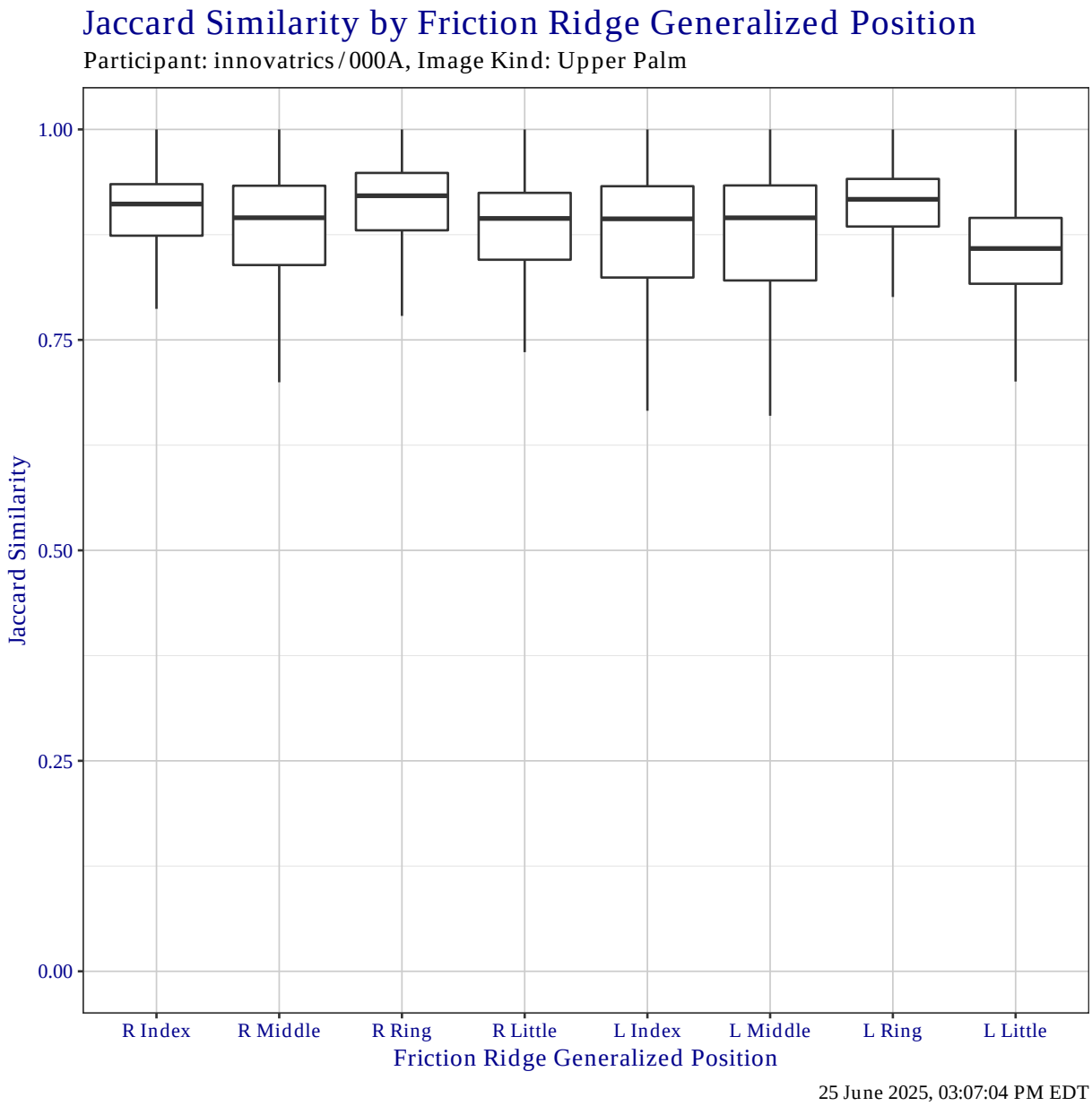


Figure 28: Boxplot of Jaccard similarity indices for each friction ridge generalized position. Outliers have been removed for clarity.

Table 85: For each subject, the percentage that at least *Number of Fingers* fingers were segmented with a Jaccard index in the indicated range.

| Number of Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| 1 | 99.7 | 99.7 | 99.6 | 99.3 | 96.2 | 58.1 | 22.8 |
| 2 | 99.3 | 99.3 | 98.9 | 98.6 | 90.4 | 28.1 | 14.0 |
| 3 | 97.4 | 97.1 | 97.0 | 95.9 | 80.4 | 14.4 | 10.4 |
| 4 | 93.8 | 93.7 | 93.0 | 91.3 | 62.2 | 6.5 | 5.8 |
| 5 | 87.1 | 86.7 | 86.2 | 83.5 | 39.5 | 3.4 | 3.4 |
| 6 | 80.6 | 80.6 | 80.6 | 76.4 | 19.5 | 2.1 | 2.1 |
| 7 | 72.5 | 72.5 | 71.8 | 65.2 | 7.2 | 0.9 | 0.9 |
| 8 | 61.0 | 60.5 | 59.0 | 45.6 | 0.9 | 0.4 | 0.4 |

Table 86: For all subjects, percentage that a particular friction ridge generalized position was segmented with a Jaccard index in the indicated range.

| Finger | 0-0.5 | 0.5-0.6 | 0.6-0.7 | 0.7-0.8 | 0.8-0.9 | 0.9-1.0 |
|---|---|---|---|---|---|---|
| **Right** | | | | | | |
| Index | 13.8 | 0.3 | 0.3 | 1.0 | 23.7 | 60.9 |
| Middle | 14.1 | 0 | 0.9 | 4.3 | 34.0 | 46.7 |
| Ring | 10.6 | 0.1 | 0.4 | 2.3 | 20.8 | 65.8 |
| Little | 8.4 | 0.2 | 0.8 | 4.8 | 40.7 | 45.1 |
| **Left** | | | | | | |
| Index | 15.9 | 0.3 | 0.3 | 4.0 | 33.0 | 46.5 |
| Middle | 18.3 | 0.1 | 0.7 | 3.6 | 29.7 | 47.6 |
| Ring | 11.8 | 0.1 | 0.3 | 1.7 | 21.4 | 64.7 |
| Little | 10.1 | 0.1 | 0.4 | 8.9 | 58.4 | 22.1 |

Table 87: Percentage of segmentation obtaining a Jaccard index in the indicated ranges, by hand, for combinations of all ten fingers of a FiveInch slap.

| Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| **Right** | | | | | | | |
| Any | 99.2 | 99.2 | 98.9 | 97.9 | 91.8 | 42.2 | 16.5 |
| At Least Two | 94.4 | 94.4 | 94.0 | 92.6 | 72.3 | 14.4 | 9.3 |
| At Least Three | 85.5 | 85.2 | 85.0 | 82.4 | 41.5 | 5.3 | 4.9 |
| All Four | 73.9 | 73.5 | 72.1 | 64.8 | 12.9 | 2.0 | 2.0 |
| **Left** | | | | | | | |
| Any | 97.9 | 97.7 | 97.3 | 96.4 | 87.0 | 35.4 | 16.2 |
| At Least Two | 91.9 | 91.8 | 91.6 | 89.7 | 62.3 | 11.3 | 7.4 |
| At Least Three | 82.2 | 82.2 | 82.1 | 78.4 | 26.9 | 3.4 | 3.2 |
| All Four | 71.9 | 71.5 | 70.6 | 59.0 | 4.8 | 0.8 | 0.8 |

Table 88: Percentage of segmentation obtaining a Jaccard index in the indicated ranges, by hand, for combinations of index and middle fingers of a FiveInch slap.

| Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| **Right** | | | | | | | |
| Either Index or Middle | 93.2 | 93.2 | 93.1 | 92.3 | 76.3 | 25.7 | 12.5 |
| Both Index and Middle | 78.9 | 78.6 | 77.5 | 73.0 | 31.2 | 4.9 | 4.3 |
| **Left** | | | | | | | |
| Either Index or Middle | 89.1 | 89.1 | 88.7 | 87.1 | 69.6 | 24.5 | 11.4 |
| Both Index and Middle | 76.7 | 76.3 | 75.7 | 69.8 | 24.5 | 4.6 | 3.4 |

Table 89: Percentage of segmentation obtaining a Jaccard index in the indicated ranges, by hand, for combinations of index, middle, and ring fingers of a FiveInch slap.

| Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| **Right** | | | | | | | |
| Any | 96.8 | 96.8 | 96.7 | 96.0 | 88.3 | 38.6 | 16.0 |
| At Least Two | 88.4 | 88.3 | 88.0 | 86.3 | 61.8 | 11.3 | 8.6 |
| All Three | 76.2 | 75.9 | 74.7 | 69.5 | 23.3 | 3.5 | 3.2 |
| **Left** | | | | | | | |
| Any | 95.1 | 95.0 | 94.7 | 93.6 | 84.6 | 33.8 | 15.5 |
| At Least Two | 84.5 | 84.5 | 84.2 | 82.5 | 55.4 | 9.0 | 6.2 |
| All Three | 74.4 | 74.0 | 73.3 | 66.8 | 18.8 | 2.8 | 2.5 |

# D Full Palm ("EightInch" Data)

## D.1 Bootstrap Confidence for Segmentation Statistics

**NOTE**: *The following segmentation statistics are based on a limited subset (approximately 15%) of the anticipated Full Palm dataset. This analysis will be updated as soon as NIST can obtain the remainder of the dataset.*

This section shows the same detailed results of segmentation of EightInch data from Section 5.3, but with an added bootstrap confidence interval. For each observation, a bootstrap routine with 1 000 replicates was run, and a 95 % confidence interval extracted. The lower and upper confidence from that confidence interval are printed in each column within square brackets.

In Table 90, results are shown of how successful innovatrics+000A segmented fingers for each subject in the test corpus. Table 91 shows success for specific finger positions over the entire test corpus. Similarly, Table 92 shows success for segmenting the same finger position from both hands.

The remainder of the tables show success per subject when considering combinations of subsets of the fingers in each slap image. Table 93 shows success for combinations of all fingers, Table 95 for the all except the little finger, and Table 94 for just the index and middle fingers.

Table 90: For each subject, the percentage that at least *Number of Fingers* fingers were correctly segmented, regardless of hand, for a maximum of eight correctly-segmented fingers. In *Standard Scoring*, scoring rules are followed exactly. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Number of Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| 1 | 100.0 [100.0, 100.0] | 100.0 [100.0, 100.0] | 100.0 [100.0, 100.0] |
| 2 | 100.0 [100.0, 100.0] | 100.0 [100.0, 100.0] | 100.0 [100.0, 100.0] |
| 3 | 99.9 [99.7, 100.0] | 99.9 [99.7, 100.0] | 99.9 [99.7, 100.0] |
| 4 | 99.5 [99.1, 99.9] | 99.5 [99.1, 99.9] | 99.7 [99.2, 100.0] |
| 5 | 99.5 [99.1, 99.9] | 99.5 [99.1, 99.9] | 99.5 [99.1, 99.9] |
| 6 | 99.1 [98.4, 99.7] | 99.1 [98.4, 99.7] | 99.1 [98.4, 99.7] |
| 7 | 96.6 [95.3, 97.7] | 96.8 [95.4, 97.9] | 97.2 [96.2, 98.3] |
| 8 | 84.9 [82.3, 87.1] | 85.4 [83.2, 87.6] | 86.1 [83.7, 88.2] |

Table 91: For all subjects, Percentage that a particular friction ridge generalized position was correctly segmented. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Finger | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Index | 94.5 [93.0, 95.9] | 94.6 [93.0, 96.1] | 94.7 [93.2, 96.1] |
| Middle | 97.7 [96.7, 98.6] | 97.8 [96.8, 98.7] | 98.0 [97.1, 99.0] |
| Ring | 98.3 [97.4, 99.1] | 98.5 [97.6, 99.2] | 98.5 [97.6, 99.3] |
| Little | 98.9 [98.2, 99.5] | 98.9 [98.0, 99.5] | 99.1 [98.3, 99.7] |
| **Left** | | | |
| Index | 96.0 [94.7, 97.2] | 96.1 [94.8, 97.4] | 96.1 [94.7, 97.2] |
| Middle | 97.5 [96.3, 98.5] | 97.5 [96.4, 98.5] | 97.7 [96.7, 98.7] |
| Ring | 98.2 [97.2, 99.0] | 98.3 [97.4, 99.1] | 98.7 [97.9, 99.4] |
| Little | 98.6 [97.8, 99.3] | 98.6 [97.8, 99.3] | 98.6 [97.7, 99.3] |

Table 92: Percentage that a particular type of fingerprint was correctly segmented on *Either* or *Both* hands. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Index** | | | |
| Either | 99.5 [99.1, 99.9] | 99.5 [99.1, 99.9] | 99.5 [99.0, 99.9] |
| Both | 90.9 [88.9, 92.8] | 91.1 [89.2, 92.9] | 91.3 [89.3, 93.1] |
| **Middle** | | | |
| Either | 99.3 [98.7, 99.8] | 99.3 [98.7, 99.8] | 99.3 [98.6, 99.8] |
| Both | 95.9 [94.5, 97.1] | 96.0 [94.5, 97.2] | 96.4 [95.2, 97.7] |
| **Ring** | | | |
| Either | 99.8 [99.4, 100.0] | 99.8 [99.4, 100.0] | 99.9 [99.5, 100.0] |
| Both | 96.7 [95.4, 97.9] | 97.0 [96.0, 98.0] | 97.4 [96.3, 98.4] |
| **Little** | | | |
| Either | 100.0 [100.0, 100.0] | 100.0 [100.0, 100.0] | 100.0 [100.0, 100.0] |
| Both | 97.5 [96.3, 98.4] | 97.5 [96.3, 98.4] | 97.7 [96.7, 98.6] |

Table 93: Percentage of segmentation success by hand for combinations of all eight fingers of a EightInch slap. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 99.9 [99.8, 100.0] | 99.9 [99.8, 100.0] | 99.9 [99.8, 100.0] |
| At Least Two | 99.3 [99.2, 99.8] | 99.3 [99.2, 99.8] | 99.3 [99.2, 99.8] |
| At Least Three | 98.5 [98.2, 99.3] | 98.6 [98.3, 99.3] | 98.9 [98.6, 99.5] |
| All Four | 91.6 [90.2, 92.8] | 92.0 [90.5, 93.1] | 92.3 [90.9, 93.5] |
| **Left** | | | |
| Any | 100.0 [99.8, 100.0] | 100.0 [99.8, 100.0] | 100.0 [99.8, 100.0] |
| At Least Two | 99.8 [99.2, 99.8] | 99.8 [99.2, 99.8] | 99.8 [99.2, 99.8] |
| At Least Three | 99.1 [98.2, 99.3] | 99.1 [98.3, 99.3] | 99.2 [98.6, 99.5] |
| All Four | 91.4 [90.2, 92.8] | 91.6 [90.5, 93.1] | 92.2 [90.9, 93.5] |

Table 94: Percentage of segmentation success by hand when only considering combinations of index and middle fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Either Index or Middle | 99.0 [98.9, 99.7] | 99.1 [98.9, 99.7] | 99.2 [99.0, 99.7] |
| Both Index and Middle | 93.2 [92.4, 94.7] | 93.3 [92.5, 94.8] | 93.6 [92.7, 95.1] |
| **Left** | | | |
| Either Index or Middle | 99.5 [98.9, 99.7] | 99.5 [98.9, 99.7] | 99.5 [99.0, 99.7] |
| Both Index and Middle | 93.9 [92.4, 94.7] | 94.0 [92.5, 94.8] | 94.3 [92.7, 95.1] |

Table 95: Percentage of segmentation success by hand when only considering combinations of index, middle, and ring fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values in square brackets represent a 95 % confidence interval after bootstrapping with 1 000 replicates.

| Fingers | Standard Scoring | Ignoring Bottom Y | Ignoring Bottom X and Y |
|---|---|---|---|
| **Right** | | | |
| Any | 99.4 [99.3, 99.9] | 99.4 [99.3, 99.9] | 99.4 [99.3, 99.9] |
| At Least Two | 98.6 [98.5, 99.4] | 98.7 [98.6, 99.4] | 98.9 [98.7, 99.5] |
| All Three | 92.4 [91.2, 93.6] | 92.8 [91.5, 94.0] | 93.0 [92.1, 94.4] |
| **Left** | | | |
| Any | 99.8 [99.3, 99.9] | 99.8 [99.3, 99.9] | 99.8 [99.3, 99.9] |
| At Least Two | 99.3 [98.5, 99.4] | 99.3 [98.6, 99.4] | 99.4 [98.7, 99.5] |
| All Three | 92.5 [91.2, 93.6] | 92.8 [91.5, 94.0] | 93.3 [92.1, 94.4] |

## D.2 Jaccard Index

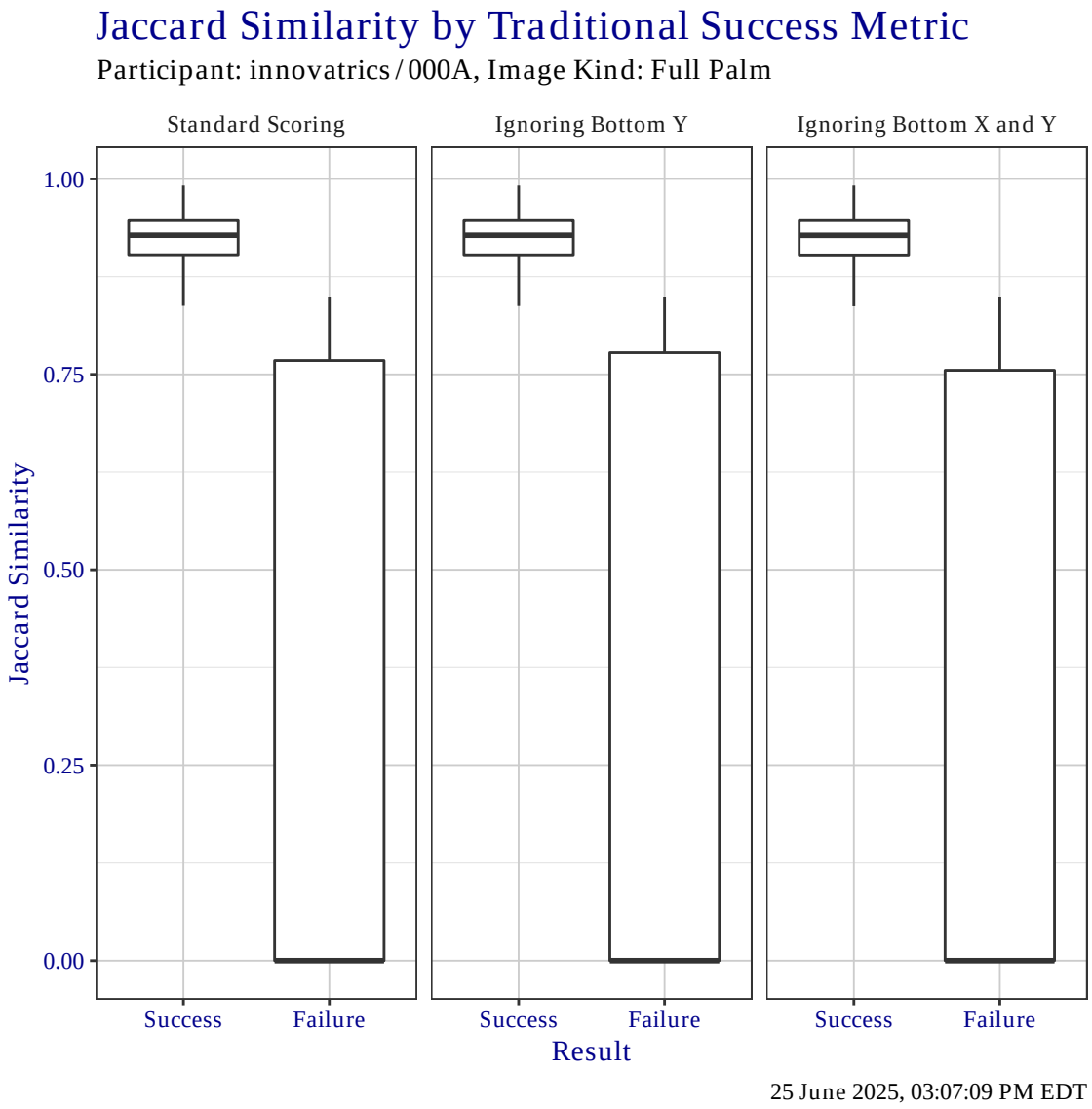


Figure 29: Boxplot of Jaccard similarity indices as compared to the traditional success metrics. Outliers have been removed for clarity.

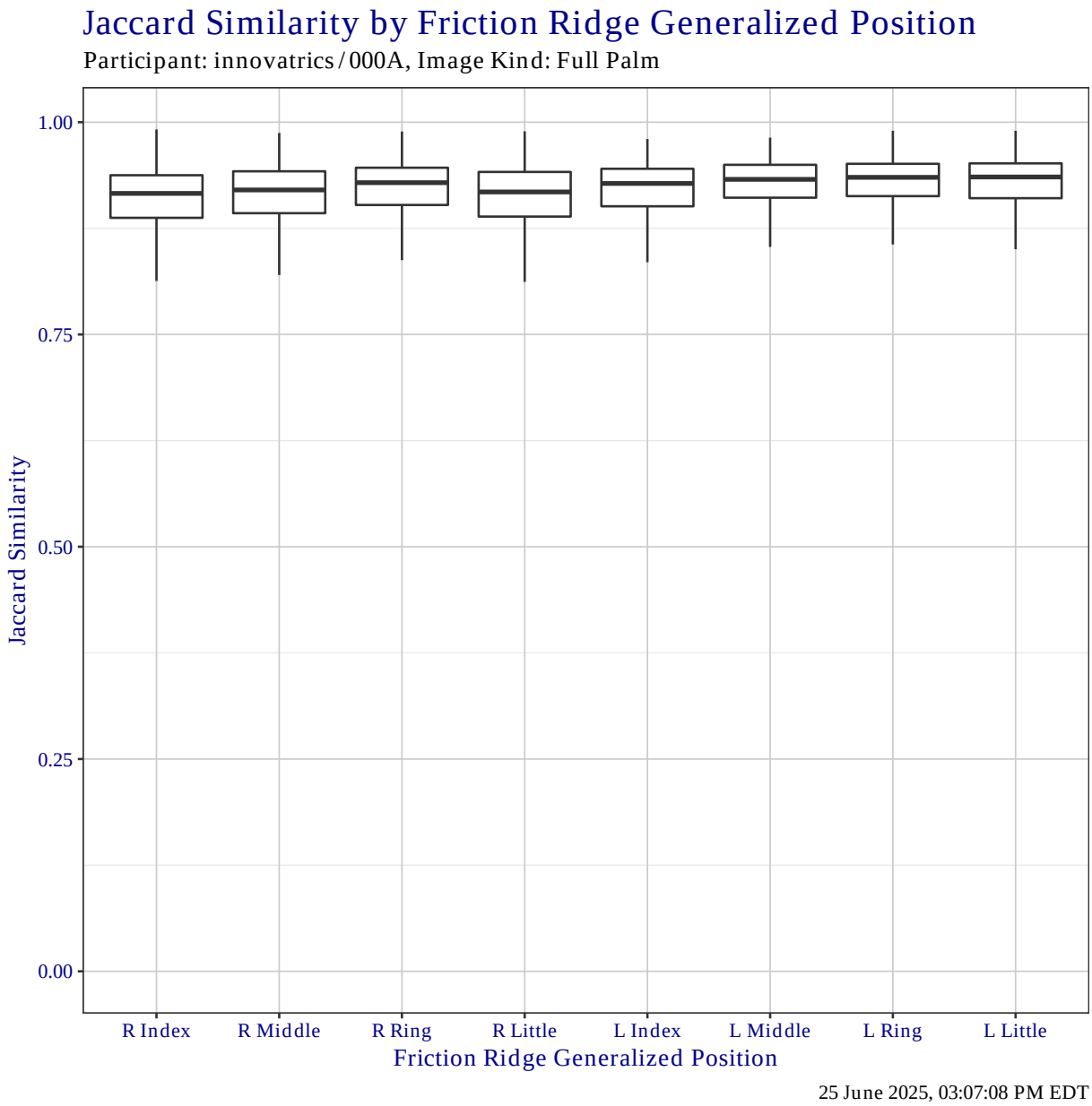


Figure 30: Boxplot of Jaccard similarity indices for each friction ridge generalized position. Outliers have been removed for clarity.

Table 96: For each subject, the percentage that at least *Number of Fingers* fingers were segmented with a Jaccard index in the indicated range.

| Number of Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| 1 | 100.0 | 100.0 | 100.0 | 100.0 | 99.9 | 78.6 | 2.8 |
| 2 | 100.0 | 100.0 | 100.0 | 100.0 | 98.4 | 47.5 | 0.1 |
| 3 | 100.0 | 100.0 | 100.0 | 99.9 | 95.7 | 24.4 | 0 |
| 4 | 99.8 | 99.8 | 99.8 | 99.7 | 91.3 | 10.3 | 0 |
| 5 | 99.8 | 99.8 | 99.7 | 99.2 | 82.0 | 3.2 | 0 |
| 6 | 99.4 | 99.4 | 99.2 | 98.4 | 67.1 | 0.6 | 0 |
| 7 | 98.2 | 98.0 | 97.8 | 96.2 | 45.6 | 0.1 | 0 |
| 8 | 90.3 | 90.2 | 88.5 | 83.3 | 19.2 | 0 | 0 |

Table 97: For all subjects, percentage that a particular friction ridge generalized position was segmented with a Jaccard index in the indicated range.

| Finger | 0-0.5 | 0.5-0.6 | 0.6-0.7 | 0.7-0.8 | 0.8-0.9 | 0.9-1.0 |
|---|---|---|---|---|---|---|
| **Right** | | | | | | |
| Index | 4.4 | 0 | 0.1 | 1.4 | 29.9 | 64.2 |
| Middle | 0.9 | 0 | 0.5 | 0.7 | 28.4 | 69.5 |
| Ring | 0.9 | 0 | 0.6 | 1.6 | 20.7 | 76.2 |
| Little | 0 | 0 | 0.2 | 0.9 | 33.0 | 65.9 |
| **Left** | | | | | | |
| Index | 3.5 | 0.1 | 0.1 | 1.0 | 19.9 | 75.4 |
| Middle | 1.2 | 0.1 | 0.3 | 1.3 | 16.0 | 81.1 |
| Ring | 1.0 | 0 | 0.4 | 0.9 | 13.6 | 84.1 |
| Little | 0.7 | 0 | 0.1 | 0.5 | 16.1 | 82.6 |

Table 98: Percentage of segmentation obtaining a Jaccard index in the indicated ranges, by hand, for combinations of all ten fingers of a EightInch slap.

| Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| **Right** | | | | | | | |
| Any | 100.0 | 100.0 | 100.0 | 99.9 | 95.7 | 49.3 | 1.7 |
| At Least Two | 99.7 | 99.7 | 99.5 | 99.0 | 86.0 | 15.3 | 0.1 |
| At Least Three | 99.1 | 99.1 | 99.0 | 98.0 | 63.9 | 2.2 | 0.0 |
| All Four | 95.1 | 95.1 | 93.9 | 90.9 | 30.2 | 0.2 | 0.0 |
| **Left** | | | | | | | |
| Any | 100.0 | 100.0 | 100.0 | 100.0 | 97.9 | 62.4 | 1.0 |
| At Least Two | 99.9 | 99.9 | 99.9 | 99.7 | 91.7 | 26.6 | 0.0 |
| At Least Three | 99.4 | 99.3 | 99.2 | 98.9 | 80.8 | 7.8 | 0.0 |
| All Four | 94.4 | 94.3 | 93.4 | 90.3 | 52.9 | 0.9 | 0.0 |

Table 99: Percentage of segmentation obtaining a Jaccard index in the indicated ranges, by hand, for combinations of index and middle fingers of a EightInch slap.

| Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| **Right** | | | | | | | |
| Either Index or Middle | 99.4 | 99.4 | 99.3 | 98.9 | 83.7 | 26.8 | 0.8 |
| Both Index and Middle | 95.3 | 95.3 | 94.8 | 93.2 | 50.1 | 3.6 | 0 |
| **Left** | | | | | | | |
| Either Index or Middle | 99.5 | 99.5 | 99.5 | 99.4 | 90.3 | 37.8 | 0.2 |
| Both Index and Middle | 95.9 | 95.6 | 95.2 | 93.0 | 66.2 | 5.6 | 0 |

Table 100: Percentage of segmentation obtaining a Jaccard index in the indicated ranges, by hand, for combinations of index, middle, and ring fingers of a EightInch slap.

| Fingers | ≥0.5 | ≥0.6 | ≥0.7 | ≥0.8 | ≥0.9 | ≥0.95 | ≥0.98 |
|---|---|---|---|---|---|---|---|
| **Right** | | | | | | | |
| Any | 99.7 | 99.7 | 99.7 | 99.0 | 92.4 | 40.3 | 1.3 |
| At Least Two | 99.1 | 99.1 | 99.0 | 98.3 | 74.9 | 9.4 | 0.1 |
| All Three | 95.1 | 95.1 | 94.0 | 91.7 | 42.6 | 0.8 | 0 |
| **Left** | | | | | | | |
| Any | 99.9 | 99.9 | 99.9 | 99.7 | 95.3 | 51.3 | 0.6 |
| At Least Two | 99.5 | 99.4 | 99.3 | 99.1 | 85.2 | 16.7 | 0 |
| All Three | 94.9 | 94.8 | 94.1 | 91.4 | 60.2 | 2.1 | 0 |