

# sequence+0002

Lakota Software Solutions

*Slap Fingerprint Segmentation Evaluation III*

*Last Updated: 17 June 2019*

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# 1 Participation Information

## 1.1 Names and Dates

- **Organization Name:** Lakota Software Solutions
- **SlapSeg III Identifier:** sequence+0002
- **Provided Marketing Name:** "Lakota Sequence"
- **Application Date:** 17 June 2019
- **First Submission Date:** 03 June 2019 (as version 0001)
- **Validation Date:** 05 June 2019
- **Completion Date:** 05 June 2019

## 1.2 Libraries

| Filename                        | MD5 Checksum                     | Size   |
|---------------------------------|----------------------------------|--------|
| libslapsegiii_sequence_0002.so  | 0c3769c45d44800f96707d870266b796 | 265 Kb |
| sequence-0.9.3-slapseg3-rc2.jar | 2a96db56e4e2f1d7f0b87ec028e7109b | 2.5 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.

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.

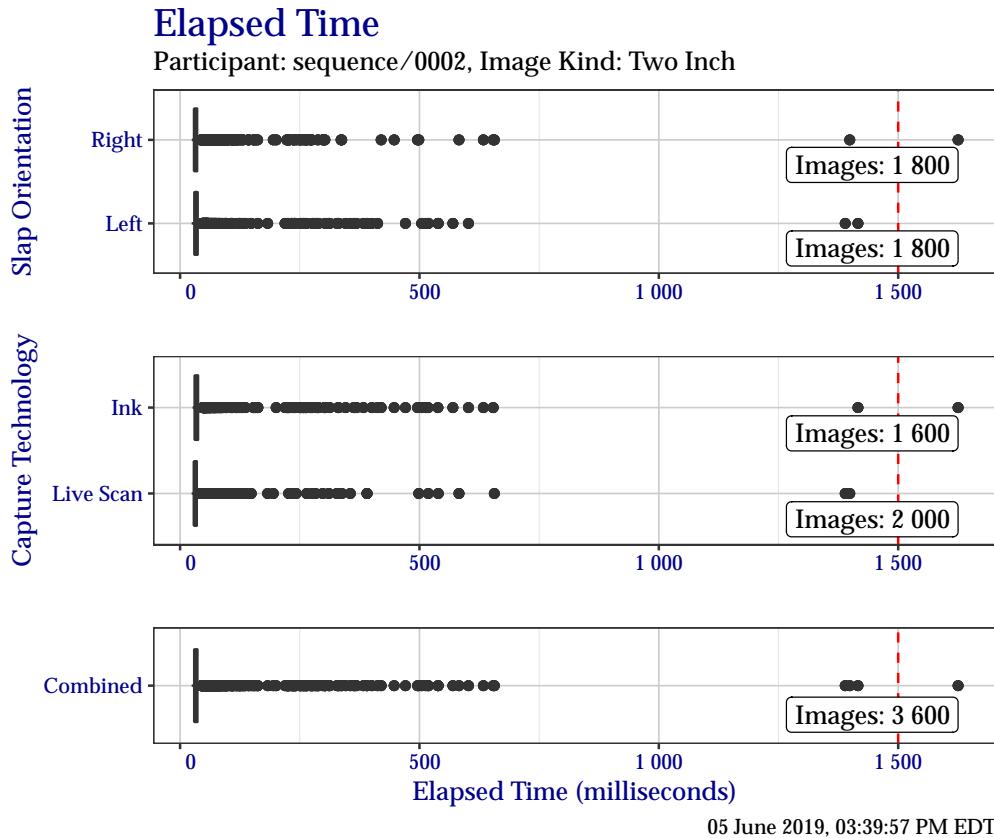


Figure 1: Box plots of elapsed time in milliseconds when segmenting the TwoInch timing test corpus, separated by slap orientation and capture technology.

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 | 24    | 24    | 24        | 26    | 24       |
| 25%     | 30    | 30    | 30        | 31    | 30       |
| Median  | 32    | 33    | 31        | 33    | 32       |
| 75%     | 35    | 37    | 35        | 37    | 36       |
| Maximum | 1 625 | 1 416 | 1 399     | 1 625 | 1 625    |

## 2.2 Segmentation Centers and Dimensions

### 2.2.1 Segmentation Centers

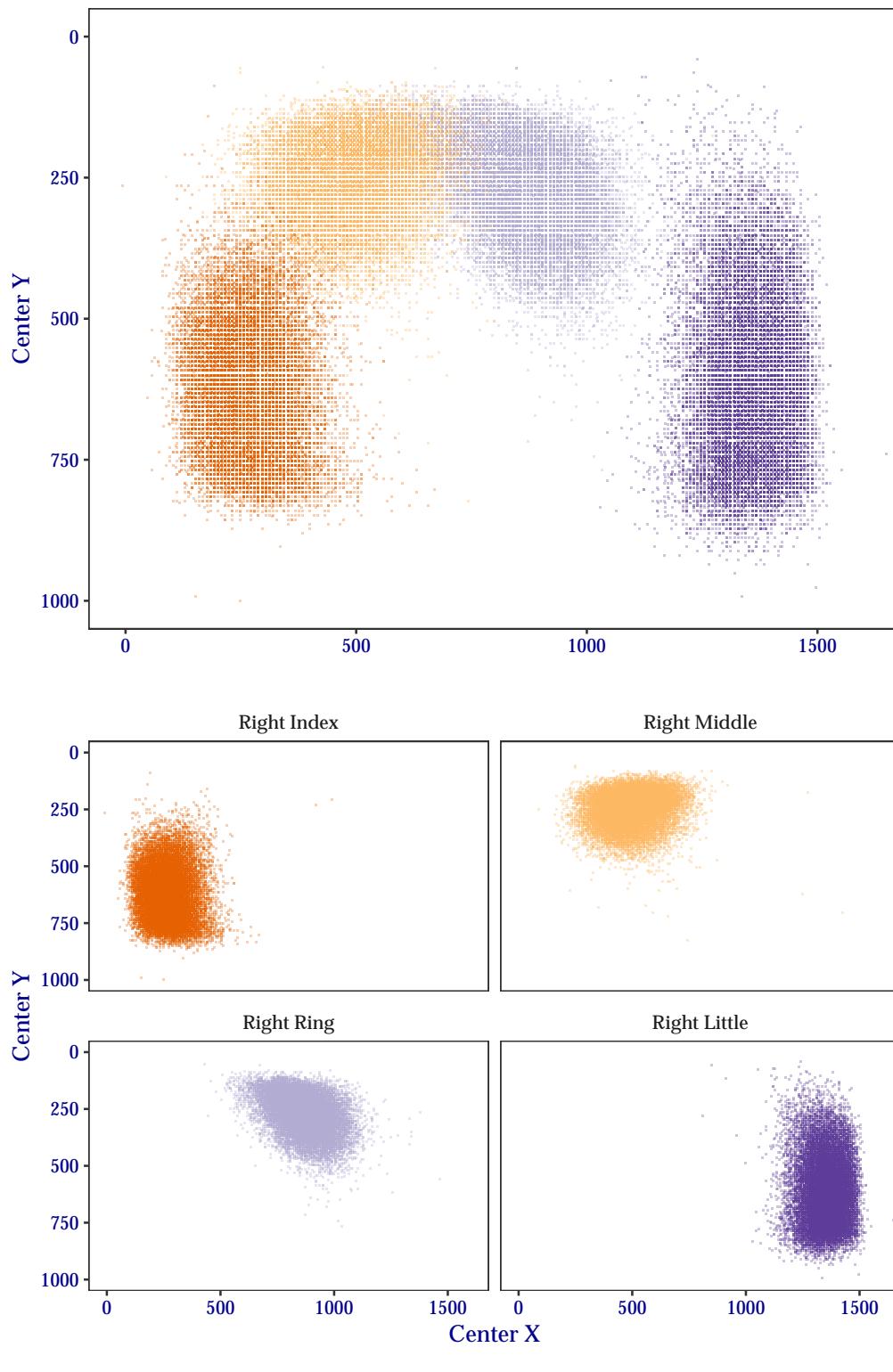
The plots in this section show the distribution of segmentation position centers ( $x, y$ ) for TwoInch data. At the top of each figure is a combined plot for all finger positions of a given slap orientation. These figures are isolated in plots faceted at the bottom of the figure.

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.

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.

## Segmentation Position Centers

Participant: sequence/0002, FRGPs: 2, 3, 4, 5, Image Kind: Two Inch



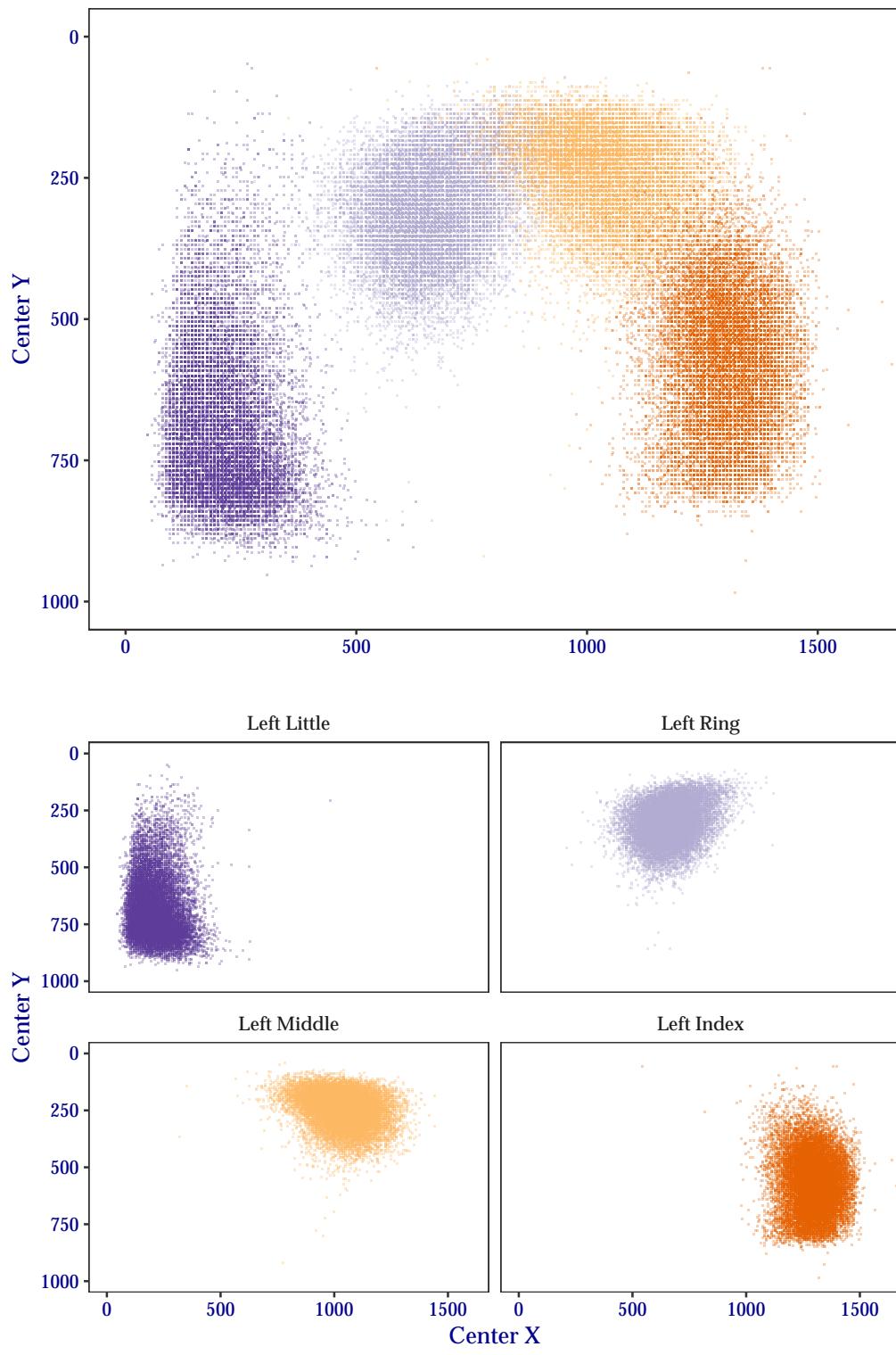
- Right Index • Right Middle • Right Ring • Right Little

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Figure 2: Segmentation centers for right hand TwoInch data.

## Segmentation Position Centers

Participant: sequence/0002, FRGPs: 7, 8, 9, 10, Image Kind: Two Inch



- Left Index • Left Middle • Left Ring • Left Little

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Figure 3: Segmentation centers for left hand TwoInch data.

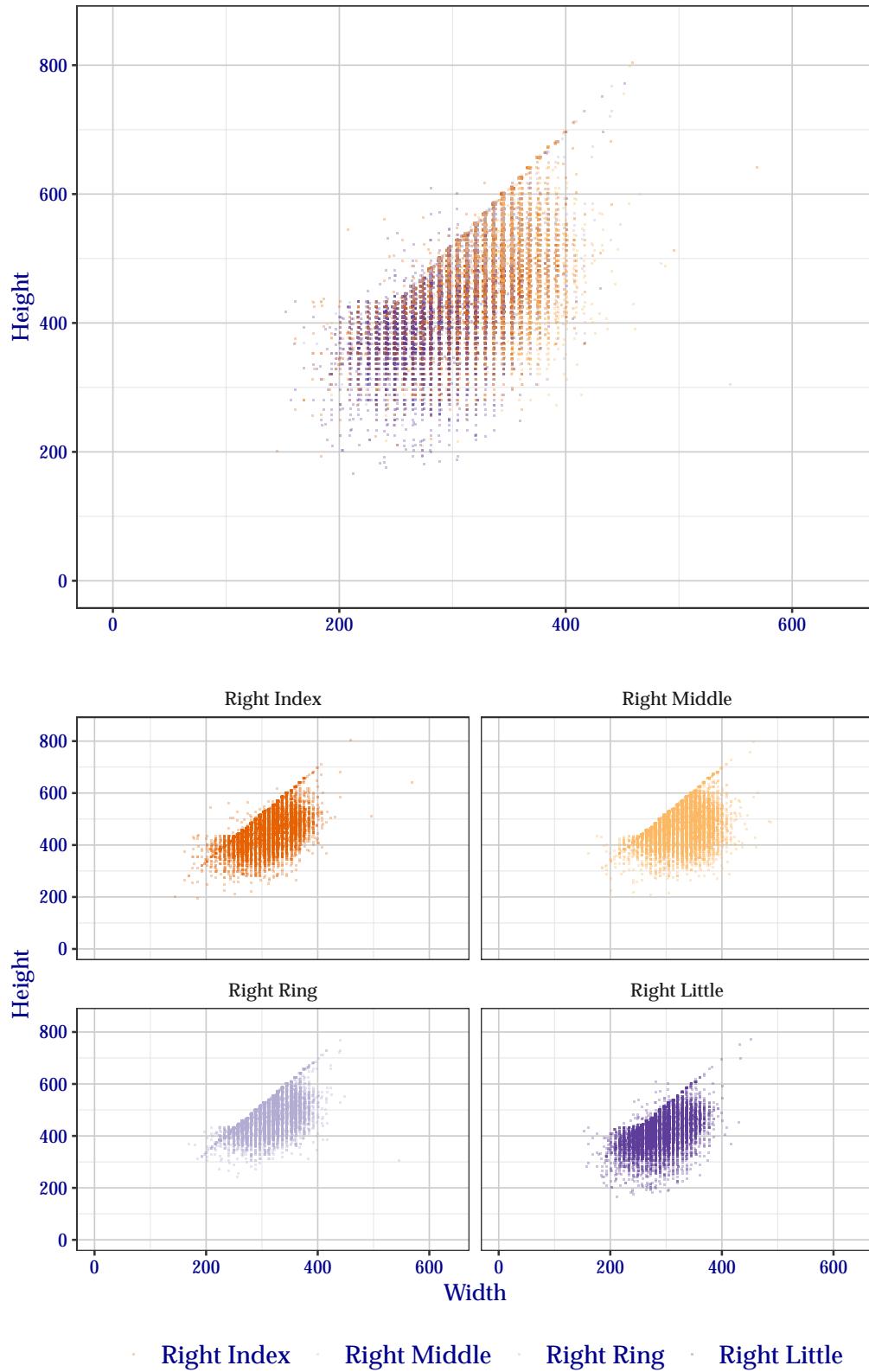
### 2.2.2 Segmentation Dimensions

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.

## Segmentation Position Dimensions

Participant: sequence/0002, FRGPs: 2, 3, 4, 5, Image Kind: Two Inch

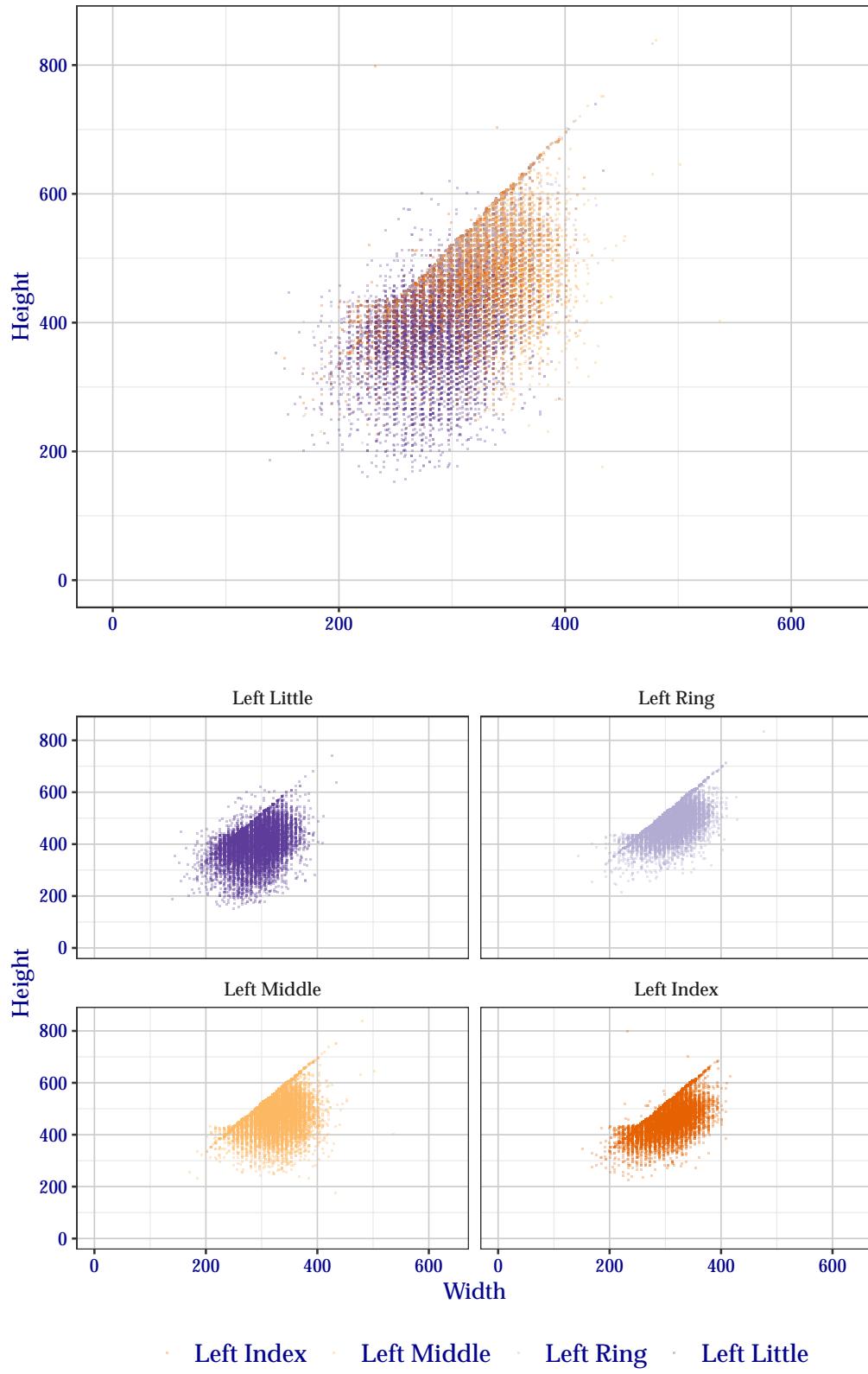


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Figure 4: Segmentation position dimensions for right hand TwoInch data.

## Segmentation Position Dimensions

Participant: sequence/0002, FRGPs: 7, 8, 9, 10, Image Kind: Two Inch



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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 sequence+0002 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                 | 99.9             | 99.9              | 99.9                    |
| 2                 | 99.8             | 99.8              | 99.8                    |
| 3                 | 99.4             | 99.6              | 99.7                    |
| 4                 | 98.3             | 99.1              | 99.2                    |
| 5                 | 94.7             | 95.1              | 95.4                    |
| 6                 | 93.0             | 94.3              | 94.6                    |
| 7                 | 87.6             | 91.5              | 92.4                    |
| 8                 | 69.4             | 79.9              | 81.3                    |

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 |
|--------------|------------------|-------------------|-------------------------|
| <b>Right</b> |                  |                   |                         |
| Index        | 92.2             | 93.8              | 94.5                    |
| Middle       | 95.1             | 97.2              | 97.3                    |
| Ring         | 95.5             | 97.9              | 98.1                    |
| Little       | 96.7             | 97.3              | 98.0                    |
| <b>Left</b>  |                  |                   |                         |
| Index        | 93.9             | 95.7              | 96.2                    |
| Middle       | 94.5             | 97.5              | 97.7                    |
| Ring         | 94.2             | 98.1              | 98.3                    |
| Little       | 97.1             | 97.9              | 98.4                    |

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 |
|---------------|------------------|-------------------|-------------------------|
| <b>Index</b>  |                  |                   |                         |
| Either        | 98.2             | 98.8              | 99.0                    |
| Both          | 83.6             | 86.7              | 87.6                    |
| <b>Middle</b> |                  |                   |                         |
| Either        | 98.5             | 99.4              | 99.5                    |
| Both          | 86.1             | 91.0              | 91.3                    |
| <b>Ring</b>   |                  |                   |                         |
| Either        | 98.8             | 99.6              | 99.7                    |
| Both          | 87.2             | 92.5              | 92.8                    |
| <b>Little</b> |                  |                   |                         |
| Either        | 99.4             | 99.6              | 99.6                    |
| Both          | 90.3             | 91.6              | 92.7                    |

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 |
|----------------|------------------|-------------------|-------------------------|
| <b>Right</b>   |                  |                   |                         |
| Any            | 99.5             | 99.6              | 99.7                    |
| At Least Two   | 99.1             | 99.2              | 99.5                    |
| At Least Three | 97.0             | 98.0              | 98.4                    |
| All Four       | 83.9             | 89.4              | 90.4                    |
| <b>Left</b>    |                  |                   |                         |
| Any            | 99.6             | 99.7              | 99.8                    |
| At Least Two   | 99.1             | 99.4              | 99.5                    |
| At Least Three | 96.9             | 98.4              | 98.8                    |
| All Four       | 84.0             | 91.7              | 92.5                    |

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 |
|------------------------|------------------|-------------------|-------------------------|
| <b>Right</b>           |                  |                   |                         |
| Either Index or Middle | 98.6             | 98.9              | 99.1                    |
| Both Index and Middle  | 88.8             | 92.0              | 92.7                    |
| <b>Left</b>            |                  |                   |                         |
| Either Index or Middle | 98.7             | 99.2              | 99.3                    |
| Both Index and Middle  | 89.7             | 94.0              | 94.5                    |

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 |
|--------------|------------------|-------------------|-------------------------|
| <b>Right</b> |                  |                   |                         |
| Any          | 99.4             | 99.5              | 99.6                    |
| At Least Two | 97.8             | 98.5              | 98.8                    |
| All Three    | 85.7             | 90.9              | 91.6                    |
| <b>Left</b>  |                  |                   |                         |
| Any          | 99.4             | 99.6              | 99.6                    |
| At Least Two | 97.5             | 98.8              | 99.0                    |
| All Three    | 85.6             | 92.9              | 93.5                    |

## 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 sequence+0002 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) | 80     |

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 |
|---------------|-------|
| Image Quality | 80    |

#### 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 80 recovery attempts sequence+0002 attempted 229 segmentations of fingers and skipped 91 fingers. More information about skipped fingers can be found in Table 11.

Table 10: Results of best-effort segmentation when sequence+0002 reported segmentation failure (229 best-effort attempts).

| Standard | Ignoring Bottom Y | Ignoring Bottom X and Y |
|----------|-------------------|-------------------------|
| 50.2     | 54.6              | 57.2                    |

## 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 sequence+0002 are enumerated in Table 11.

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

| Failure Reason                  | Fingers |
|---------------------------------|---------|
| Finger Found, but Can't Segment | 91      |
| Finger Not Found                | 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 sequence+0002 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 sequence+0002 at detecting fingers missing from an image.

| Result   | Percentage |
|--|------------|
| Missed   | 76.9       |
| Correctly Identified                           | 0.0        |
| Other Failure: Finger Found, but Can't Segment | 23.1       |
| Other Failure: Vendor Defined                  | 0.0        |

## 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 hand, right hand, or thumbs.

**Overall Two Inch accuracy:** 99.7%

Table 13: 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 | 0.3  | 99.7  |

### 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.

Box plots of segmentation times are separated by hand in Figure 6, with tabular representations are enumerated in Table 14. 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 14: Elapsed time in milliseconds when segmenting the ThreeInch timing test corpus, separated by slap orientation.

|         | Right | Left  | Thumbs | Combined |
|---------|-------|-------|--------|----------|
| Minimum | 33    | 32    | 13     | 13       |
| 25%     | 37    | 38    | 18     | 36       |
| Median  | 39    | 39    | 19     | 38       |
| 75%     | 43    | 43    | 21     | 42       |
| Maximum | 1 419 | 1 412 | 449    | 1 419    |

## 3.2 Segmentation Centers and Dimensions

### 3.2.1 Segmentation Centers

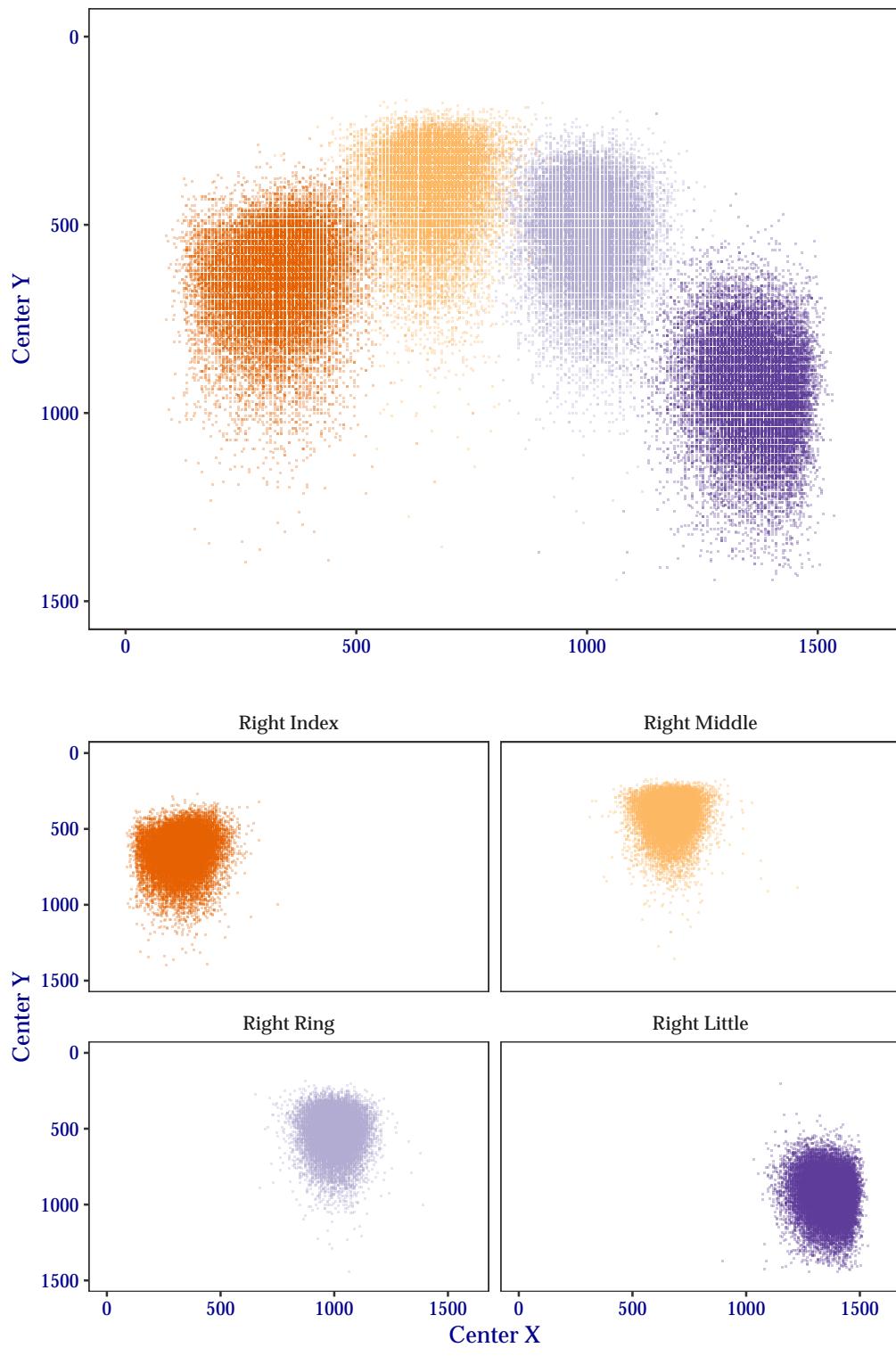
The plots in this section show the distribution of segmentation position centers  $(x, y)$  for ThreeInch data. At the top of each figure is a combined plot for all finger positions of a given hand orientation. These figures are isolated in plots faceted at the bottom of the figure.

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.

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.

## Segmentation Position Centers

Participant: sequence/0002, FRGPs: 2, 3, 4, 5, Image Kind: Three Inch

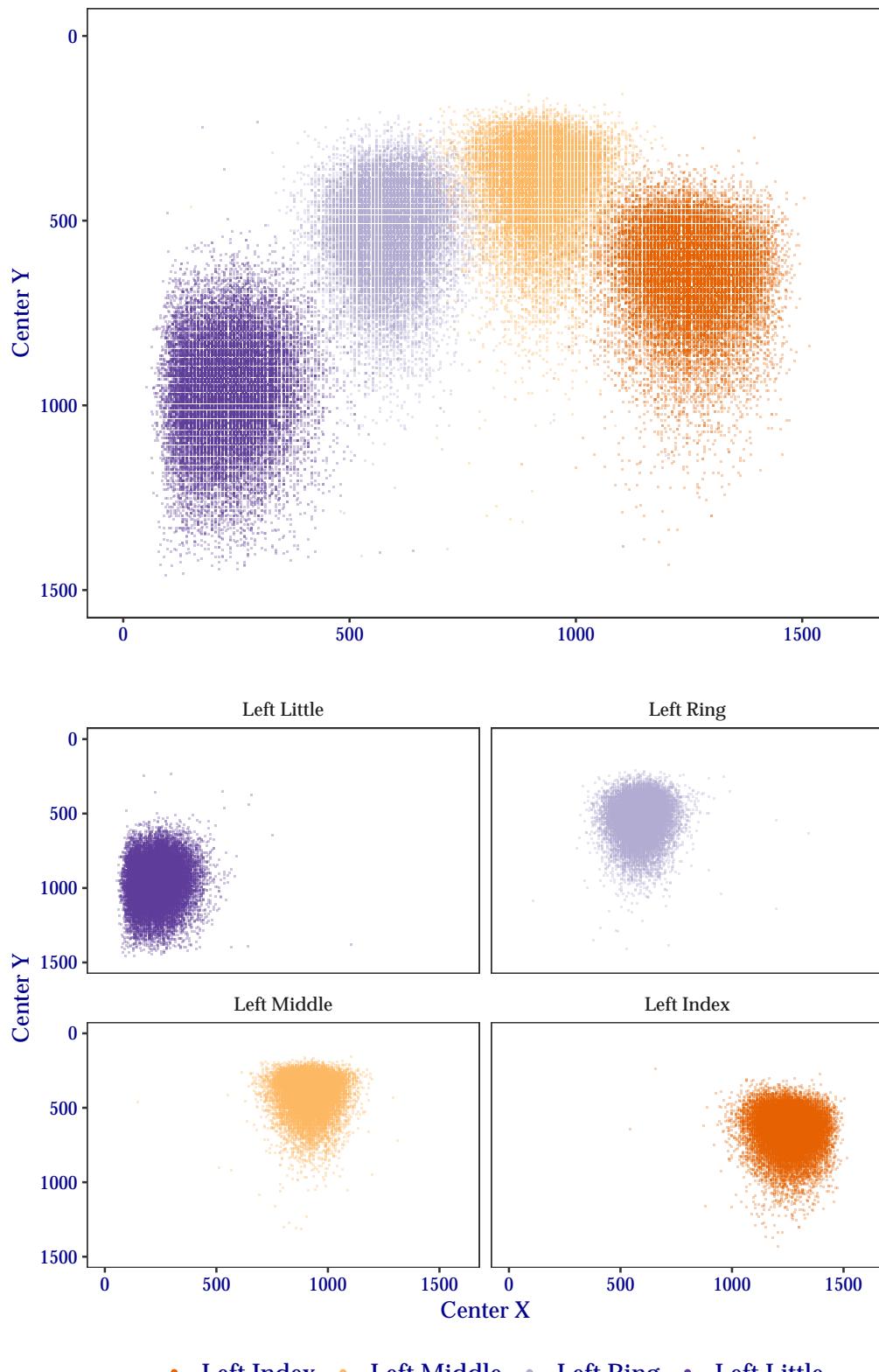


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Figure 7: Segmentation centers for right hand ThreeInch data.

## Segmentation Position Centers

Participant: sequence/0002, FRGPs: 7, 8, 9, 10, Image Kind: Three Inch

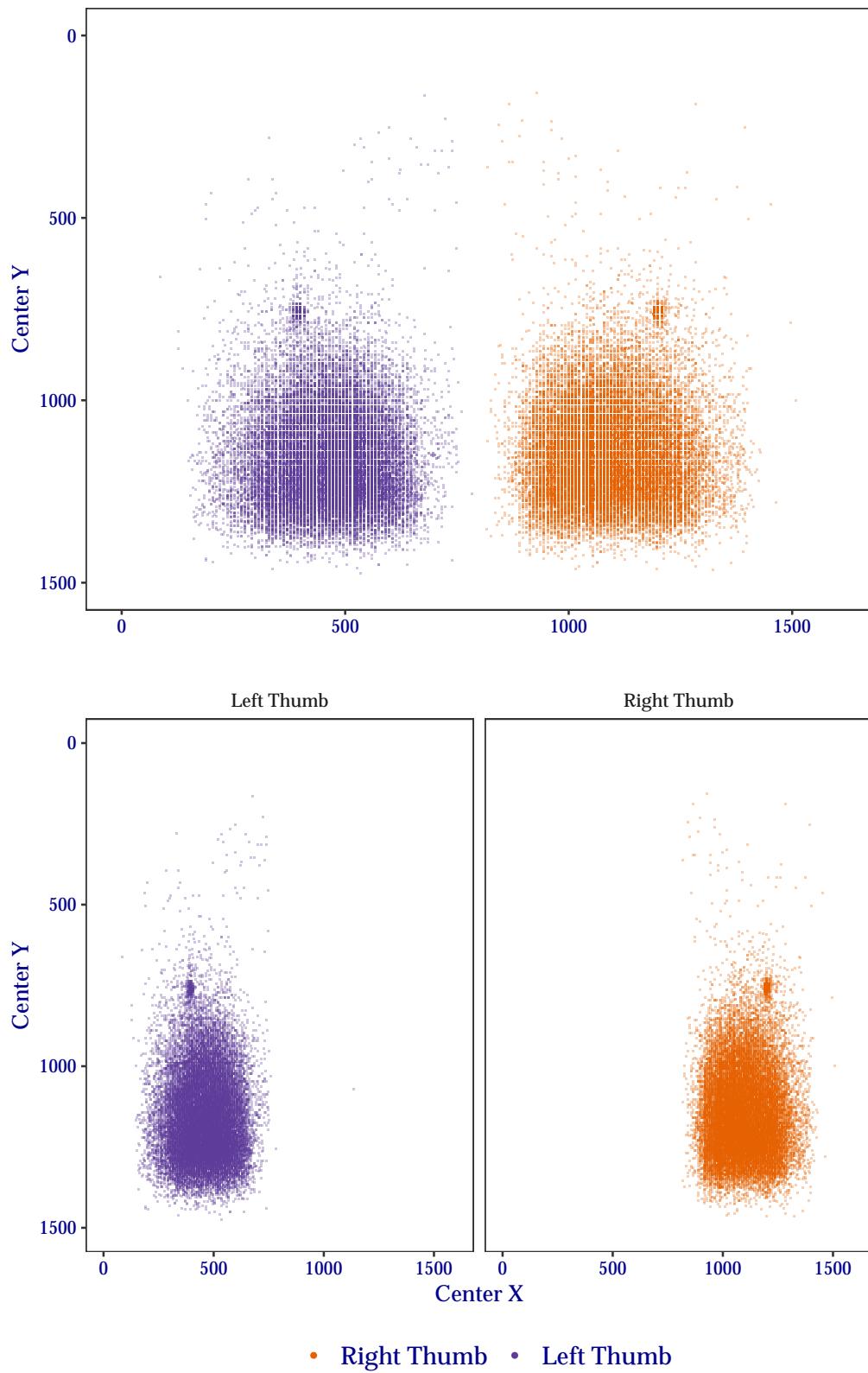


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Figure 8: Segmentation centers for left hand ThreeInch data.

## Segmentation Position Centers

Participant: sequence/0002, FRGPs: 1, 6, Image Kind: Three Inch



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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.

## Segmentation Position Dimensions

Participant: sequence/0002, FRGPs: 7, 8, 9, 10, Image Kind: Three Inch

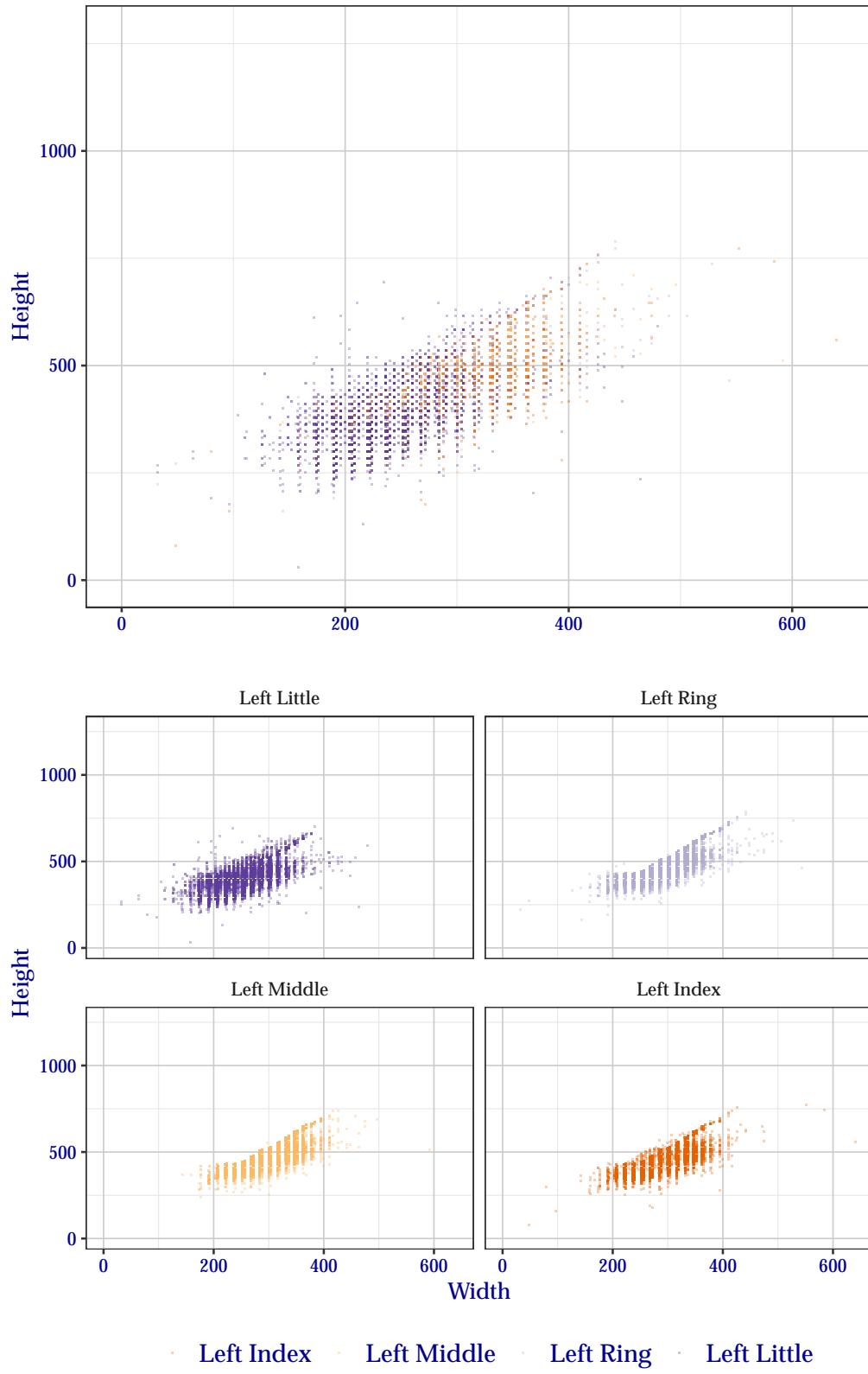
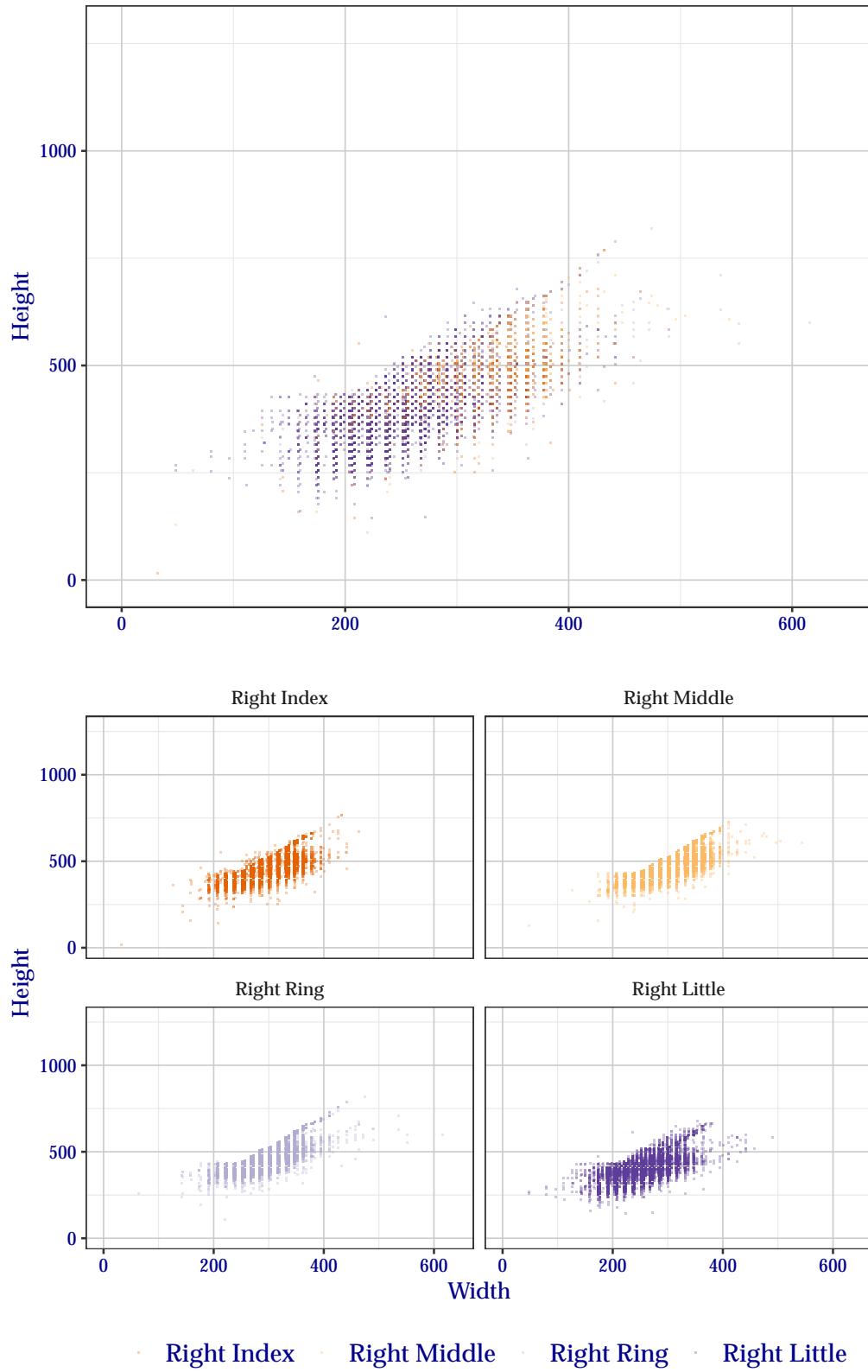


Figure 10: Segmentation position dimensions for left hand ThreeInch data.

## Segmentation Position Dimensions

Participant: sequence/0002, FRGPs: 2, 3, 4, 5, Image Kind: Three Inch

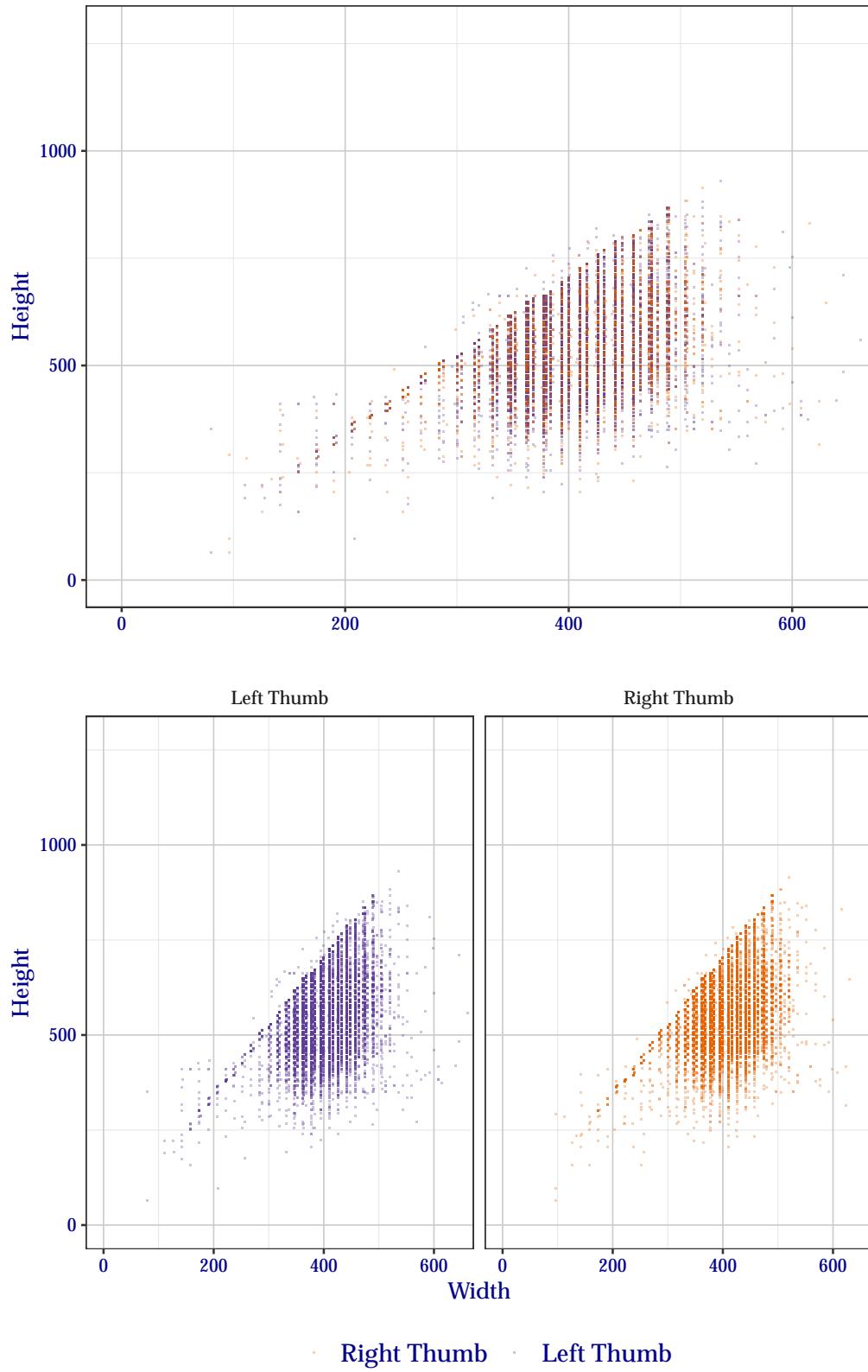


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Figure 11: Segmentation position dimensions for right hand ThreeInch data.

## Segmentation Position Dimensions

Participant: sequence/0002, FRGPs: 1, 6, Image Kind: Three Inch



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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 15 shows how successful sequence+0002 segmented fingers for each subject in the test corpus. Table 16 shows success for specific finger positions over the entire test corpus. Similarly, Table 17 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 18 shows success for combinations of all fingers, Table 19 for just the index and middle fingers, and Table 20 for all except the little finger.

Table 15: 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                 | 99.8             | 99.8              | 99.8                    |
| 2                 | 99.4             | 99.5              | 99.6                    |
| 3                 | 98.2             | 98.3              | 98.4                    |
| 4                 | 97.6             | 97.9              | 98.1                    |
| 5                 | 95.6             | 95.8              | 95.9                    |
| 6                 | 94.9             | 95.6              | 95.8                    |
| 7                 | 93.3             | 95.1              | 95.5                    |
| 8                 | 88.7             | 93.6              | 95.0                    |
| 9                 | 75.6             | 88.5              | 92.2                    |
| 10                | 50.3             | 70.3              | 79.1                    |

Table 16: 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 |
|--------------|------------------|-------------------|-------------------------|
| <b>Right</b> |                  |                   |                         |
| Thumb        | 82.4             | 94.9              | 95.3                    |
| Index        | 97.2             | 98.2              | 98.8                    |
| Middle       | 94.8             | 97.3              | 99.0                    |
| Ring         | 92.5             | 95.2              | 97.8                    |
| Little       | 95.0             | 96.4              | 97.4                    |
| <b>Left</b>  |                  |                   |                         |
| Thumb        | 80.1             | 96.0              | 96.4                    |
| Index        | 95.8             | 96.8              | 97.6                    |
| Middle       | 93.7             | 96.2              | 98.7                    |
| Ring         | 91.4             | 93.3              | 97.4                    |
| Little       | 95.0             | 96.1              | 97.1                    |

Table 17: 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 |
|---------------|------------------|-------------------|-------------------------|
| <b>Thumb</b>  |                  |                   |                         |
| Either        | 90.8             | 99.1              | 99.2                    |
| Both          | 71.7             | 91.9              | 92.6                    |
| <b>Index</b>  |                  |                   |                         |
| Either        | 99.2             | 99.5              | 99.7                    |
| Both          | 91.2             | 92.9              | 94.2                    |
| <b>Middle</b> |                  |                   |                         |
| Either        | 98.4             | 99.2              | 99.7                    |
| Both          | 87.7             | 91.7              | 95.4                    |
| <b>Ring</b>   |                  |                   |                         |
| Either        | 97.7             | 98.5              | 99.5                    |
| Both          | 83.8             | 87.5              | 93.1                    |
| <b>Little</b> |                  |                   |                         |
| Either        | 99.0             | 99.3              | 99.5                    |
| Both          | 88.4             | 90.6              | 92.3                    |

Table 18: 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 |
|----------------|------------------|-------------------|-------------------------|
| <b>Right</b>   |                  |                   |                         |
| Any            | 99.6             | 99.7              | 99.7                    |
| At Least Two   | 98.2             | 98.4              | 98.4                    |
| At Least Three | 97.0             | 98.0              | 98.2                    |
| At Least Four  | 92.1             | 95.9              | 97.1                    |
| All Five       | 66.6             | 81.1              | 86.0                    |
| <b>Left</b>    |                  |                   |                         |
| Any            | 99.6             | 99.7              | 99.8                    |
| At Least Two   | 98.1             | 98.3              | 98.3                    |
| At Least Three | 96.6             | 97.7              | 98.0                    |
| At Least Four  | 90.6             | 94.8              | 96.6                    |
| All Five       | 62.8             | 79.0              | 85.4                    |

Table 19: 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 |
|--------------|------------------|-------------------|-------------------------|
| <b>Right</b> |                  |                   |                         |
| Either       | 99.2             | 99.6              | 99.7                    |
| Both         | 92.7             | 95.8              | 98.1                    |
| <b>Left</b>  |                  |                   |                         |
| Either       | 98.9             | 99.3              | 99.6                    |
| Both         | 90.6             | 93.8              | 96.7                    |

Table 20: 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 |
|--------------|------------------|-------------------|-------------------------|
| <b>Right</b> |                  |                   |                         |
| Any          | 99.6             | 99.8              | 99.8                    |
| At Least Two | 97.6             | 98.8              | 99.5                    |
| All Three    | 87.2             | 92.2              | 96.4                    |
| <b>Left</b>  |                  |                   |                         |
| Any          | 99.4             | 99.6              | 99.7                    |
| At Least Two | 96.7             | 97.9              | 99.1                    |
| All Three    | 84.8             | 88.8              | 94.8                    |

## 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 sequence+0002 are enumerated in Table 21.

Table 21: Count of self-reported capture-type failure reasoning.

| Failure Reason              | Images |
|-----------------------------|--------|
| Request Recapture (Attempt) | 119    |

In situations where the algorithm feels that the presented image should be recaptured (Table 21), one or more image deficiencies must be identified. These deficiencies are enumerated in Table 22. 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 22: Count of image deficiencies reported when requesting a recapture.

| Deficiency    | Count |
|---------------|-------|
| Image Quality | 119   |

#### 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 23.

Out of 119 recovery attempts sequence+0002 attempted 327 segmentations of fingers and skipped 145 fingers. More information about skipped fingers can be found in Table 24.

Table 23: Results of best-effort segmentation when sequence+0002 reported segmentation failure (327 best-effort attempts).

| Standard | Ignoring Bottom Y | Ignoring Bottom X and Y |
|----------|-------------------|-------------------------|
| 55.7     | 58.4              | 61.8                    |

### 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 sequence+0002 are enumerated in Table 24.

Table 24: Count of self-reported segmentation failure reasoning.

| Failure Reason                  | Fingers |
|---------------------------------|---------|
| Finger Found, but Can't Segment | 145     |
| Finger Not Found                | 0       |
| Vendor Defined                  | 0       |

### 3.4.3 Identifying Missing Fingers

A small portion of the test corpus in SlapSeg III are missing fingers. Table 25 shows how successful sequence+0002 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 25: Performance of sequence+0002 at detecting fingers missing from an image.

| Result   | Percentage |
|--|------------|
| Missed   | 65.0       |
| Correctly Identified                           | 0.0        |
| Other Failure: Finger Found, but Can't Segment | 35.0       |
| Other Failure: Vendor Defined                  | 0.0        |

### 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., Tenprint card) and capture technology (e.g., ink), and needed to determine whether the image was of the left hand, right hand, or thumbs.

**Overall Three Inch accuracy:** 97.7%

Table 26: 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       | Skip | Thumbs      |
|--------|-------------|-------------|------|-------------|
| Left   | <b>99.3</b> | 0.6         | 0    | 0.1         |
| Right  | 0.8         | <b>99.2</b> | 0    | 0           |
| Thumbs | 3           | 2.5         | 0    | <b>94.5</b> |

## 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 27, results are shown of how successful sequence+0002 segmented fingers for each subject in the test corpus. Table 28 shows success for specific finger positions over the entire test corpus. Similarly, Table 29 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 30 shows success for combinations of all fingers, Table 32 for the all except the little finger, and Table 31 for just the index and middle fingers.

Table 27: 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 [99.8, 99.9] | 99.9 [99.8, 100.0] | 99.9 [99.9, 100.0]      |
| 2                 | 99.8 [99.7, 99.8] | 99.8 [99.7, 99.9]  | 99.8 [99.7, 99.9]       |
| 3                 | 99.4 [99.2, 99.5] | 99.6 [99.5, 99.7]  | 99.7 [99.6, 99.8]       |
| 4                 | 98.3 [98.1, 98.6] | 99.1 [99.0, 99.3]  | 99.2 [99.0, 99.3]       |
| 5                 | 94.7 [94.3, 95.1] | 95.1 [94.8, 95.5]  | 95.4 [95.0, 95.7]       |
| 6                 | 93.0 [92.6, 93.5] | 94.3 [93.9, 94.7]  | 94.6 [94.2, 95.0]       |
| 7                 | 87.6 [87.0, 88.1] | 91.5 [91.0, 92.0]  | 92.4 [91.9, 92.8]       |
| 8                 | 69.4 [68.6, 70.1] | 79.9 [79.2, 80.6]  | 81.3 [80.7, 82.0]       |

Table 28: 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 |
|--------------|-------------------|-------------------|-------------------------|
| <b>Right</b> |                   |                   |                         |
| Index        | 92.2 [91.9, 92.6] | 93.8 [93.5, 94.1] | 94.5 [94.2, 94.7]       |
| Middle       | 95.1 [94.8, 95.4] | 97.2 [96.9, 97.4] | 97.3 [97.1, 97.5]       |
| Ring         | 95.5 [95.2, 95.8] | 97.9 [97.7, 98.1] | 98.1 [98.0, 98.3]       |
| Little       | 96.7 [96.5, 96.9] | 97.3 [97.1, 97.6] | 98.0 [97.8, 98.2]       |
| <b>Left</b>  |                   |                   |                         |
| Index        | 93.9 [93.5, 94.2] | 95.7 [95.5, 96.0] | 96.2 [95.9, 96.4]       |
| Middle       | 94.5 [94.1, 94.8] | 97.5 [97.2, 97.7] | 97.7 [97.5, 97.9]       |
| Ring         | 94.2 [93.8, 94.5] | 98.1 [97.9, 98.3] | 98.3 [98.1, 98.5]       |
| Little       | 97.1 [96.9, 97.3] | 97.9 [97.7, 98.1] | 98.4 [98.2, 98.6]       |

Table 29: 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 |
|---------------|-------------------|-------------------|-------------------------|
| <b>Index</b>  |                   |                   |                         |
| Either        | 98.2 [98.0, 98.4] | 98.8 [98.6, 99.0] | 99.0 [98.8, 99.2]       |
| Both          | 83.6 [83.0, 84.3] | 86.7 [86.1, 87.3] | 87.6 [87.1, 88.2]       |
| <b>Middle</b> |                   |                   |                         |
| Either        | 98.5 [98.3, 98.7] | 99.4 [99.3, 99.6] | 99.5 [99.4, 99.6]       |
| Both          | 86.1 [85.5, 86.7] | 91.0 [90.5, 91.5] | 91.3 [90.8, 91.8]       |
| <b>Ring</b>   |                   |                   |                         |
| Either        | 98.8 [98.6, 98.9] | 99.6 [99.5, 99.7] | 99.7 [99.6, 99.8]       |
| Both          | 87.2 [86.6, 87.7] | 92.5 [92.0, 93.0] | 92.8 [92.4, 93.3]       |
| <b>Little</b> |                   |                   |                         |
| Either        | 99.4 [99.3, 99.6] | 99.6 [99.5, 99.7] | 99.6 [99.5, 99.7]       |
| Both          | 90.3 [89.8, 90.8] | 91.6 [91.1, 92.0] | 92.7 [92.2, 93.1]       |

Table 30: 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 |
|----------------|-------------------|-------------------|-------------------------|
| <b>Right</b>   |                   |                   |                         |
| Any            | 99.5 [99.5, 99.7] | 99.6 [99.6, 99.7] | 99.7 [99.7, 99.8]       |
| At Least Two   | 99.1 [99.0, 99.2] | 99.2 [99.2, 99.4] | 99.5 [99.4, 99.5]       |
| At Least Three | 97.0 [96.8, 97.1] | 98.0 [98.1, 98.3] | 98.4 [98.5, 98.7]       |
| All Four       | 83.9 [83.6, 84.3] | 89.4 [90.2, 90.7] | 90.4 [91.1, 91.7]       |
| <b>Left</b>    |                   |                   |                         |
| Any            | 99.6 [99.5, 99.7] | 99.7 [99.6, 99.7] | 99.8 [99.7, 99.8]       |
| At Least Two   | 99.1 [99.0, 99.2] | 99.4 [99.2, 99.4] | 99.5 [99.4, 99.5]       |
| At Least Three | 96.9 [96.8, 97.1] | 98.4 [98.1, 98.3] | 98.8 [98.5, 98.7]       |
| All Four       | 84.0 [83.6, 84.3] | 91.7 [90.2, 90.7] | 92.5 [91.1, 91.7]       |

Table 31: 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 |
|------------------------|-------------------|-------------------|-------------------------|
| <b>Right</b>           |                   |                   |                         |
| Either Index or Middle | 98.6 [98.5, 98.7] | 98.9 [99.0, 99.2] | 99.1 [99.1, 99.3]       |
| Both Index and Middle  | 88.8 [88.9, 89.5] | 92.0 [92.7, 93.2] | 92.7 [93.3, 93.8]       |
| <b>Left</b>            |                   |                   |                         |
| Either Index or Middle | 98.7 [98.5, 98.7] | 99.2 [99.0, 99.2] | 99.3 [99.1, 99.3]       |
| Both Index and Middle  | 89.7 [88.9, 89.5] | 94.0 [92.7, 93.2] | 94.5 [93.3, 93.8]       |

Table 32: 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 |
|--------------|-------------------|-------------------|-------------------------|
| <b>Right</b> |                   |                   |                         |
| Any          | 99.4 [99.3, 99.5] | 99.5 [99.4, 99.6] | 99.6 [99.6, 99.7]       |
| At Least Two | 97.8 [97.5, 97.8] | 98.5 [98.6, 98.8] | 98.8 [98.8, 99.0]       |
| All Three    | 85.7 [85.3, 86.0] | 90.9 [91.6, 92.1] | 91.6 [92.2, 92.7]       |
| <b>Left</b>  |                   |                   |                         |
| Any          | 99.4 [99.3, 99.5] | 99.6 [99.4, 99.6] | 99.6 [99.6, 99.7]       |
| At Least Two | 97.5 [97.5, 97.8] | 98.8 [98.6, 98.8] | 99.0 [98.8, 99.0]       |
| All Three    | 85.6 [85.3, 86.0] | 92.9 [91.6, 92.1] | 93.5 [92.2, 92.7]       |

## A.2 Jaccard Index

Table 33: For each subject, the percentage that at least *Number of Fingers* fingers were segmented with a Jaccard index in the indicated range.

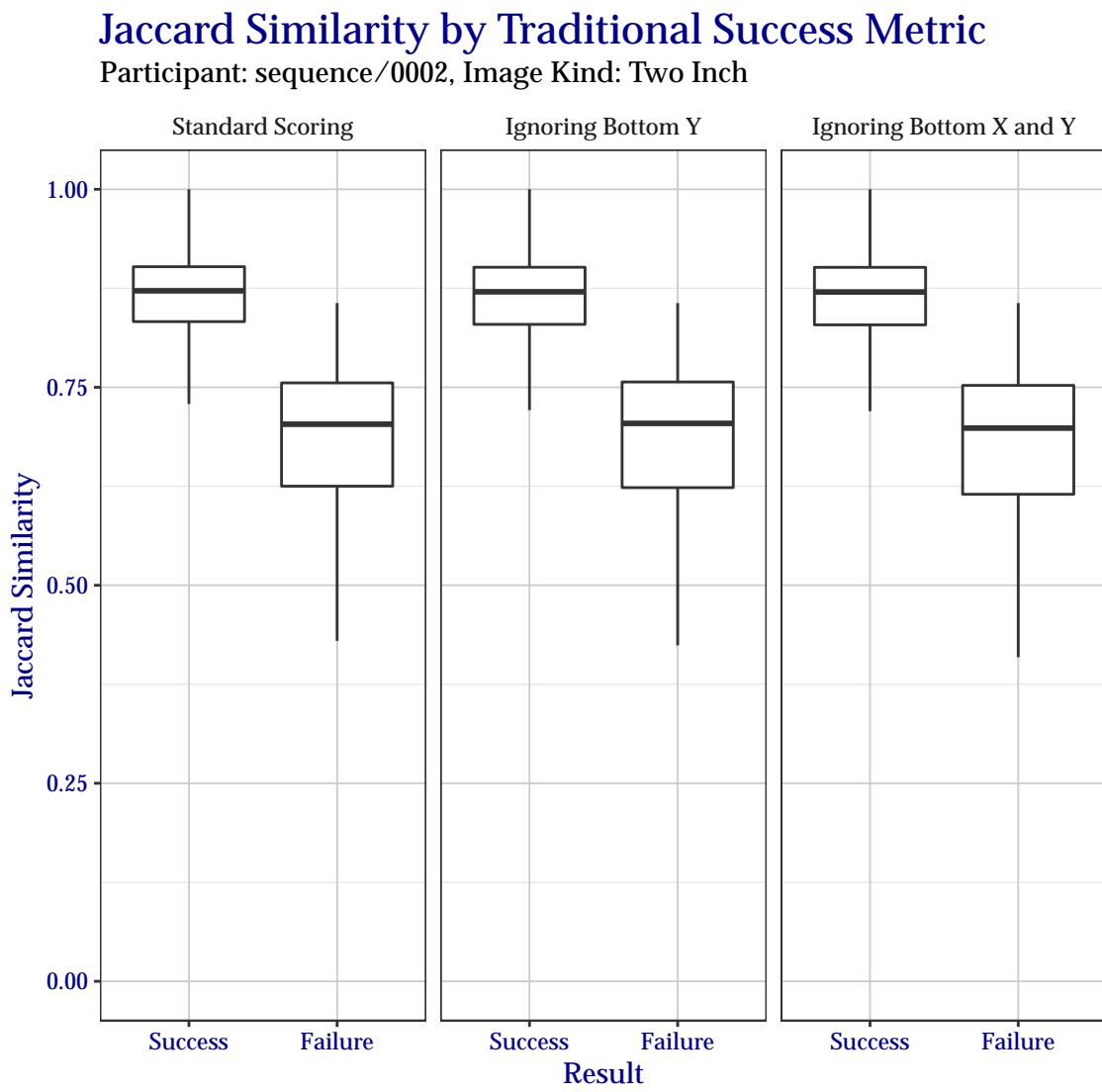
| Number of Fingers | $\geq 0.5$ | $\geq 0.6$ | $\geq 0.7$ | $\geq 0.8$ | $\geq 0.9$ | $\geq 0.95$ | $\geq 0.98$ |
|-------------------|------------|------------|------------|------------|------------|-------------|-------------|
| 1                 | 100.0      | 100.0      | 99.9       | 99.7       | 82.3       | 9.9         | 0.6         |
| 2                 | 99.9       | 99.9       | 99.9       | 98.6       | 56.6       | 0.8         | 0.0         |
| 3                 | 99.8       | 99.8       | 99.5       | 96.2       | 32.1       | 0.1         | 0           |
| 4                 | 99.7       | 99.4       | 98.4       | 91.7       | 15.4       | 0           | 0           |
| 5                 | 95.8       | 95.7       | 95.0       | 84.3       | 5.8        | 0           | 0           |
| 6                 | 95.7       | 95.5       | 93.3       | 74.3       | 1.5        | 0           | 0           |
| 7                 | 95.4       | 94.4       | 88.7       | 58.6       | 0.3        | 0           | 0           |
| 8                 | 93.5       | 88.5       | 72.9       | 33.3       | 0.0        | 0           | 0           |

Table 34: For all subjects, percentage that a particular friction ridge generalized position was segmented with a Jaccard index in the indicated range.

| Finger       | $0-0.5$ | $0.5-0.6$ | $0.6-0.7$ | $0.7-0.8$ | $0.8-0.9$ | $0.9-1.0$ |
|--------------|---------|-----------|-----------|-----------|-----------|-----------|
| <b>Right</b> |         |           |           |           |           |           |
| Index        | 0.4     | 0.8       | 3.3       | 15.8      | 60.9      | 18.8      |
| Middle       | 0.5     | 0.6       | 2.4       | 11.4      | 56.7      | 28.4      |
| Ring         | 0.2     | 0.3       | 1.7       | 9.6       | 54.4      | 33.8      |
| Little       | 0.4     | 0.4       | 1.5       | 9.1       | 61.1      | 27.5      |
| <b>Left</b>  |         |           |           |           |           |           |
| Index        | 0.4     | 1.1       | 3.9       | 14.8      | 55.6      | 24.2      |
| Middle       | 0.8     | 1.3       | 4.7       | 15.8      | 51.9      | 25.5      |
| Ring         | 0.3     | 0.7       | 3.4       | 14.8      | 54.0      | 26.8      |
| Little       | 0.3     | 0.6       | 2.5       | 15.2      | 63.9      | 17.5      |

Table 35: Percentage of segmentation obtaining a Jaccard index in the indicated ranges, by hand, for combinations of all eight fingers of a TwoInch slap.

| Fingers        | $\geq 0.5$ | $\geq 0.6$ | $\geq 0.7$ | $\geq 0.8$ | $\geq 0.9$ | $\geq 0.95$ | $\geq 0.98$ |
|----------------|------------|------------|------------|------------|------------|-------------|-------------|
| <b>Right</b>   |            |            |            |            |            |             |             |
| Any            | 99.9       | 99.9       | 99.9       | 99.0       | 66.1       | 5.9         | 0.3         |
| At Least Two   | 99.9       | 99.9       | 99.7       | 96.6       | 31.9       | 0.4         | 0.0         |
| At Least Three | 99.8       | 99.7       | 98.5       | 87.1       | 9.2        | 0.0         | 0.0         |
| All Four       | 98.9       | 96.9       | 89.3       | 58.8       | 1.3        | 0.0         | 0.0         |
| <b>Left</b>    |            |            |            |            |            |             |             |
| Any            | 100.0      | 100.0      | 99.8       | 97.8       | 58.0       | 4.6         | 0.3         |
| At Least Two   | 99.9       | 99.8       | 99.2       | 91.8       | 27.1       | 0.2         | 0.0         |
| At Least Three | 99.7       | 99.3       | 96.7       | 78.7       | 7.7        | 0.0         | 0.0         |
| All Four       | 98.5       | 95.3       | 84.3       | 51.0       | 1.2        | 0.0         | 0.0         |

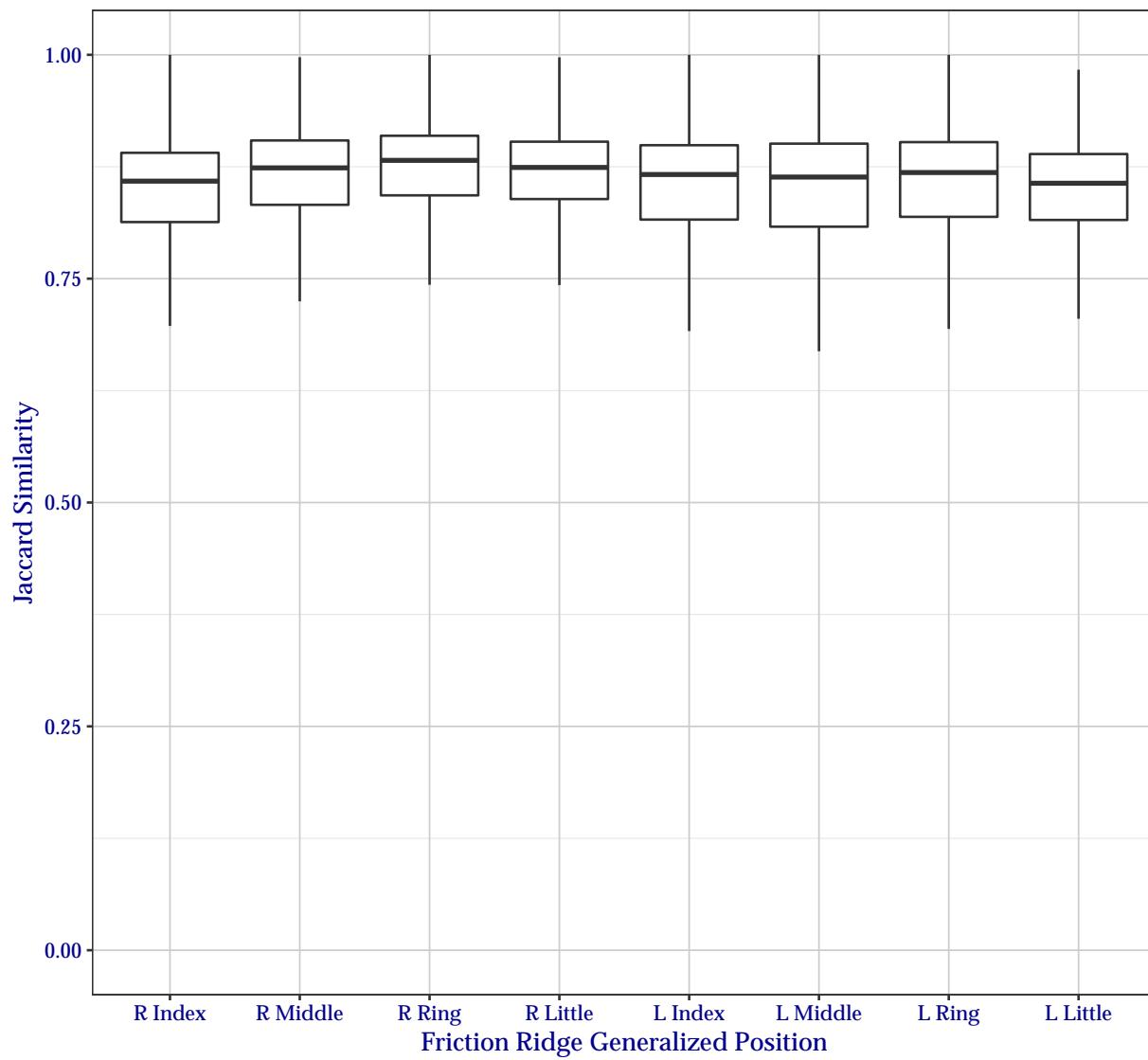


05 June 2019, 02:50:44 PM EDT

Figure 13: Boxplot of Jaccard similarity indices as compared to the traditional success metrics. Outliers have been removed for clarity.

## Jaccard Similarity by Friction Ridge Generalized Position

Participant: sequence/0002, Image Kind: Two Inch



05 June 2019, 02:50:40 PM EDT

Figure 14: Boxplot of Jaccard similarity indices for each friction ridge generalized position. Outliers have been removed for clarity.

Table 36: 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                | $\geq 0.5$ | $\geq 0.6$ | $\geq 0.7$ | $\geq 0.8$ | $\geq 0.9$ | $\geq 0.95$ | $\geq 0.98$ |
|------------------------|------------|------------|------------|------------|------------|-------------|-------------|
| <b>Right</b>           |            |            |            |            |            |             |             |
| Either Index or Middle | 99.9       | 99.8       | 99.4       | 94.7       | 40.4       | 2.3         | 0.1         |
| Both Index and Middle  | 99.2       | 97.8       | 92.6       | 70.1       | 6.8        | 0.0         | 0           |
| <b>Left</b>            |            |            |            |            |            |             |             |
| Either Index or Middle | 99.9       | 99.7       | 98.6       | 91.3       | 41.0       | 2.6         | 0.2         |
| Both Index and Middle  | 98.9       | 96.6       | 89.2       | 65.8       | 8.6        | 0.0         | 0           |

Table 37: 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      | $\geq 0.5$ | $\geq 0.6$ | $\geq 0.7$ | $\geq 0.8$ | $\geq 0.9$ | $\geq 0.95$ | $\geq 0.98$ |
|--------------|------------|------------|------------|------------|------------|-------------|-------------|
| <b>Right</b> |            |            |            |            |            |             |             |
| Any          | 99.9       | 99.9       | 99.8       | 98.1       | 57.0       | 4.3         | 0.2         |
| At Least Two | 99.8       | 99.8       | 99.0       | 90.6       | 20.7       | 0.2         | 0           |
| All Three    | 99.1       | 97.5       | 90.9       | 64.3       | 3.3        | 0.0         | 0           |
| <b>Left</b>  |            |            |            |            |            |             |             |
| Any          | 99.9       | 99.9       | 99.5       | 95.5       | 52.3       | 3.8         | 0.3         |
| At Least Two | 99.8       | 99.5       | 97.4       | 84.2       | 20.3       | 0.1         | 0.0         |
| All Three    | 98.7       | 96.0       | 86.6       | 58.3       | 3.8        | 0.0         | 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 38, results are shown of how successful sequence+0002 segmented fingers for each subject in the test corpus. Table 39 shows success for specific finger positions over the entire test corpus. Similarly, Table 40 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 41 shows success for combinations of all fingers, Table 43 for the all except the little finger, and Table 42 for just the index and middle fingers.

Table 38: 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                 | 99.8 [99.7, 99.9] | 99.8 [99.8, 99.9] | 99.8 [99.8, 99.9]       |
| 2                 | 99.4 [99.3, 99.5] | 99.5 [99.5, 99.6] | 99.6 [99.5, 99.7]       |
| 3                 | 98.2 [98.0, 98.4] | 98.3 [98.2, 98.5] | 98.4 [98.2, 98.5]       |
| 4                 | 97.6 [97.4, 97.8] | 97.9 [97.7, 98.1] | 98.1 [97.9, 98.3]       |
| 5                 | 95.6 [95.3, 95.8] | 95.8 [95.6, 96.1] | 95.9 [95.7, 96.1]       |
| 6                 | 94.9 [94.6, 95.1] | 95.6 [95.4, 95.9] | 95.8 [95.6, 96.1]       |
| 7                 | 93.3 [93.0, 93.6] | 95.1 [94.9, 95.4] | 95.5 [95.3, 95.8]       |
| 8                 | 88.7 [88.3, 89.1] | 93.6 [93.4, 94.0] | 95.0 [94.7, 95.2]       |
| 9                 | 75.6 [75.1, 76.1] | 88.5 [88.1, 88.9] | 92.2 [91.8, 92.5]       |
| 10                | 50.3 [49.7, 50.9] | 70.3 [69.8, 70.9] | 79.1 [78.6, 79.6]       |

Table 39: 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 |
|--------------|-------------------|-------------------|-------------------------|
| <b>Right</b> |                   |                   |                         |
| Thumb        | 82.4 [81.9, 82.8] | 94.9 [94.6, 95.1] | 95.3 [95.0, 95.6]       |
| Index        | 97.2 [96.9, 97.4] | 98.2 [98.0, 98.3] | 98.8 [98.7, 98.9]       |
| Middle       | 94.8 [94.5, 95.1] | 97.3 [97.1, 97.5] | 99.0 [98.9, 99.2]       |
| Ring         | 92.5 [92.1, 92.8] | 95.2 [95.0, 95.5] | 97.8 [97.6, 98.0]       |
| Little       | 95.0 [94.7, 95.2] | 96.4 [96.2, 96.6] | 97.4 [97.2, 97.6]       |
| <b>Left</b>  |                   |                   |                         |
| Thumb        | 80.1 [79.6, 80.6] | 96.0 [95.7, 96.2] | 96.4 [96.1, 96.6]       |
| Index        | 95.8 [95.5, 96.0] | 96.8 [96.6, 97.1] | 97.6 [97.4, 97.8]       |
| Middle       | 93.7 [93.4, 94.0] | 96.2 [96.0, 96.4] | 98.7 [98.5, 98.8]       |
| Ring         | 91.4 [91.1, 91.8] | 93.3 [93.0, 93.6] | 97.4 [97.2, 97.6]       |
| Little       | 95.0 [94.7, 95.3] | 96.1 [95.9, 96.4] | 97.1 [96.9, 97.3]       |

Table 40: 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 |
|---------------|-------------------|-------------------|-------------------------|
| <b>Thumb</b>  |                   |                   |                         |
| Either        | 90.8 [90.4, 91.2] | 99.1 [98.9, 99.2] | 99.2 [99.1, 99.3]       |
| Both          | 71.7 [71.1, 72.3] | 91.9 [91.6, 92.2] | 92.6 [92.2, 92.9]       |
| <b>Index</b>  |                   |                   |                         |
| Either        | 99.2 [99.1, 99.3] | 99.5 [99.4, 99.6] | 99.7 [99.6, 99.7]       |
| Both          | 91.2 [90.8, 91.5] | 92.9 [92.6, 93.2] | 94.2 [93.9, 94.5]       |
| <b>Middle</b> |                   |                   |                         |
| Either        | 98.4 [98.3, 98.6] | 99.2 [99.1, 99.3] | 99.7 [99.7, 99.8]       |
| Both          | 87.7 [87.3, 88.1] | 91.7 [91.4, 92.1] | 95.4 [95.1, 95.6]       |
| <b>Ring</b>   |                   |                   |                         |
| Either        | 97.7 [97.5, 97.9] | 98.5 [98.3, 98.6] | 99.5 [99.4, 99.6]       |
| Both          | 83.8 [83.3, 84.2] | 87.5 [87.1, 87.9] | 93.1 [92.8, 93.4]       |
| <b>Little</b> |                   |                   |                         |
| Either        | 99.0 [98.9, 99.2] | 99.3 [99.2, 99.4] | 99.5 [99.4, 99.6]       |
| Both          | 88.4 [88.0, 88.8] | 90.6 [90.2, 91.0] | 92.3 [92.0, 92.7]       |

Table 41: 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 |
|----------------|-------------------|-------------------|-------------------------|
| <b>Right</b>   |                   |                   |                         |
| Any            | 99.6 [99.5, 99.7] | 99.7 [99.7, 99.8] | 99.7 [99.7, 99.8]       |
| At Least Two   | 98.2 [98.0, 98.3] | 98.4 [98.2, 98.5] | 98.4 [98.3, 98.5]       |
| At Least Three | 97.0 [96.6, 96.9] | 98.0 [97.7, 97.9] | 98.2 [98.0, 98.2]       |
| At Least Four  | 92.1 [91.1, 91.6] | 95.9 [95.2, 95.5] | 97.1 [96.7, 97.0]       |
| All Five       | 66.6 [64.3, 65.1] | 81.1 [79.7, 80.5] | 86.0 [85.3, 85.9]       |
| <b>Left</b>    |                   |                   |                         |
| Any            | 99.6 [99.5, 99.7] | 99.7 [99.7, 99.8] | 99.8 [99.7, 99.8]       |
| At Least Two   | 98.1 [98.0, 98.3] | 98.3 [98.2, 98.5] | 98.3 [98.3, 98.5]       |
| At Least Three | 96.6 [96.6, 96.9] | 97.7 [97.7, 97.9] | 98.0 [98.0, 98.2]       |
| At Least Four  | 90.6 [91.1, 91.6] | 94.8 [95.2, 95.5] | 96.6 [96.7, 97.0]       |
| All Five       | 62.8 [64.3, 65.1] | 79.0 [79.7, 80.5] | 85.4 [85.3, 85.9]       |

Table 42: 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 |
|------------------------|-------------------|-------------------|-------------------------|
| <b>Right</b>           |                   |                   |                         |
| Either Index or Middle | 99.2 [99.0, 99.1] | 99.6 [99.4, 99.5] | 99.7 [99.6, 99.7]       |
| Both Index and Middle  | 92.7 [91.4, 91.9] | 95.8 [94.6, 95.0] | 98.1 [97.3, 97.6]       |
| <b>Left</b>            |                   |                   |                         |
| Either Index or Middle | 98.9 [99.0, 99.1] | 99.3 [99.4, 99.5] | 99.6 [99.6, 99.7]       |
| Both Index and Middle  | 90.6 [91.4, 91.9] | 93.8 [94.6, 95.0] | 96.7 [97.3, 97.6]       |

Table 43: 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 |
|--------------|-------------------|-------------------|-------------------------|
| <b>Right</b> |                   |                   |                         |
| Any          | 99.6 [99.4, 99.6] | 99.8 [99.6, 99.7] | 99.8 [99.7, 99.8]       |
| At Least Two | 97.6 [97.0, 97.3] | 98.8 [98.2, 98.4] | 99.5 [99.2, 99.4]       |
| All Three    | 87.2 [85.7, 86.3] | 92.2 [90.2, 90.8] | 96.4 [95.4, 95.8]       |
| <b>Left</b>  |                   |                   |                         |
| Any          | 99.4 [99.4, 99.6] | 99.6 [99.6, 99.7] | 99.7 [99.7, 99.8]       |
| At Least Two | 96.7 [97.0, 97.3] | 97.9 [98.2, 98.4] | 99.1 [99.2, 99.4]       |
| All Three    | 84.8 [85.7, 86.3] | 88.8 [90.2, 90.8] | 94.8 [95.4, 95.8]       |

## B.2 Jaccard Index

Table 44: 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 | $\geq 0.5$ | $\geq 0.6$ | $\geq 0.7$ | $\geq 0.8$ | $\geq 0.9$ | $\geq 0.95$ | $\geq 0.98$ |
|-------------------|------------|------------|------------|------------|------------|-------------|-------------|
| 1                 | 99.9       | 99.9       | 99.9       | 99.5       | 92.2       | 29.7        | 1.4         |
| 2                 | 99.9       | 99.8       | 99.6       | 98.5       | 80.1       | 6.6         | 0.1         |
| 3                 | 98.5       | 98.3       | 98.0       | 96.2       | 64.4       | 1.3         | 0.0         |
| 4                 | 98.2       | 98.0       | 97.3       | 93.7       | 46.8       | 0.2         | 0.0         |
| 5                 | 95.9       | 95.9       | 95.2       | 89.7       | 30.3       | 0.0         | 0           |
| 6                 | 95.9       | 95.7       | 94.2       | 84.4       | 17.0       | 0.0         | 0           |
| 7                 | 95.8       | 95.3       | 92.1       | 76.4       | 7.7        | 0           | 0           |
| 8                 | 95.6       | 94.3       | 87.3       | 64.3       | 2.8        | 0           | 0           |
| 9                 | 94.8       | 90.8       | 76.7       | 46.7       | 0.7        | 0           | 0           |
| 10                | 90.5       | 79.1       | 55.4       | 24.8       | 0.1        | 0           | 0           |

Table 45: 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 |
|--------------|-------|---------|---------|---------|---------|---------|
| <b>Right</b> |       |         |         |         |         |         |
| Thumb        | 1.0   | 3.0     | 8.6     | 12.4    | 44.1    | 30.9    |
| Index        | 0.5   | 0.6     | 2.2     | 9.5     | 44.8    | 42.4    |
| Middle       | 0.5   | 1.1     | 4.4     | 14.4    | 42.6    | 37.0    |
| Ring         | 0.8   | 2.0     | 6.2     | 15.1    | 39.4    | 36.5    |
| Little       | 1.0   | 1.7     | 3.6     | 8.6     | 44.3    | 40.8    |
| <b>Left</b>  |       |         |         |         |         |         |
| Thumb        | 1.3   | 3.9     | 10.4    | 15.2    | 42.9    | 26.3    |
| Index        | 0.5   | 0.8     | 2.8     | 9.8     | 46.9    | 39.2    |
| Middle       | 0.7   | 1.3     | 4.9     | 15.4    | 45.2    | 32.5    |
| Ring         | 1.0   | 2.3     | 6.5     | 16.2    | 41.8    | 32.2    |
| Little       | 1.4   | 1.9     | 3.7     | 9.3     | 51.7    | 32.0    |

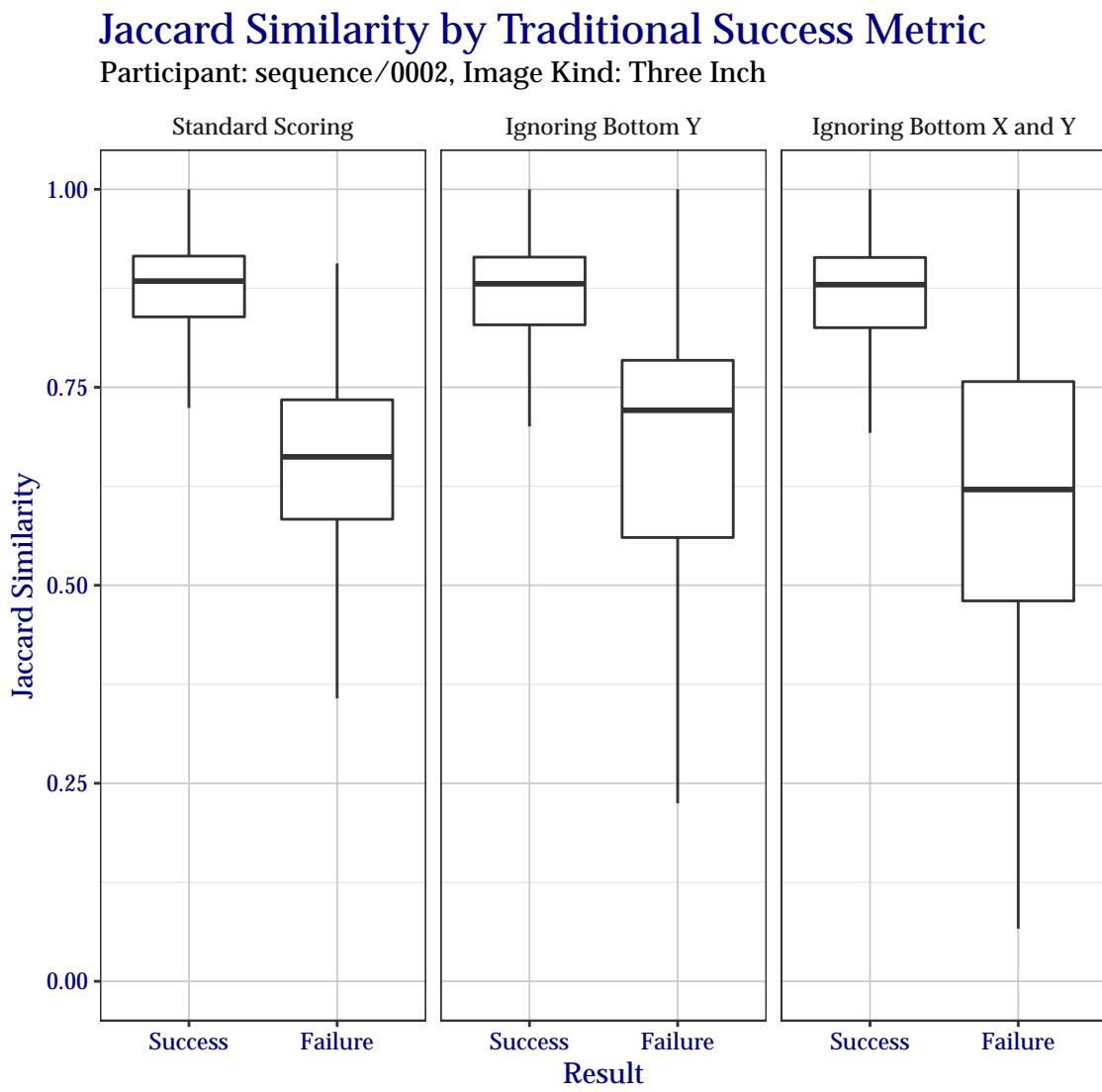
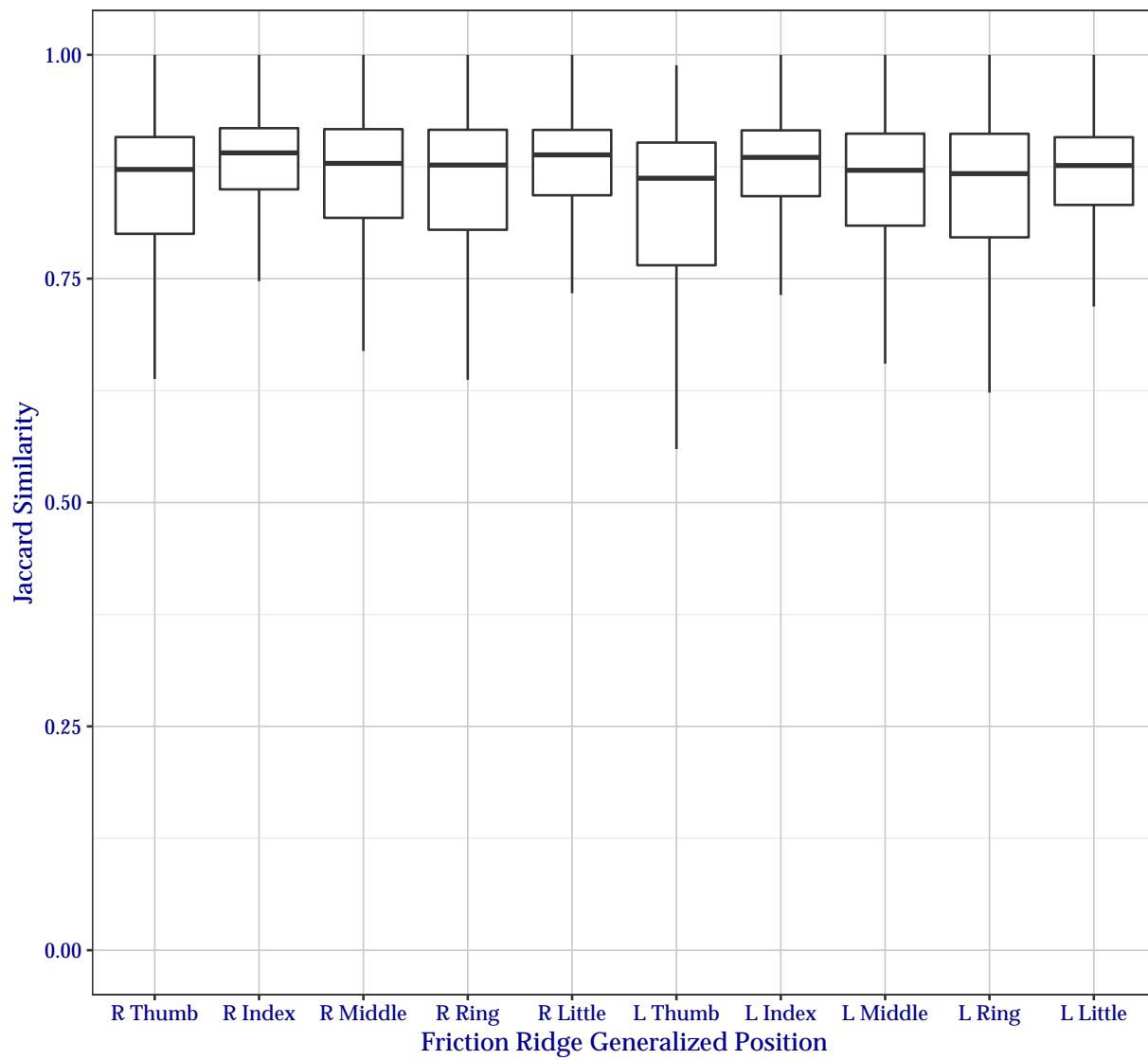


Figure 15: Boxplot of Jaccard similarity indices as compared to the traditional success metrics. Outliers have been removed for clarity.

## Jaccard Similarity by Friction Ridge Generalized Position

Participant: sequence/0002, Image Kind: Three Inch



05 June 2019, 02:53:51 PM EDT

Figure 16: Boxplot of Jaccard similarity indices for each friction ridge generalized position. Outliers have been removed for clarity.

Table 46: Percentage of segmentation obtaining a Jaccard index in the indicated ranges, by hand, for combinations of all ten fingers of a ThreeInch slap.

| Fingers        | $\geq 0.5$ | $\geq 0.6$ | $\geq 0.7$ | $\geq 0.8$ | $\geq 0.9$ | $\geq 0.95$ | $\geq 0.98$ |
|----------------|------------|------------|------------|------------|------------|-------------|-------------|
| <b>Right</b>   |            |            |            |            |            |             |             |
| Any            | 99.9       | 99.9       | 99.7       | 98.5       | 82.4       | 19.1        | 0.8         |
| At Least Two   | 98.4       | 98.3       | 97.8       | 93.8       | 56.8       | 2.4         | 0.0         |
| At Least Three | 98.4       | 98.1       | 96.2       | 86.8       | 31.6       | 0.2         | 0.0         |
| At Least Four  | 98.0       | 96.6       | 90.9       | 72.7       | 11.5       | 0.0         | 0.0         |
| All Five       | 92.3       | 86.1       | 69.9       | 43.8       | 2.1        | 0.0         | 0.0         |
| <b>Left</b>    |            |            |            |            |            |             |             |
| Any            | 99.9       | 99.8       | 99.7       | 98.5       | 76.9       | 15.0        | 0.6         |
| At Least Two   | 98.4       | 98.3       | 97.6       | 93.5       | 48.8       | 1.7         | 0.0         |
| At Least Three | 98.3       | 97.7       | 95.5       | 85.0       | 24.4       | 0.1         | 0.0         |
| At Least Four  | 97.7       | 95.9       | 89.3       | 68.6       | 8.1        | 0.0         | 0.0         |
| All Five       | 91.7       | 84.2       | 66.2       | 38.1       | 1.3        | 0.0         | 0.0         |

Table 47: 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                | $\geq 0.5$ | $\geq 0.6$ | $\geq 0.7$ | $\geq 0.8$ | $\geq 0.9$ | $\geq 0.95$ | $\geq 0.98$ |
|------------------------|------------|------------|------------|------------|------------|-------------|-------------|
| <b>Right</b>           |            |            |            |            |            |             |             |
| Either Index or Middle | 99.8       | 99.7       | 98.7       | 92.8       | 59.2       | 8.8         | 0.3         |
| Both Index and Middle  | 99.2       | 97.7       | 92.1       | 74.1       | 20.3       | 0.4         | 0.0         |
| <b>Left</b>            |            |            |            |            |            |             |             |
| Either Index or Middle | 99.8       | 99.5       | 98.3       | 92.8       | 53.9       | 7.2         | 0.3         |
| Both Index and Middle  | 99.0       | 97.2       | 90.7       | 71.1       | 17.8       | 0.3         | 0           |

Table 48: 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      | $\geq 0.5$ | $\geq 0.6$ | $\geq 0.7$ | $\geq 0.8$ | $\geq 0.9$ | $\geq 0.95$ | $\geq 0.98$ |
|--------------|------------|------------|------------|------------|------------|-------------|-------------|
| <b>Right</b> |            |            |            |            |            |             |             |
| Any          | 99.9       | 99.8       | 99.2       | 94.9       | 67.9       | 12.7        | 0.5         |
| At Least Two | 99.7       | 99.2       | 96.5       | 85.0       | 36.7       | 1.1         | 0.0         |
| All Three    | 98.7       | 95.7       | 86.2       | 62.9       | 11.4       | 0.1         | 0.0         |
| <b>Left</b>  |            |            |            |            |            |             |             |
| Any          | 99.9       | 99.7       | 98.9       | 95.1       | 63.0       | 10.6        | 0.5         |
| At Least Two | 99.6       | 98.8       | 95.7       | 83.6       | 31.6       | 0.9         | 0           |
| All Three    | 98.3       | 94.8       | 84.5       | 59.2       | 9.3        | 0.0         | 0           |