

rankone+0001

Rank One Computing

Slap Fingerprint Segmentation Evaluation III

Last Updated: 05 July 2023

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1 Participation Information

1.1 Names and Dates

- **Organization Name:** Rank One Computing
- **SlapSeg III Identifier:** rankone+0001
- **SlapSeg III API Version:** 1.2.0
- **Provided Marketing Name:** “ROC SDK v2.5.0”
- **Application Date:** 30 May 2023
- **First Submission Date:** 22 June 2023 (as version 0001)
- **Validation Date:** 03 July 2023
- **Completion Date:** 05 July 2023

1.2 Libraries

Filename	MD5 Checksum	Size
libicutu.so.66	e52a996730797512d6bdbda16e38b111	220 kB
libpftiii_rankone_0001.so	3f7d9c40d6452e03daae2ffbb22f64d7	31 kB
libicuuc.so.66	847a1dc2d266d158449beb5b4229ba45	2 MB
libicuio.so.66	d8b76e7ef55aa79a367725beeb1e82a9	60 kB
libQt5Concurrent.so.5.14	47ce700bc77c3e88816b4dc51327a65c	31 kB
libicudata.so.66	2236674edbe8efc94f2f681a6e373cdb	28 MB
libicui18n.so.66	053f6f9d58e59a75509e4bf5e2c21f96	3 MB
libicutest.so.66	b5e76b46ddafa3671ac90bbe8fa8d240	82 kB
libQt5Core.so.5	56beb55e6c63caf0b622281eb7efca2e	7 MB
libroc.so.2.5	d7be6ba0569ead8cccca7adb959ed29	101 MB
libQt5Concurrent.so.5.14.2	47ce700bc77c3e88816b4dc51327a65c	31 kB
libroc.so.2.5.0	d7be6ba0569ead8cccca7adb959ed29	101 MB
libQt5Core.so	56beb55e6c63caf0b622281eb7efca2e	7 MB
libQt5Network.so.5	04318595fd24ee8a5c1b0d4eb5aeee838	2 MB
libslapsegiii_rankone_0001.so	b4d578a8c7a08ada11c05218c80a7f4e	56 kB
libQt5Network.so.5.14	04318595fd24ee8a5c1b0d4eb5aeee838	2 MB
libicutu.so.66.1	e52a996730797512d6bdbda16e38b111	220 kB
libicudata.so.66.1	2236674edbe8efc94f2f681a6e373cdb	28 MB
libQt5Network.so	04318595fd24ee8a5c1b0d4eb5aeee838	2 MB
libQt5Core.so.5.14	56beb55e6c63caf0b622281eb7efca2e	7 MB
libQt5Core.so.5.14.2	56beb55e6c63caf0b622281eb7efca2e	7 MB
libQt5Concurrent.so.5	47ce700bc77c3e88816b4dc51327a65c	31 kB
libicuuc.so.66.1	847a1dc2d266d158449beb5b4229ba45	2 MB
libicutest.so.66.1	b5e76b46ddafa3671ac90bbe8fa8d240	82 kB
libicui18n.so.66.1	053f6f9d58e59a75509e4bf5e2c21f96	3 MB
libQt5Network.so.5.14.2	04318595fd24ee8a5c1b0d4eb5aeee838	2 MB
libroc.so	d7be6ba0569ead8cccca7adb959ed29	101 MB
libicuio.so.66.1	d8b76e7ef55aa79a367725beeb1e82a9	60 kB
libQt5Concurrent.so	47ce700bc77c3e88816b4dc51327a65c	31 kB
libroc_fingerprint_representation.so	e0f96bc08e9975c874fcfc87012468f8	77 MB
ROC.lic	9b52c2cd781a775314a214ad1d03e922	586 B
libroc_fingerprint_representation.so.2.5	e0f96bc08e9975c874fcfc87012468f8	77 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.

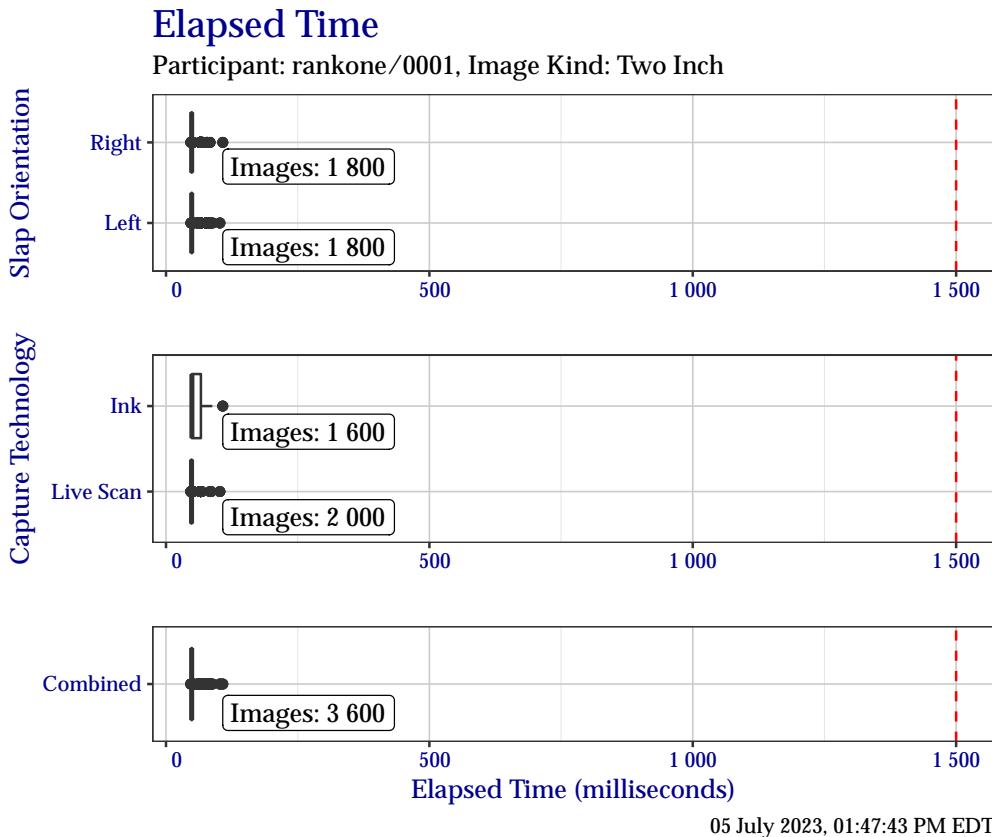


Figure 1: Box plots of elapsed time in milliseconds when segmenting the TwoInch timing test corpus, separated by slap orientation and capture technology.

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	47	47	47	48	47
25%	48	48	48	49	48
Median	49	49	48	49	49
75%	49	49	49	66	49
Maximum	108	102	102	108	108

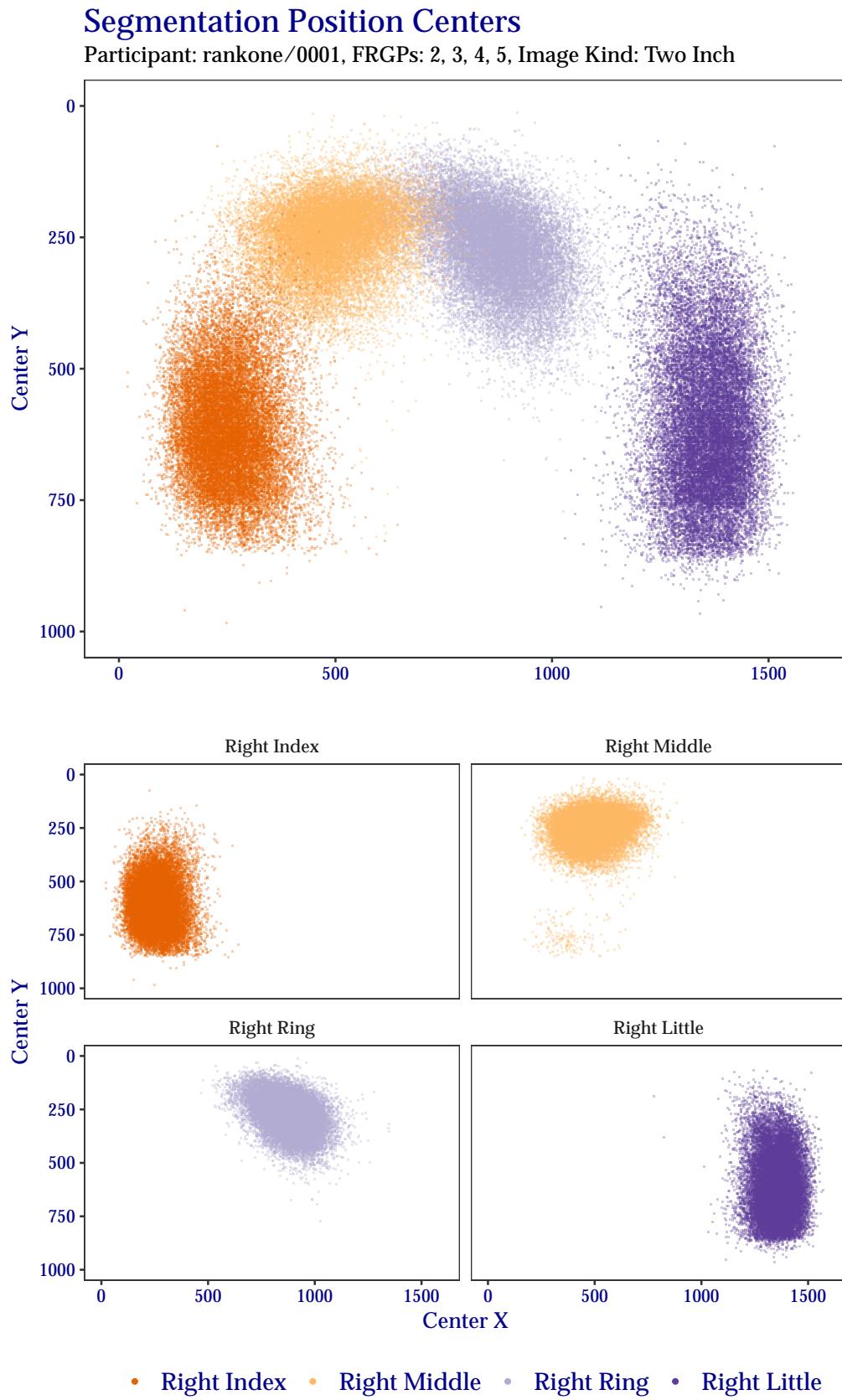
2.2 Segmentation Centers and Dimensions

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.



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Figure 2: Segmentation centers for right hand TwoInch data.

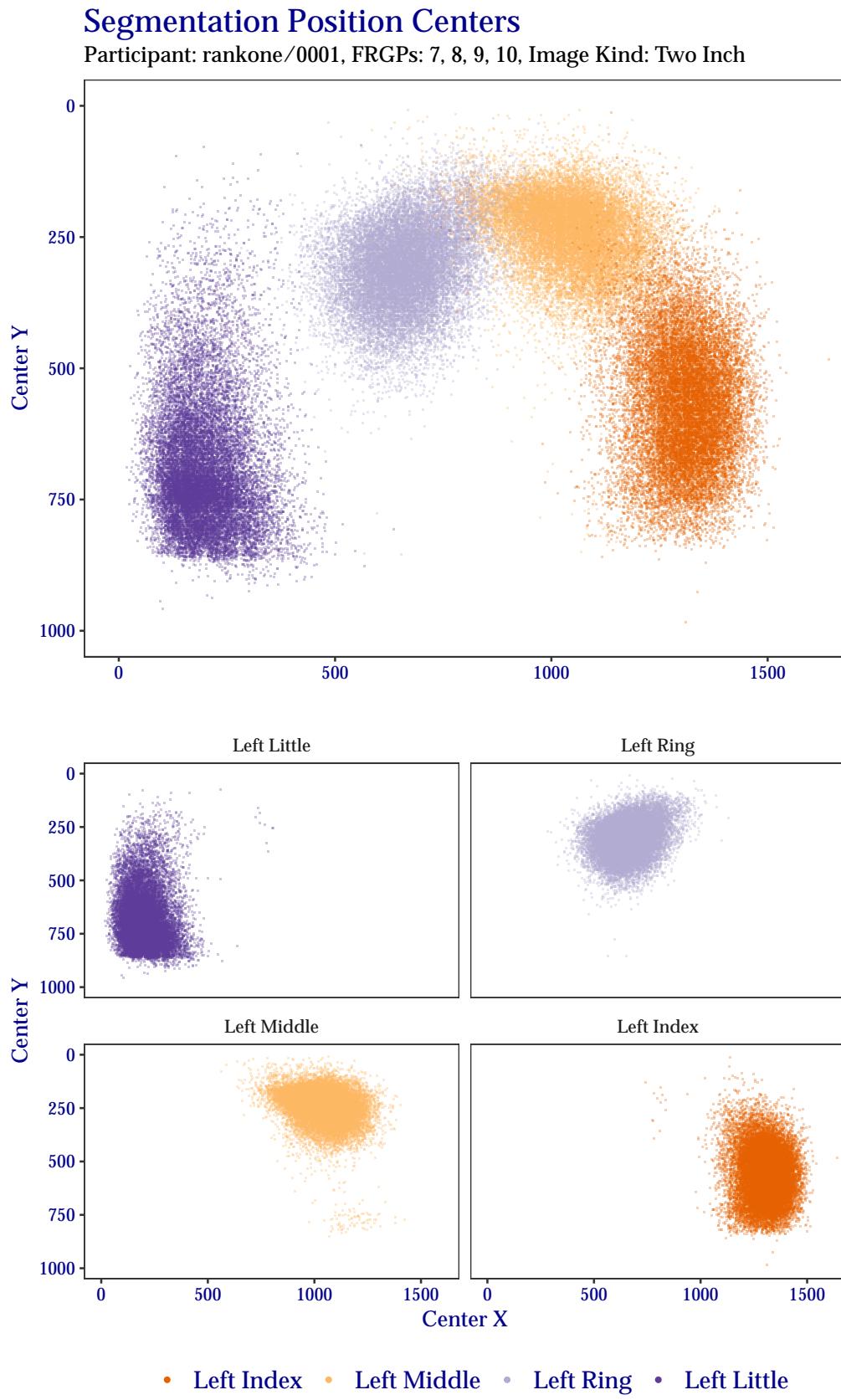


Figure 3: Segmentation centers for left hand TwoInch data.

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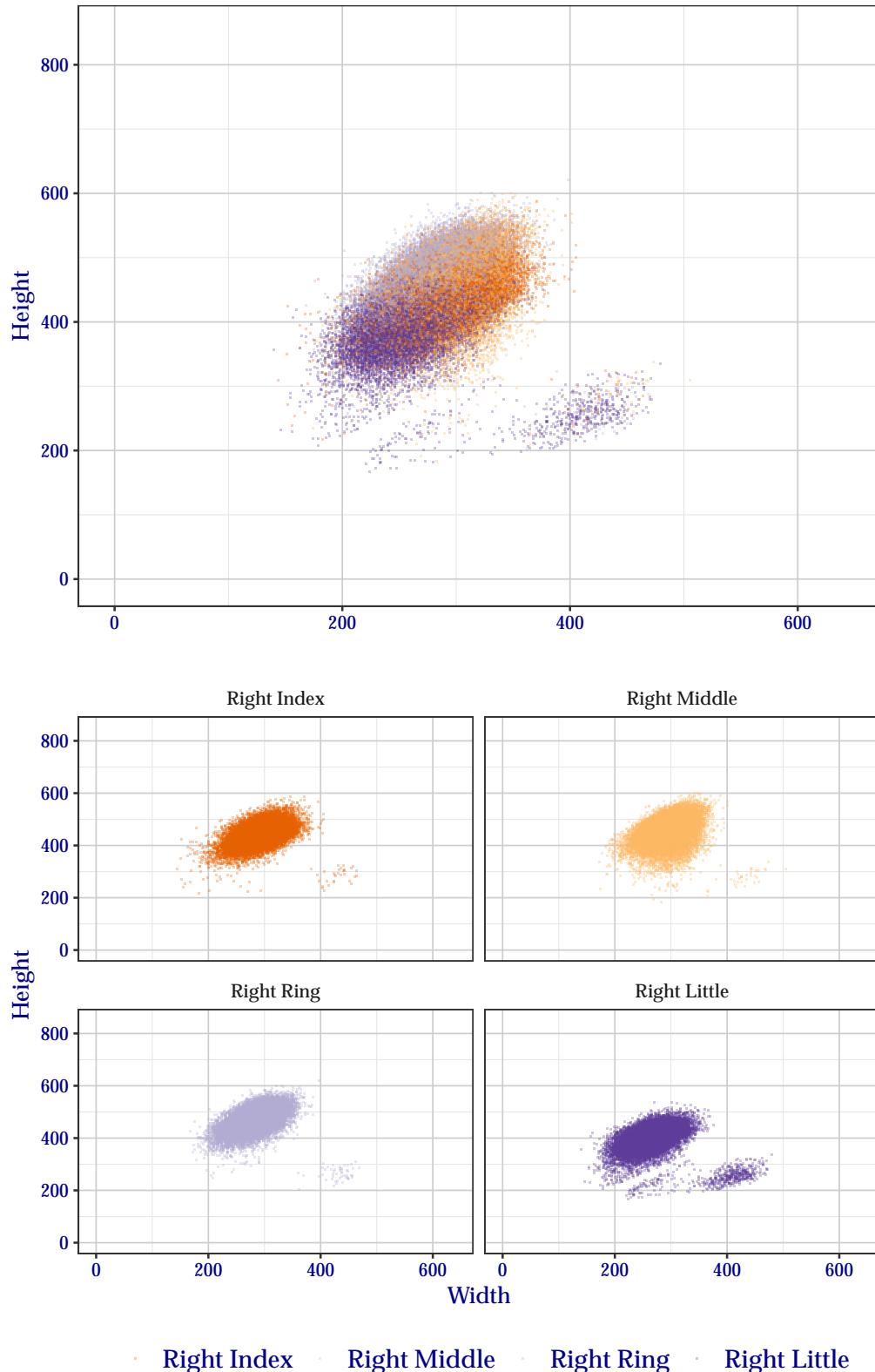
2.2.2 Segmentation Dimensions

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.

Segmentation Position Dimensions

Participant: rankone/0001, FRGPs: 2, 3, 4, 5, Image Kind: Two Inch

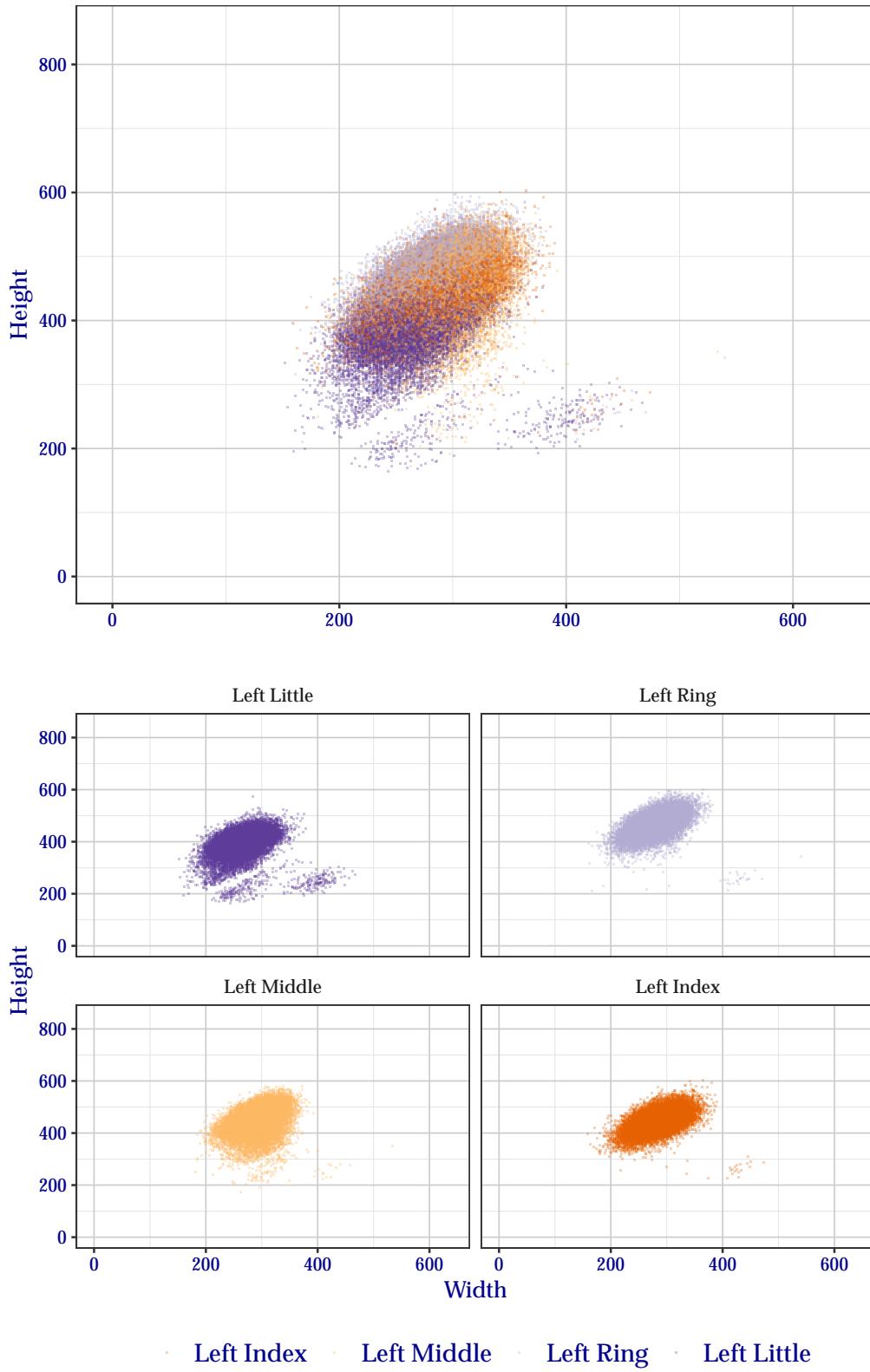


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Figure 4: Segmentation position dimensions for right hand TwoInch data.

Segmentation Position Dimensions

Participant: rankone/0001, 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 rankone+0001 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	99.6	99.6	99.6
2	99.3	99.3	99.5
3	98.8	98.8	99.2
4	97.3	97.6	98.1
5	91.2	91.4	92.3
6	89.1	89.8	90.9
7	84.7	86.4	87.9
8	70.3	75.8	77.8

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	90.5	93.4	94.0
Middle	92.2	92.9	93.7
Ring	92.0	92.7	93.6
Little	91.5	92.7	94.6
Left			
Index	95.7	96.6	96.9
Middle	94.6	95.5	95.8
Ring	95.6	96.5	97.1
Little	94.9	95.5	96.4

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
Index			
Either	98.4	98.7	99.0
Both	83.5	86.9	87.5
Middle			
Either	98.4	98.6	98.8
Both	84.4	85.6	86.5
Ring			
Either	98.6	98.8	99.1
Both	85.2	86.6	87.9
Little			
Either	98.3	98.5	98.8
Both	83.5	85.1	87.5

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	96.6	96.7	97.3
At Least Two	95.3	95.6	96.4
At Least Three	92.7	93.5	94.7
All Four	81.6	85.9	87.6
Left			
Any	98.5	98.6	98.7
At Least Two	97.7	97.8	98.2
At Least Three	96.2	96.6	97.2
All Four	88.4	91.1	92.1

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	95.4	95.7	96.3
Both Index and Middle	87.3	90.5	91.4
Left			
Either Index or Middle	97.6	97.8	98.0
Both Index and Middle	92.7	94.2	94.7

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	96.2	96.4	96.9
At Least Two	93.9	94.5	95.2
All Three	84.6	88.1	89.2
Left			
Any	98.3	98.4	98.6
At Least Two	96.8	97.1	97.5
All Three	90.8	93.0	93.7

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.

rankone+0001 did **not** report any capture failures.

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.

rankone+0001 did not attempt any recovery segmentations.

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 rankone+0001 are enumerated in Table 8.

Table 8: Count of self-reported segmentation failure reasoning.

Failure Reason	Fingers
Finger Not Found	331
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 9 shows how successful rankone+0001 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 9: Performance of rankone+0001 at detecting fingers missing from an image.

Result	Percentage
Missed	25.0
Correctly Identified	75.0
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 10 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 10: 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	0.36	0.37	0.41
Right	0.18	0.19	0.24
Combined	0.26	0.27	0.32

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: 98.7%

Table 11: 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	Skip
Left	99.2	0.8	0
Right	1.8	98.2	0

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 12. Results are reported in milliseconds

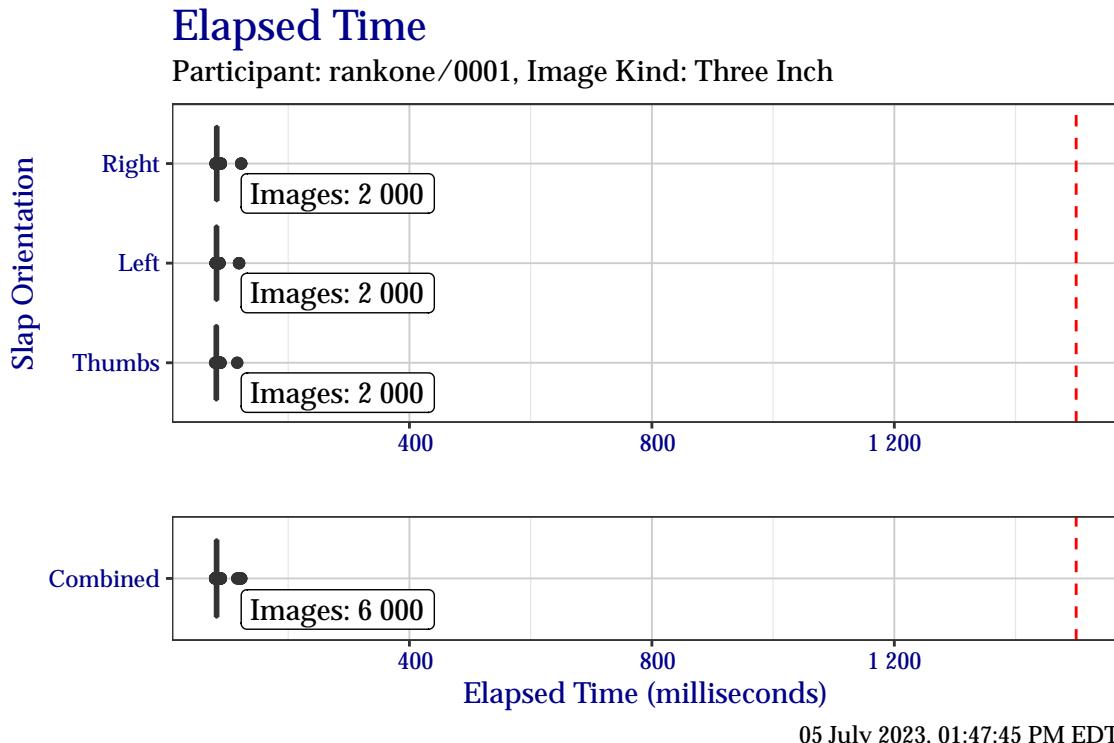


Figure 6: Box plots of elapsed time in milliseconds when segmenting the ThreeInch timing test corpus, separated by slap orientation.

Table 12: Elapsed time in milliseconds when segmenting the ThreeInch timing test corpus, separated by slap orientation.

	Right	Left	Thumbs	Combined
Minimum	80	80	79	79
25%	82	81	81	81
Median	82	82	81	82
75%	82	82	82	82
Maximum	122	119	116	122

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.

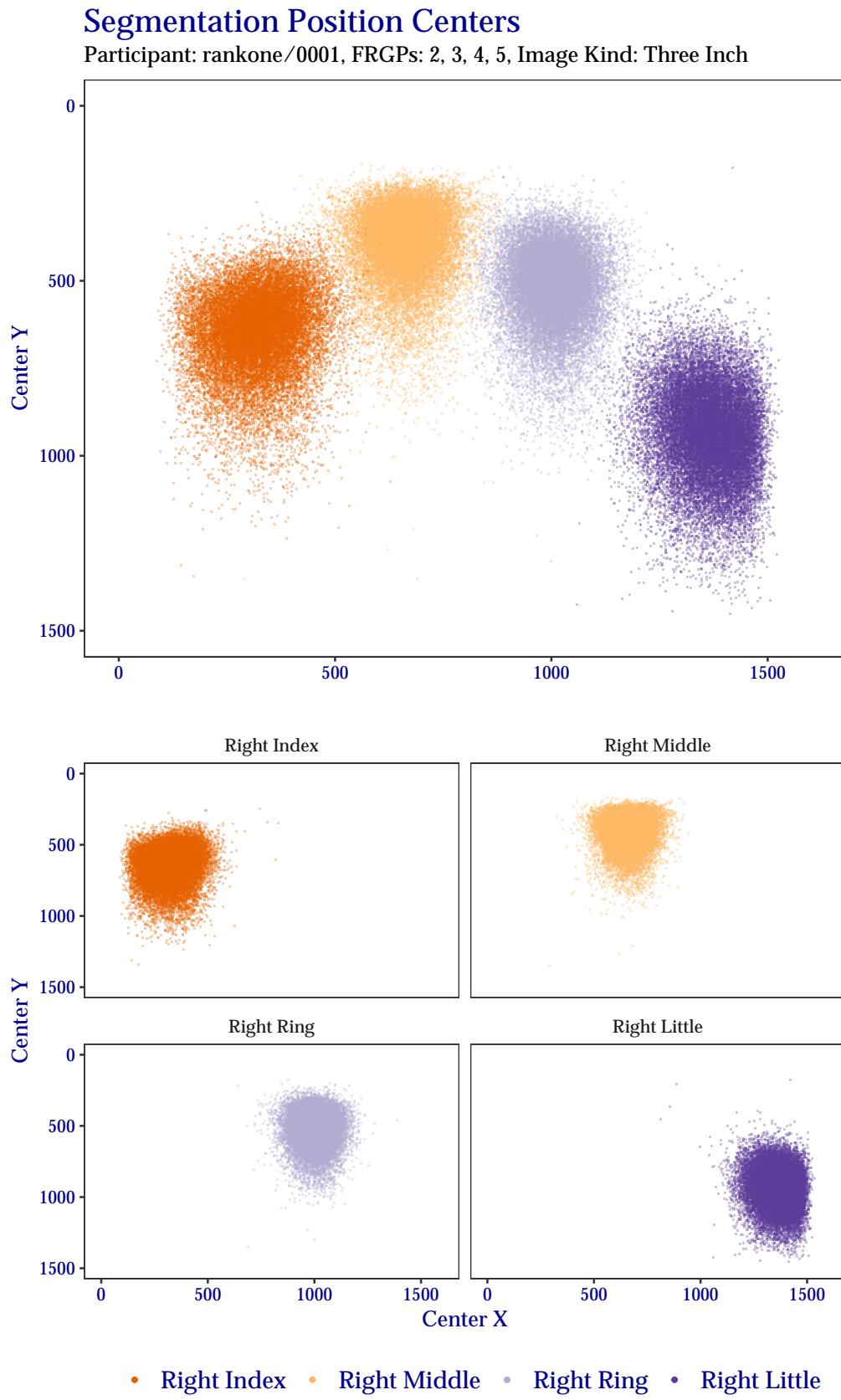


Figure 7: Segmentation centers for right hand ThreeInch data.

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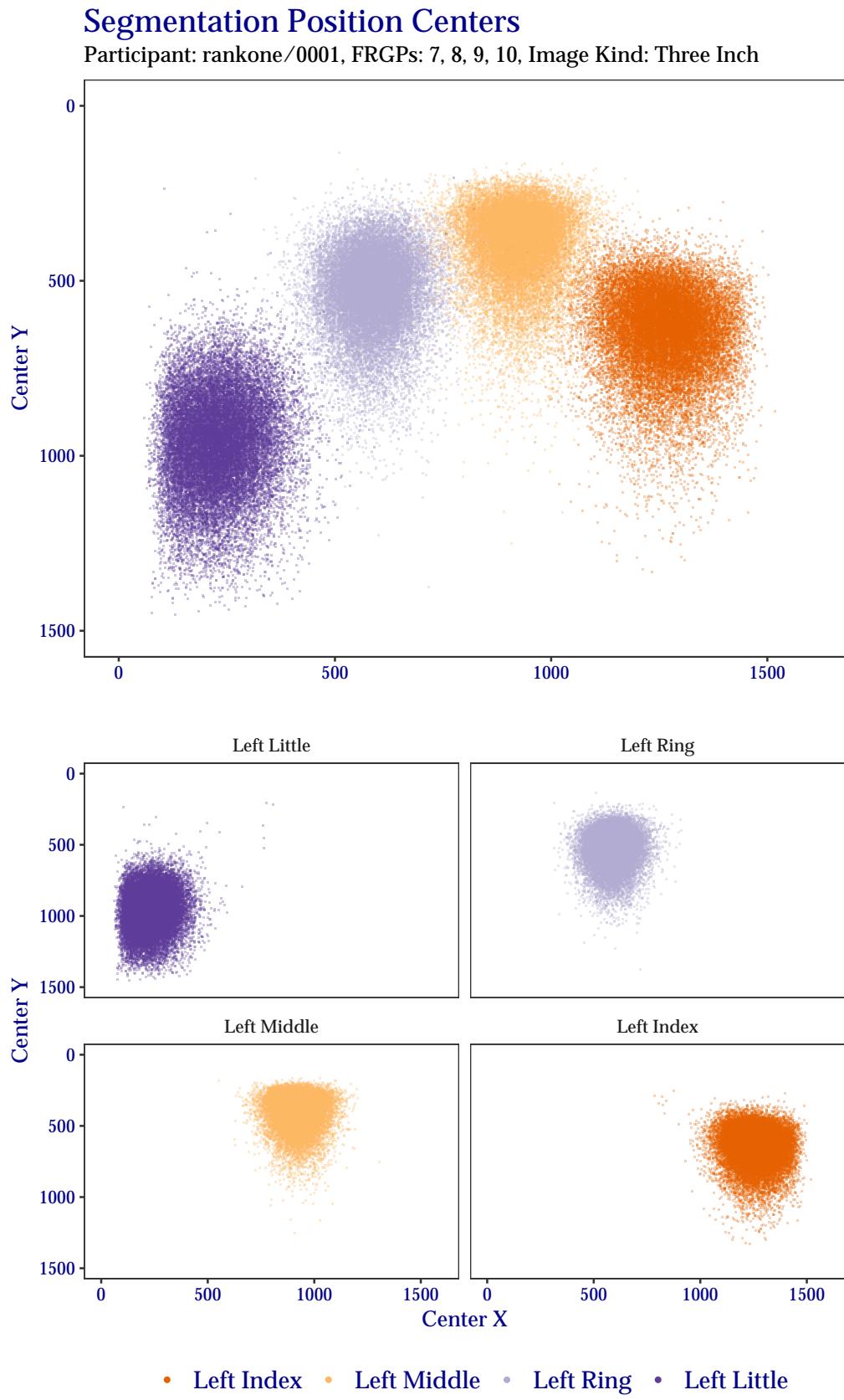
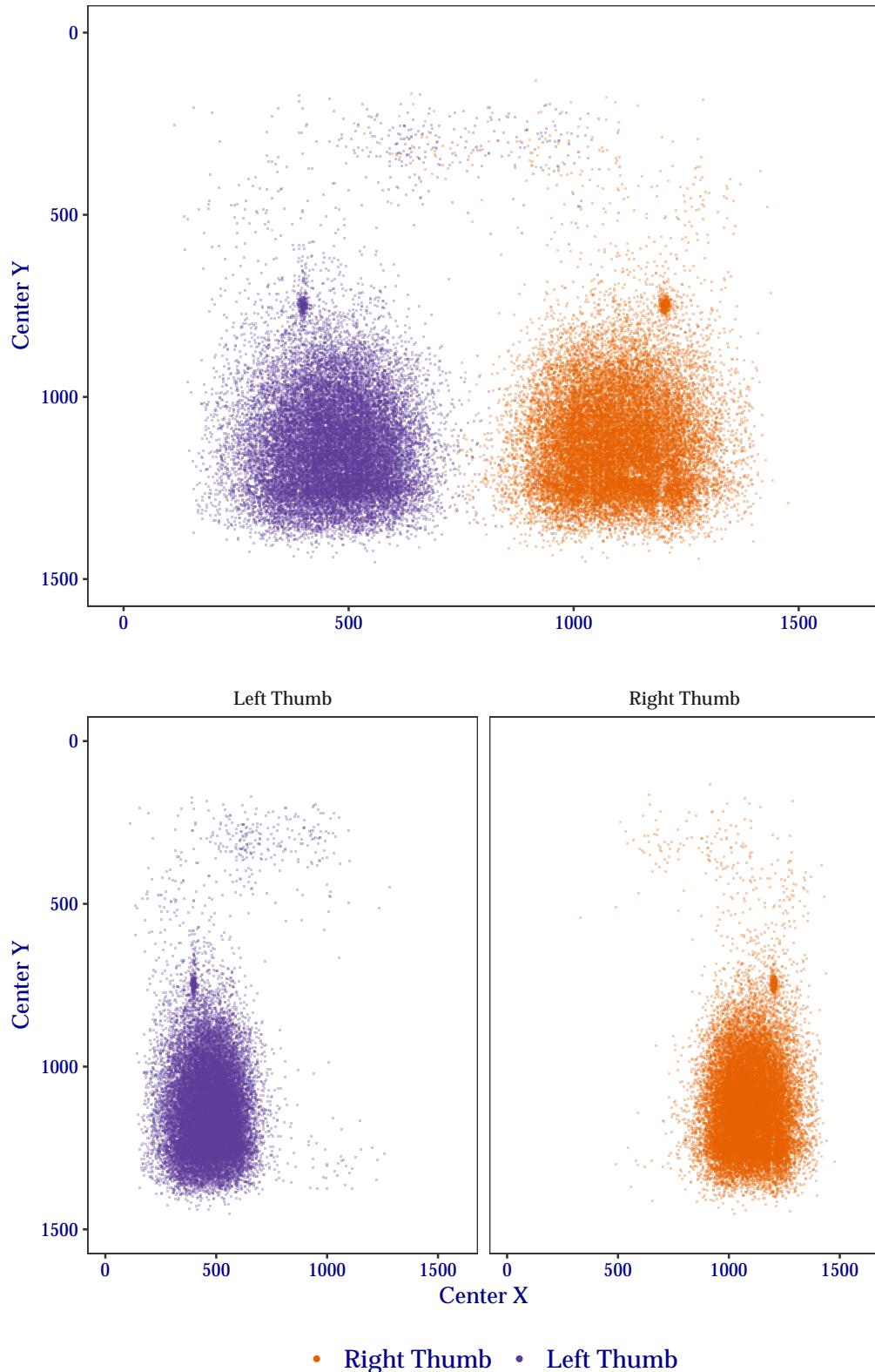


Figure 8: Segmentation centers for left hand ThreeInch data.

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Segmentation Position Centers

Participant: rankone/0001, FRGPs: 1, 6, Image Kind: Three Inch



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Figure 9: Segmentation centers for thumb ThreeInch data.

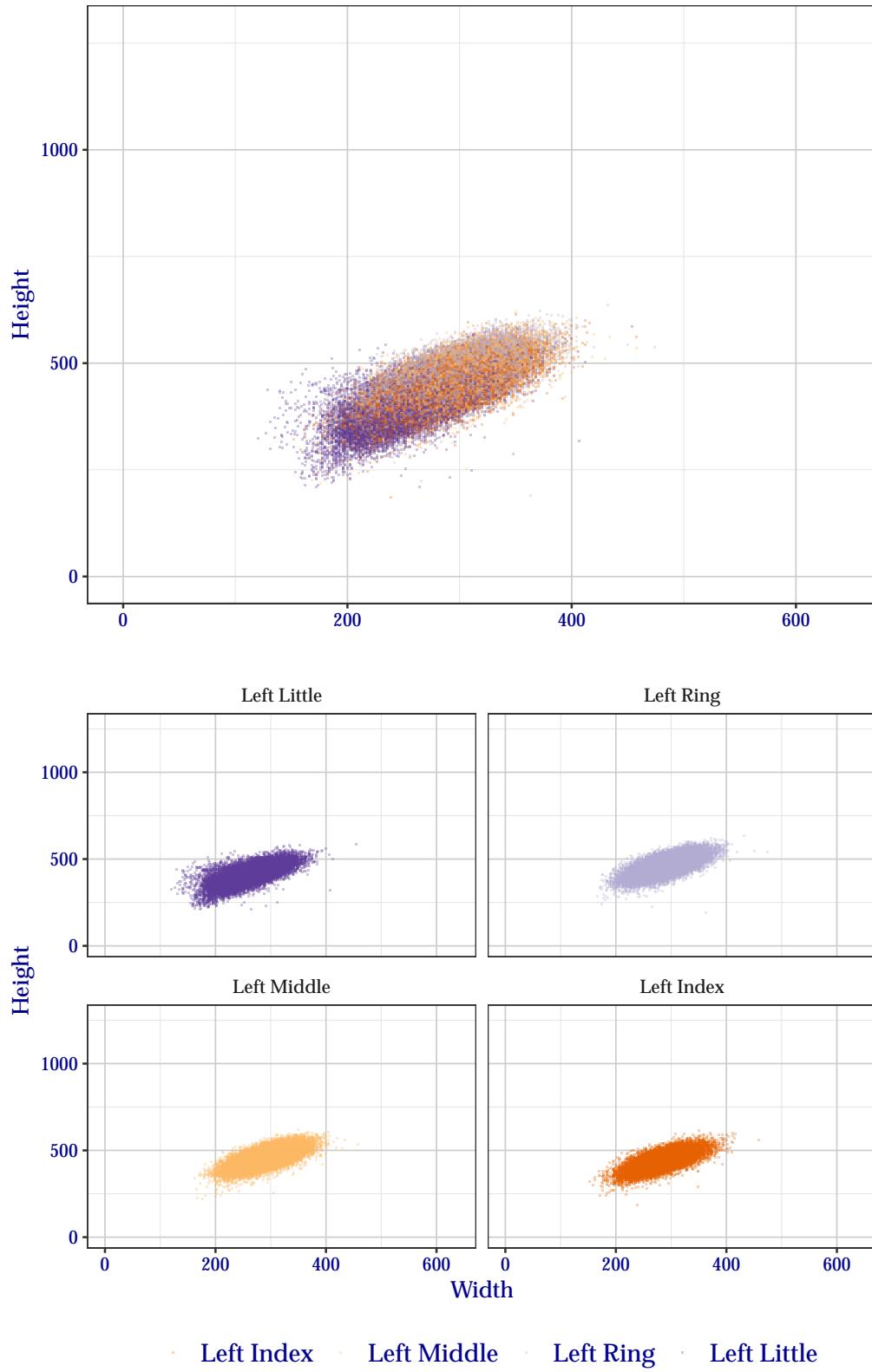
3.2.2 Segmentation Dimensions

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. Dimensions have been normalized to 500 pixels per inch.

Segmentation Position Dimensions

Participant: rankone/0001, FRGPs: 7, 8, 9, 10, Image Kind: Three Inch

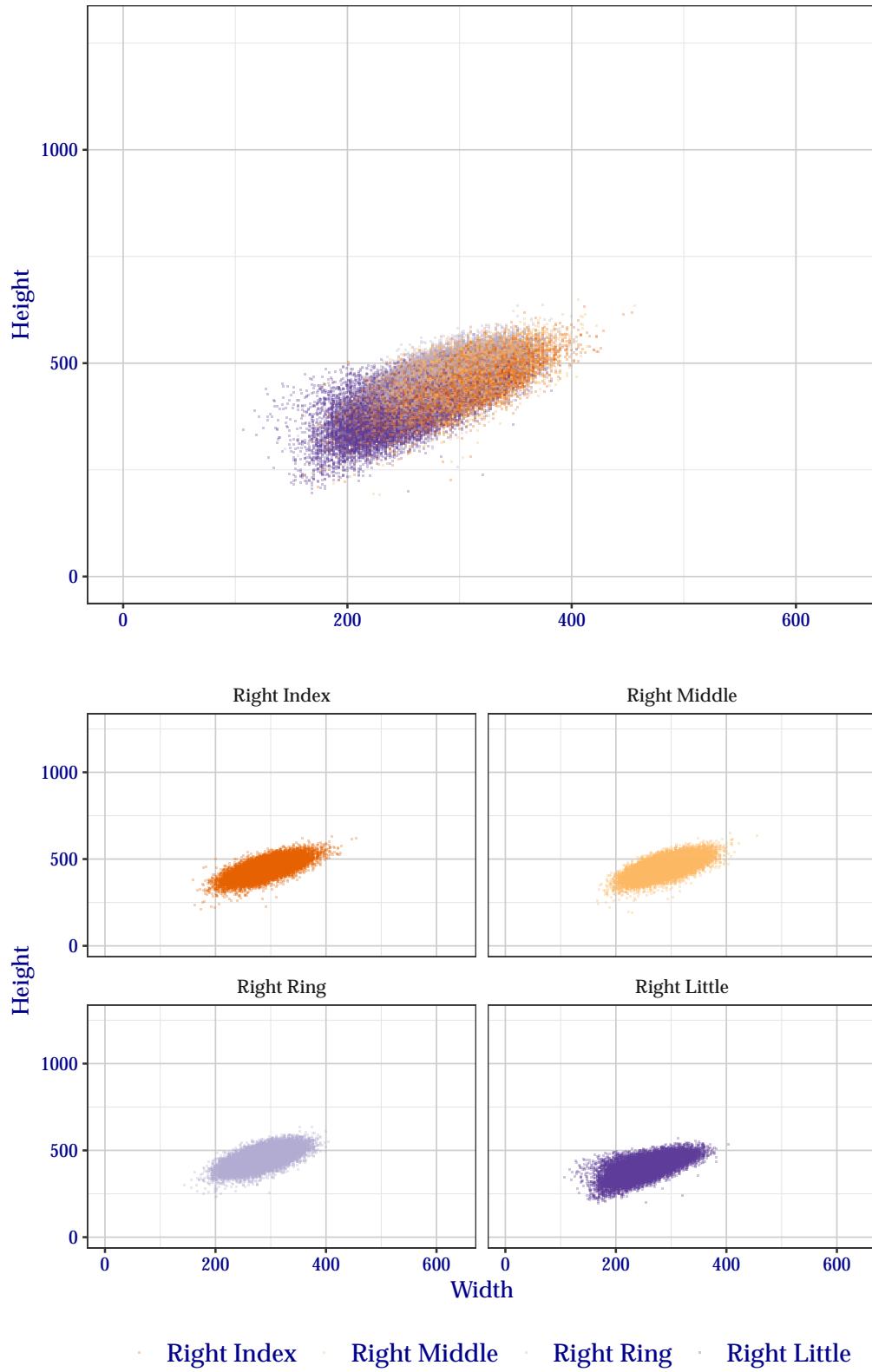


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Figure 10: Segmentation position dimensions for left hand ThreeInch data.

Segmentation Position Dimensions

Participant: rankone/0001, 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: rankone/0001, FRGPs: 1, 6, Image Kind: Three Inch

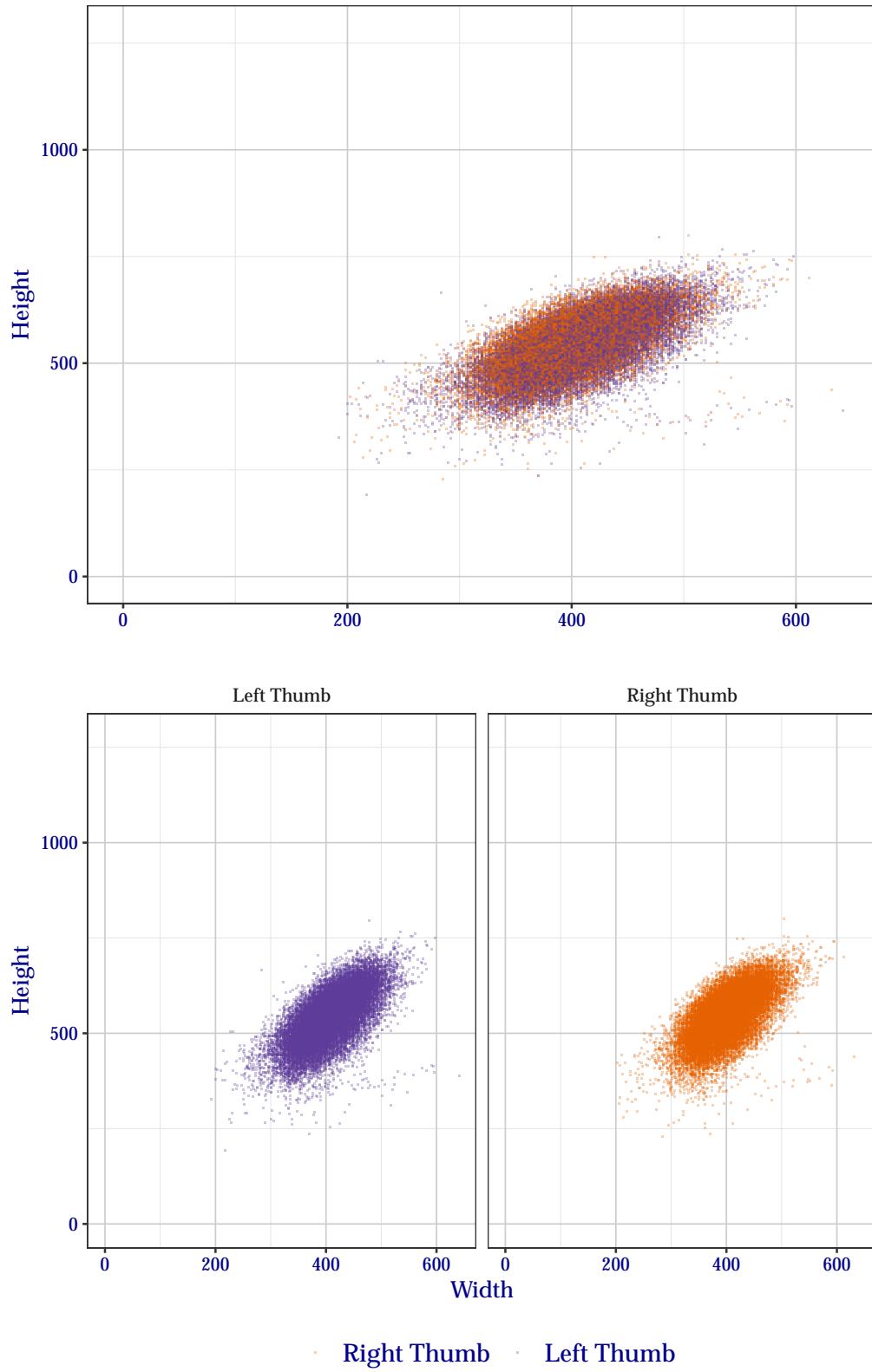


Figure 12: Segmentation position dimensions for thumb ThreeInch data.

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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 13 shows how successful rankone+0001 segmented fingers for each subject in the test corpus. Table 14 shows success for specific finger positions over the entire test corpus. Similarly, Table 15 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 16 shows success for combinations of all fingers, Table 17 for just the index and middle fingers, and Table 18 for all except the little finger.

Table 13: 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	99.6	99.6	99.6
3	98.5	98.5	98.5
4	98.2	98.3	98.3
5	95.9	95.9	95.9
6	95.9	95.9	95.9
7	95.9	95.9	95.9
8	95.7	95.7	95.8
9	94.2	94.5	94.8
10	85.7	87.0	89.5

Table 14: 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	96.5	97.0	97.5
Index	99.5	99.5	99.6
Middle	99.2	99.3	99.7
Ring	98.7	98.9	99.3
Little	99.0	99.1	99.1
Left			
Thumb	96.6	97.2	97.7
Index	99.2	99.2	99.3
Middle	99.0	99.1	99.5
Ring	99.2	99.3	99.7
Little	99.2	99.3	99.4

Table 15: 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	99.1	99.2	99.3
Both	94.0	95.1	96.0
Index			
Either	99.9	99.9	99.9
Both	96.1	96.2	96.4
Middle			
Either	99.8	99.8	99.9
Both	95.8	95.8	96.6
Ring			
Either	99.8	99.9	99.9
Both	95.3	95.6	96.4
Little			
Either	99.8	99.8	99.8
Both	95.9	95.9	96.0

Table 16: 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	99.7	99.7	99.7
At Least Two	98.5	98.5	98.5
At Least Three	98.4	98.4	98.4
At Least Four	97.9	98.0	98.1
All Five	89.3	90.0	91.4
Left			
Any	99.8	99.8	99.8
At Least Two	98.5	98.5	98.5
At Least Three	98.4	98.4	98.4
At Least Four	97.9	98.0	98.1
All Five	89.4	90.2	91.6

Table 17: 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	99.9	99.9	99.9
Both	98.8	98.9	99.4
Left			
Either	99.9	99.9	99.9
Both	98.3	98.4	99.0

Table 18: 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	99.8	99.8	99.8
All Three	97.7	97.9	98.8
Left			
Any	100.0	100.0	100.0
At Least Two	99.8	99.8	99.8
All Three	97.6	97.8	98.8

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.

rankone+0001 did **not** report any capture failures.

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.

rankone+0001 did not attempt any recovery segmentations.

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 rankone+0001 are enumerated in Table 19.

Table 19: Count of self-reported segmentation failure reasoning.

Failure Reason	Fingers
Finger Not Found	203
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 20 shows how successful rankone+0001 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 20: Performance of rankone+0001 at detecting fingers missing from an image.

Result	Percentage
Missed	48.9
Correctly Identified	51.1
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 21 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 21: 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	0.10	0.10	0.10
Right	0.10	0.10	0.10
Thumbs	0.23	0.23	0.23
Combined	0.14	0.14	0.14

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: 90.4%

Table 22: 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	99.7	0.3	0	0
Right	1	99	0	0
Thumbs	17.7	10.1	0.2	72

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 1500 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 23. Results are reported in milliseconds.

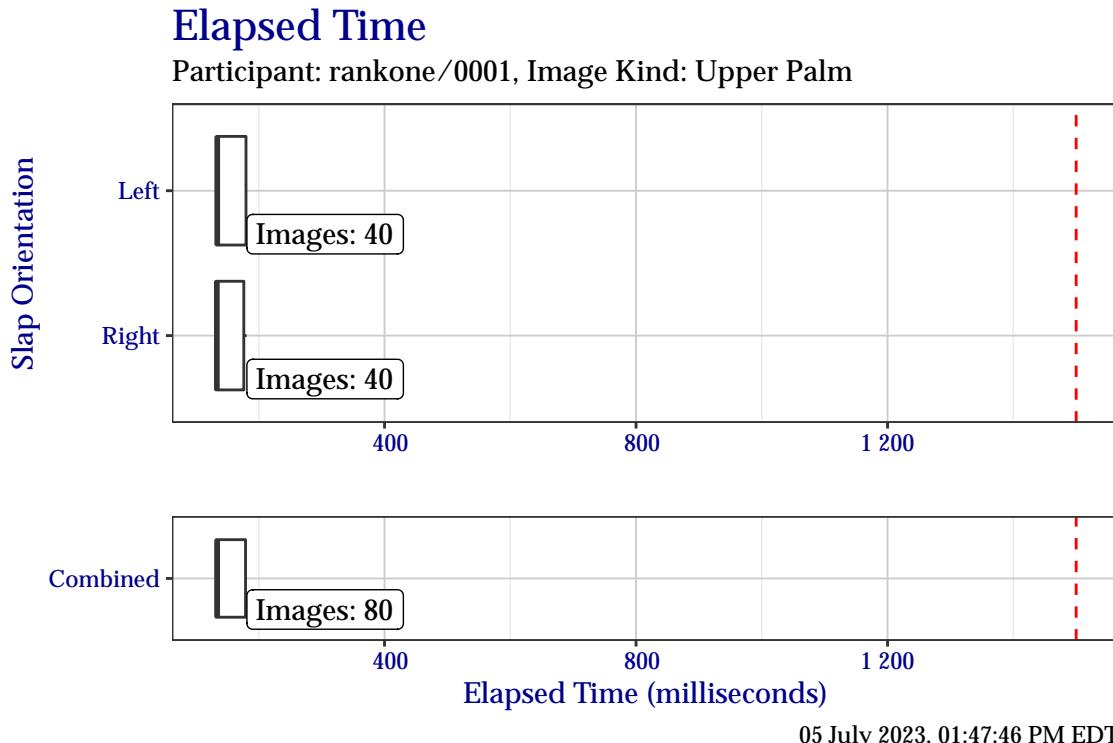


Figure 13: Box plots of elapsed time in milliseconds when segmenting the FiveInch timing test corpus, separated by slap orientation.

Table 23: Elapsed time in milliseconds when segmenting the FiveInch timing test corpus, separated by slap orientation.

	Right	Left	Combined
Minimum	131	131	131
25%	132	133	132
Median	133	134	134
75%	176	180	179
Maximum	181	181	181

4.2 Segmentation Centers and Dimensions

4.2.1 Segmentation Centers

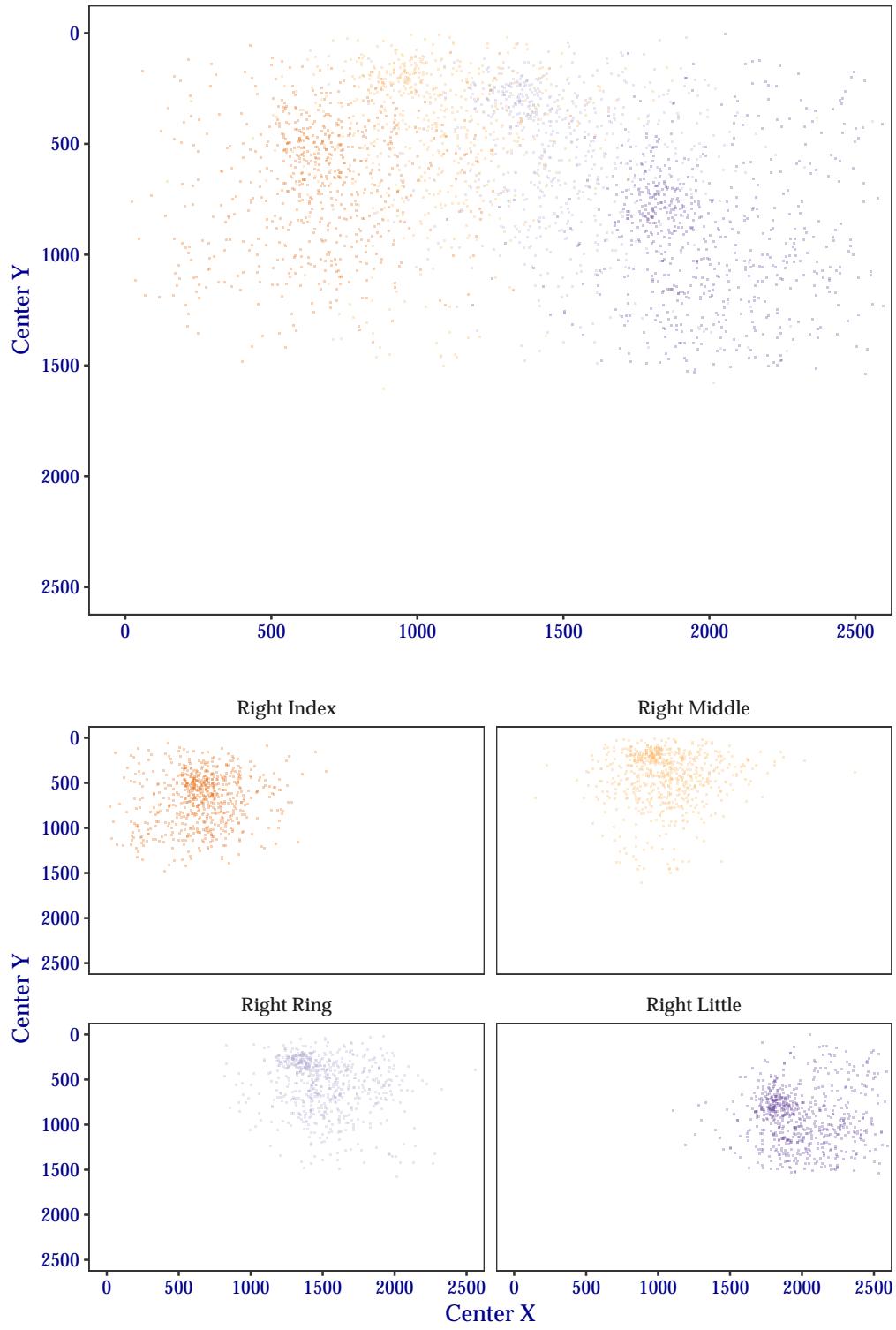
The plots in this section show the distribution of segmentation position centers (x, y) for FiveInch data. At the top of each figure is a combined plot for all finger positions of a given slap orientation. These figures are isolated in plots faceted at the bottom of the figure.

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.

Segmentation Position Centers

Participant: rankone/0001, FRGPs: 2, 3, 4, 5, Image Kind: Upper Palm



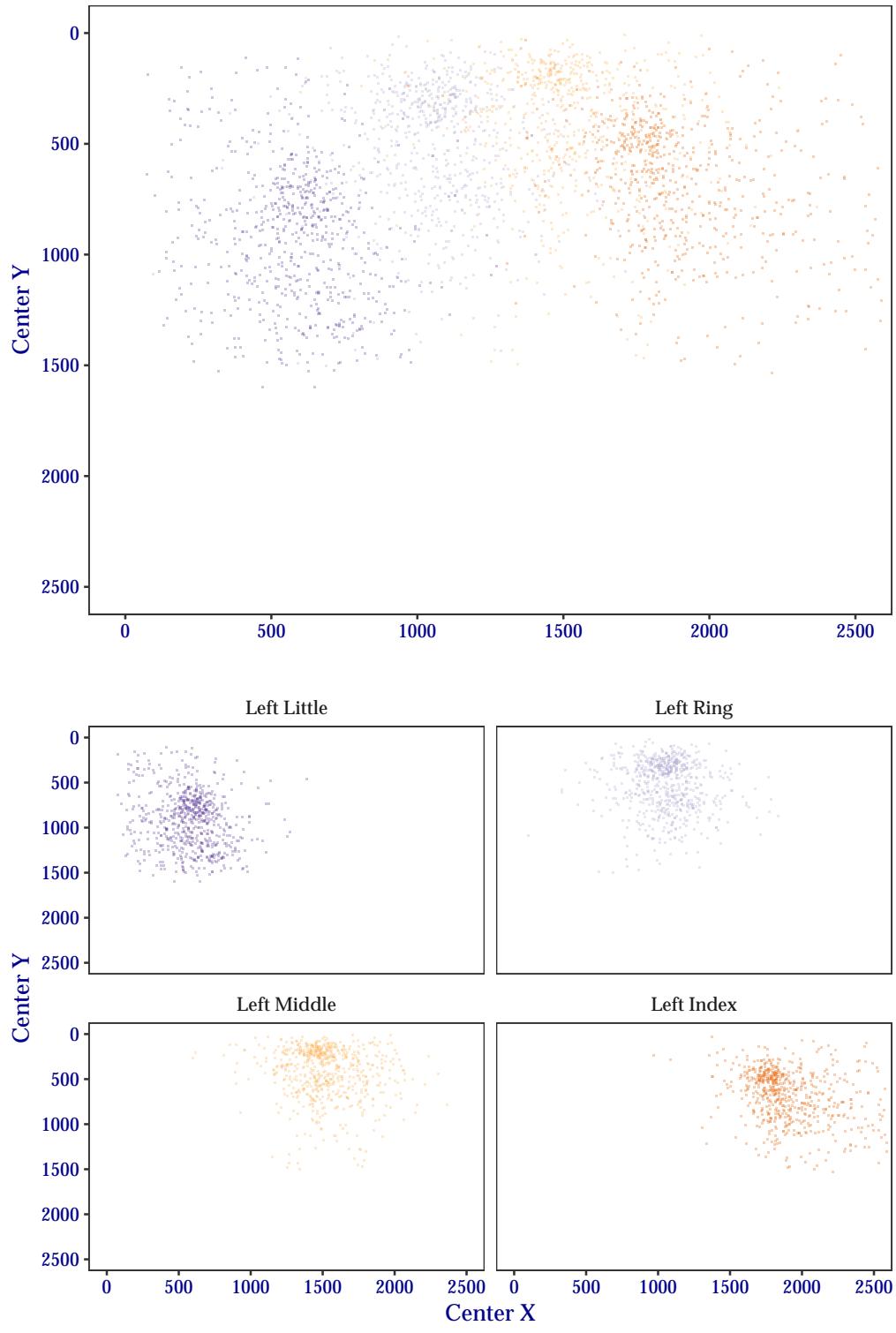
- Right Index • Right Middle • Right Ring • Right Little

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Figure 14: Segmentation centers for right hand FiveInch data.

Segmentation Position Centers

Participant: rankone/0001, FRGPs: 7, 8, 9, 10, Image Kind: Upper Palm



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

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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.

Segmentation Position Dimensions

Participant: rankone/0001, FRGPs: 2, 3, 4, 5, Image Kind: Upper Palm

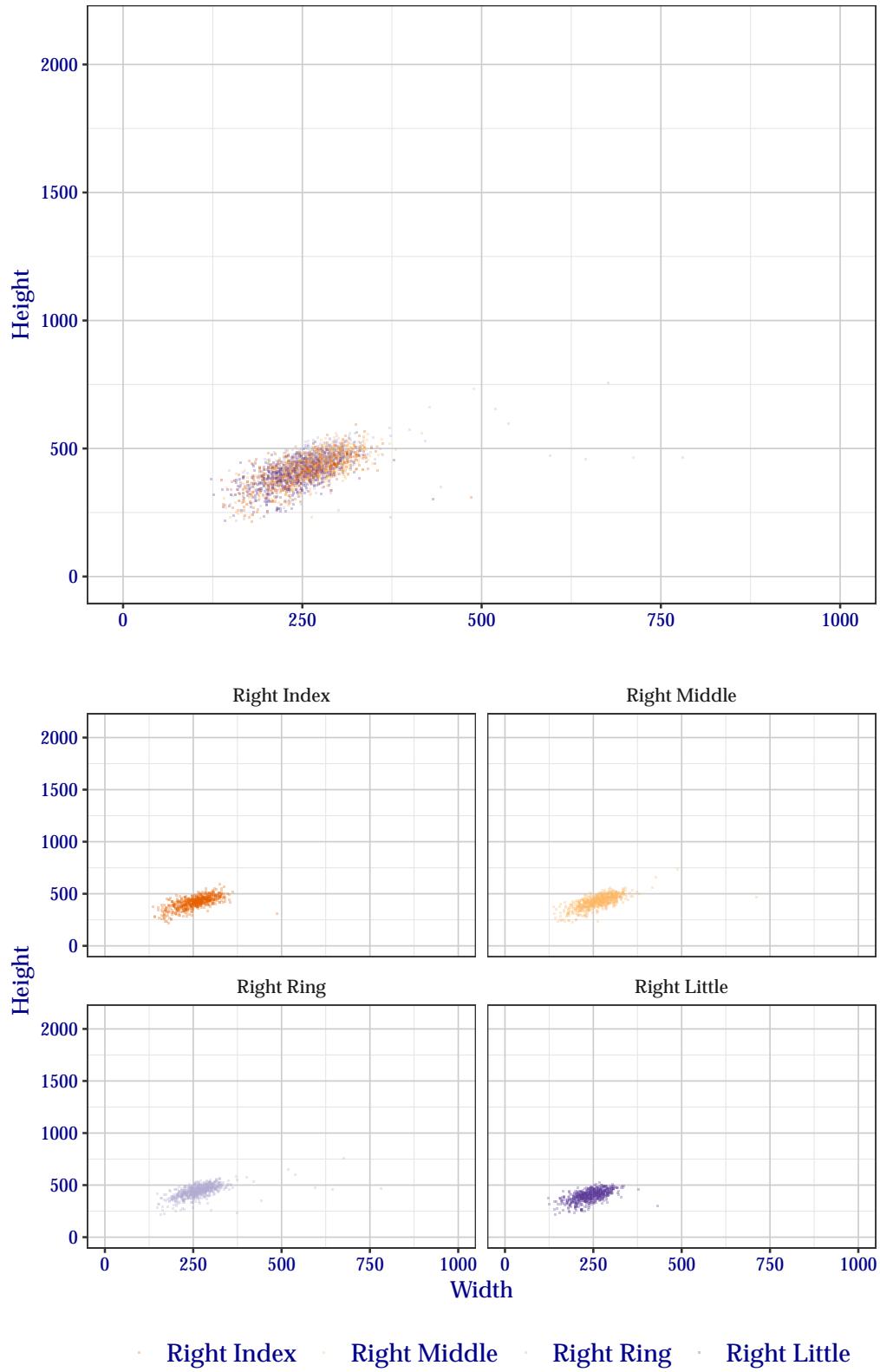
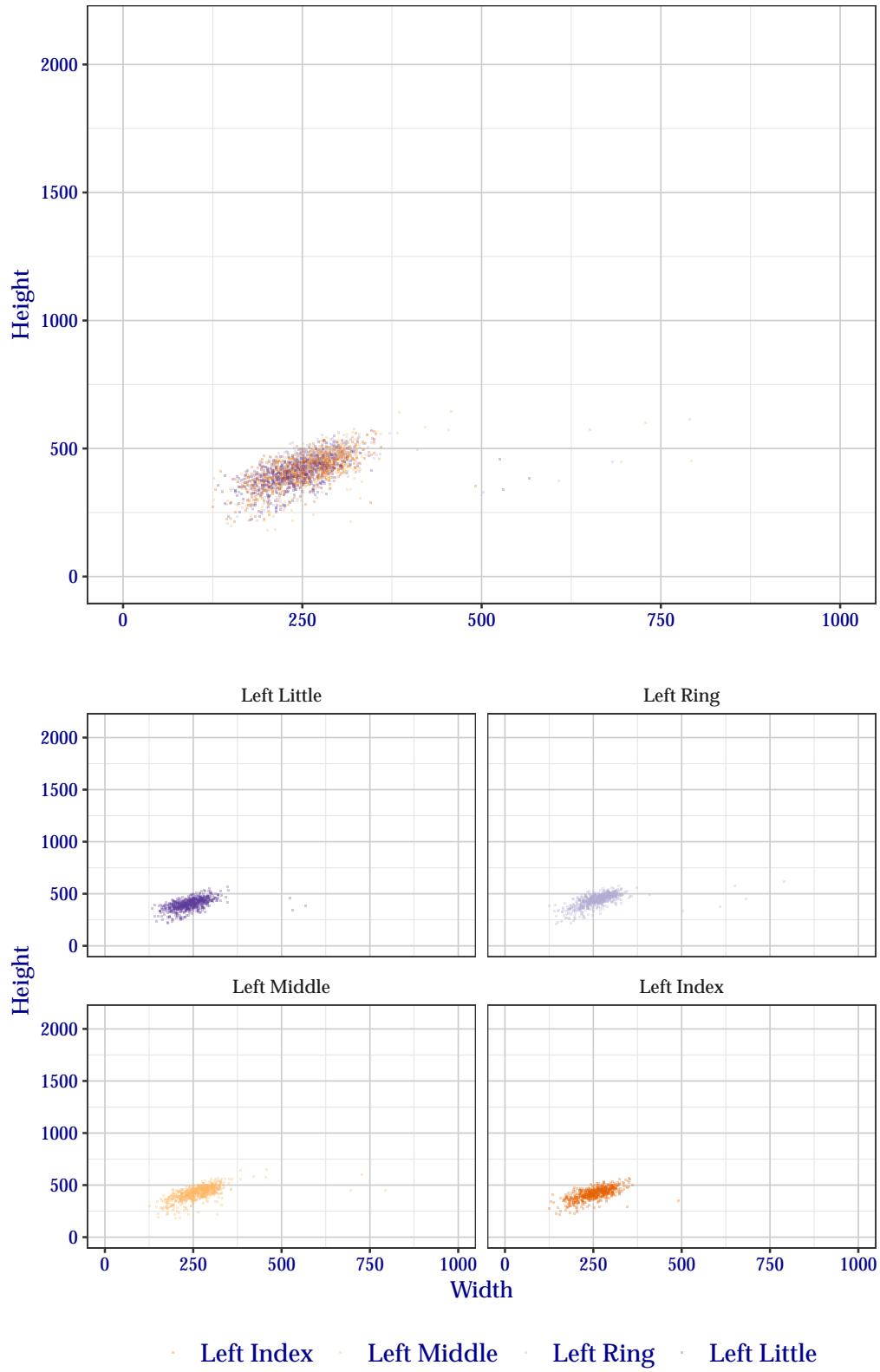


Figure 16: Segmentation position dimensions for right hand FiveInch data.

Segmentation Position Dimensions

Participant: rankone/0001, FRGPs: 7, 8, 9, 10, Image Kind: Upper Palm



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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 24 shows how successful rankone+0001 segmented fingers for each subject in the test corpus. Table 25 shows success for specific finger positions over the entire test corpus. Similarly, Table 26 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 27 shows success for combinations of all fingers, Table 28 for just the index and middle fingers, and Table 29 for all except the little finger.

Table 24: 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	99.1	99.6	99.6
2	97.8	98.4	98.7
3	96.2	96.4	96.8
4	92.6	93.7	93.8
5	85.5	86.4	86.8
6	77.7	78.9	80.0
7	63.0	64.6	65.9
8	41.2	45.2	47.4

Table 25: 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	85.2	85.8	85.8
Middle	78.1	78.6	79.3
Ring	86.2	87.4	87.6
Little	83.5	85.9	86.6
Left			
Index	82.4	83.6	84.0
Middle	78.0	78.5	79.0
Ring	86.7	87.8	89.0
Little	78.2	81.0	83.2

Table 26: 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	93.9	94.9	94.9
Both	72.3	73.1	73.5
Middle			
Either	91.2	91.8	92.1
Both	63.6	64.0	65.0
Ring			
Either	95.1	96.0	96.0
Both	76.4	77.7	79.2
Little			
Either	92.8	94.5	94.9
Both	67.7	71.1	73.5

Table 27: 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	96.3	96.7	96.7
At Least Two	91.4	91.8	91.9
At Least Three	81.9	82.6	82.7
All Four	63.4	66.6	68.0
Left			
Any	97.2	98.0	98.4
At Least Two	91.2	91.6	92.4
At Least Three	79.8	80.8	81.7
All Four	57.0	60.5	62.6

Table 28: 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	90.2	90.4	90.4
Both Index and Middle	73.1	73.9	74.6
Left			
Either Index or Middle	89.0	89.4	89.9
Both Index and Middle	71.4	72.7	73.1

Table 29: 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	94.8	95.2	95.2
At Least Two	85.6	86.2	86.3
All Three	69.0	70.3	71.1
Left			
Any	95.2	96.2	96.8
At Least Two	84.2	84.5	84.6
All Three	67.6	69.2	70.6

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.

rankone+0001 did **not** report any capture failures.

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.

rankone+0001 did not attempt any recovery segmentations.

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 rankone+0001 are enumerated in Table 30.

Table 30: Count of self-reported segmentation failure reasoning.

Failure Reason	Fingers
Finger Not Found	852
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 31 shows how successful rankone+0001 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 31: Performance of rankone+0001 at detecting fingers missing from an image.

Result	Percentage
Missed	33.3
Correctly Identified	66.7
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 32 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 32: 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	9.55	9.68	9.81
Right	9.97	10.11	10.11
Combined	9.76	9.89	9.96

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: 85.6%

Table 33: 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	Skip
Left	83.1	11.6	5.3
Right	4.1	88.1	7.8

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 1500 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 34. Results are reported in milliseconds.

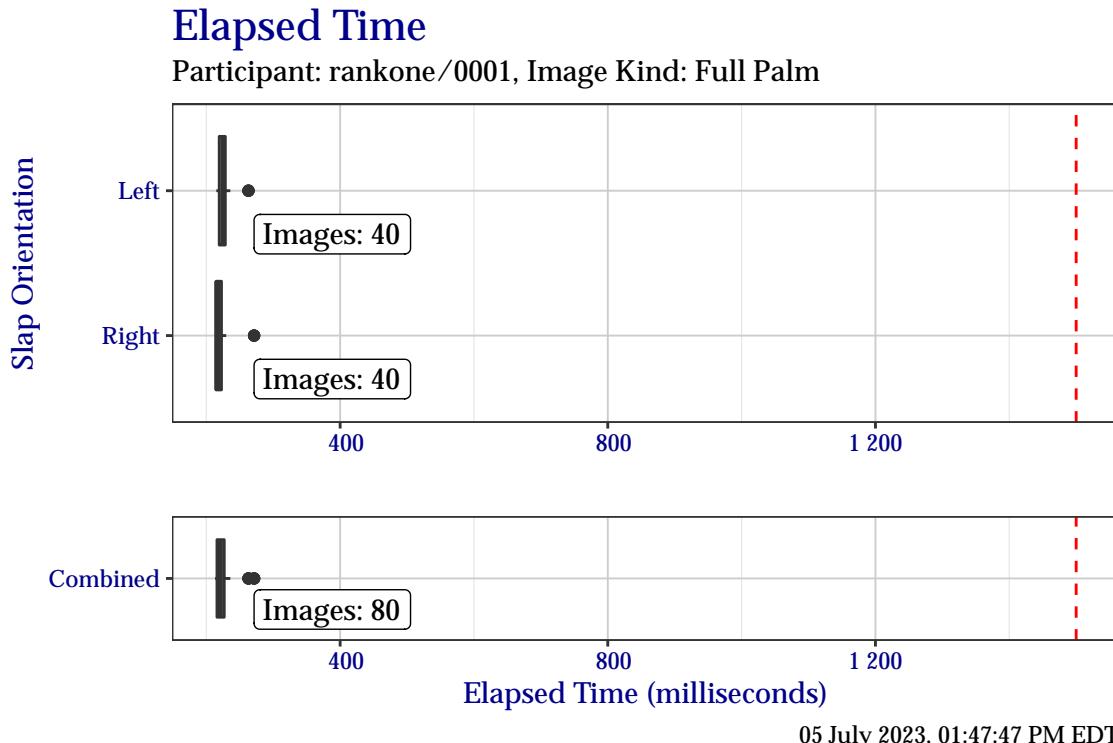


Figure 18: Box plots of elapsed time in milliseconds when segmenting the EightInch timing test corpus, separated by slap orientation.

Table 34: Elapsed time in milliseconds when segmenting the EightInch timing test corpus, separated by slap orientation and capture technology.

	Right	Left	Combined
Minimum	213	215	213
25%	215	219	216
Median	216	225	221
75%	223	228	227
Maximum	271	263	271

5.2 Segmentation Centers and Dimensions

5.2.1 Segmentation Centers

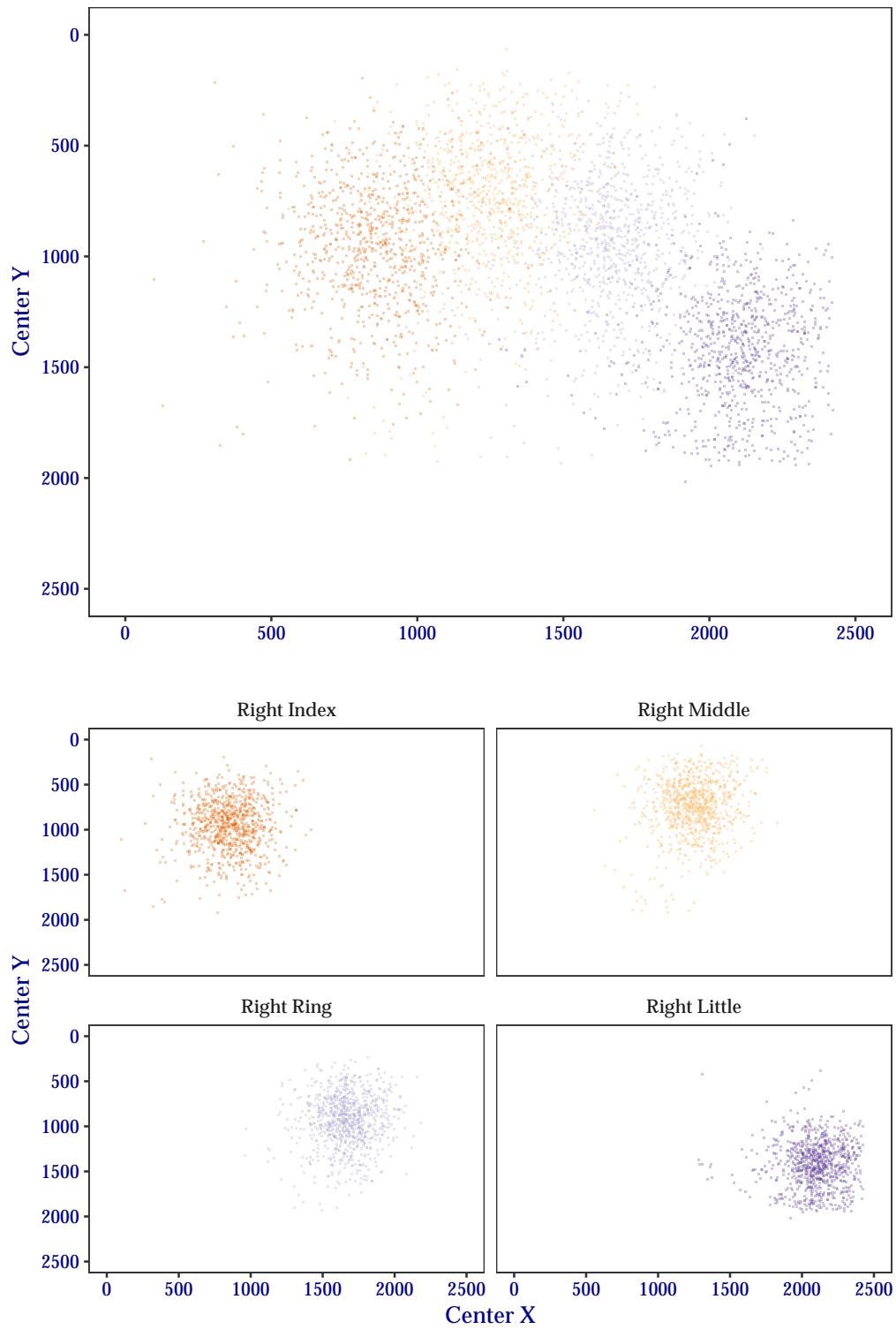
The plots in this section show the distribution of segmentation position centers (x, y) for EightInch data. At the top of each figure is a combined plot for all finger positions of a given slap orientation. These figures are isolated in plots faceted at the bottom of the figure.

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.

Segmentation Position Centers

Participant: rankone/0001, FRGPs: 2, 3, 4, 5, Image Kind: Full Palm



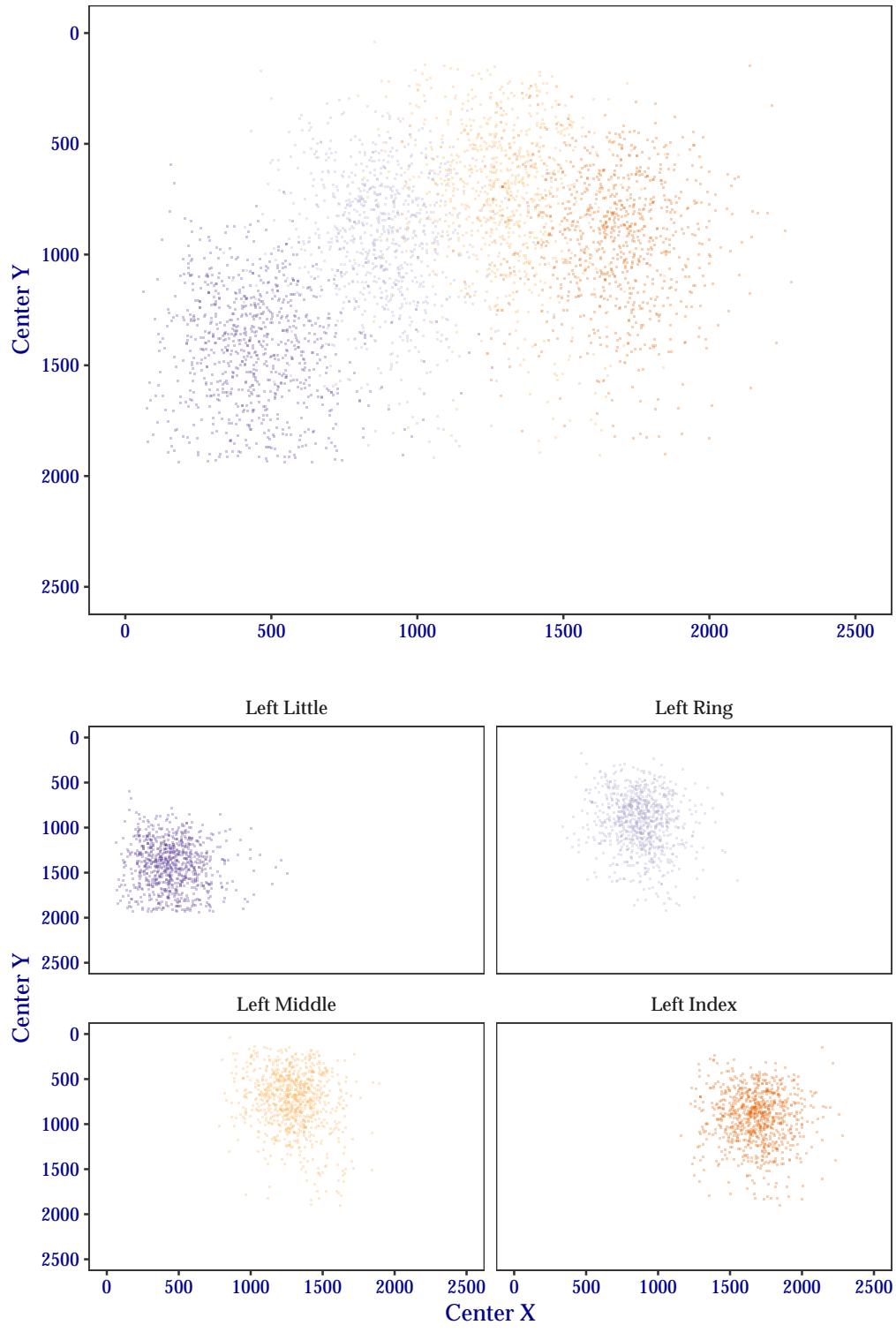
- Right Index • Right Middle • Right Ring • Right Little

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Figure 19: Segmentation centers for right hand EightInch data.

Segmentation Position Centers

Participant: rankone/0001, FRGPs: 7, 8, 9, 10, Image Kind: Full Palm



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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.

Segmentation Position Dimensions

Participant: rankone/0001, FRGPs: 2, 3, 4, 5, Image Kind: Full Palm

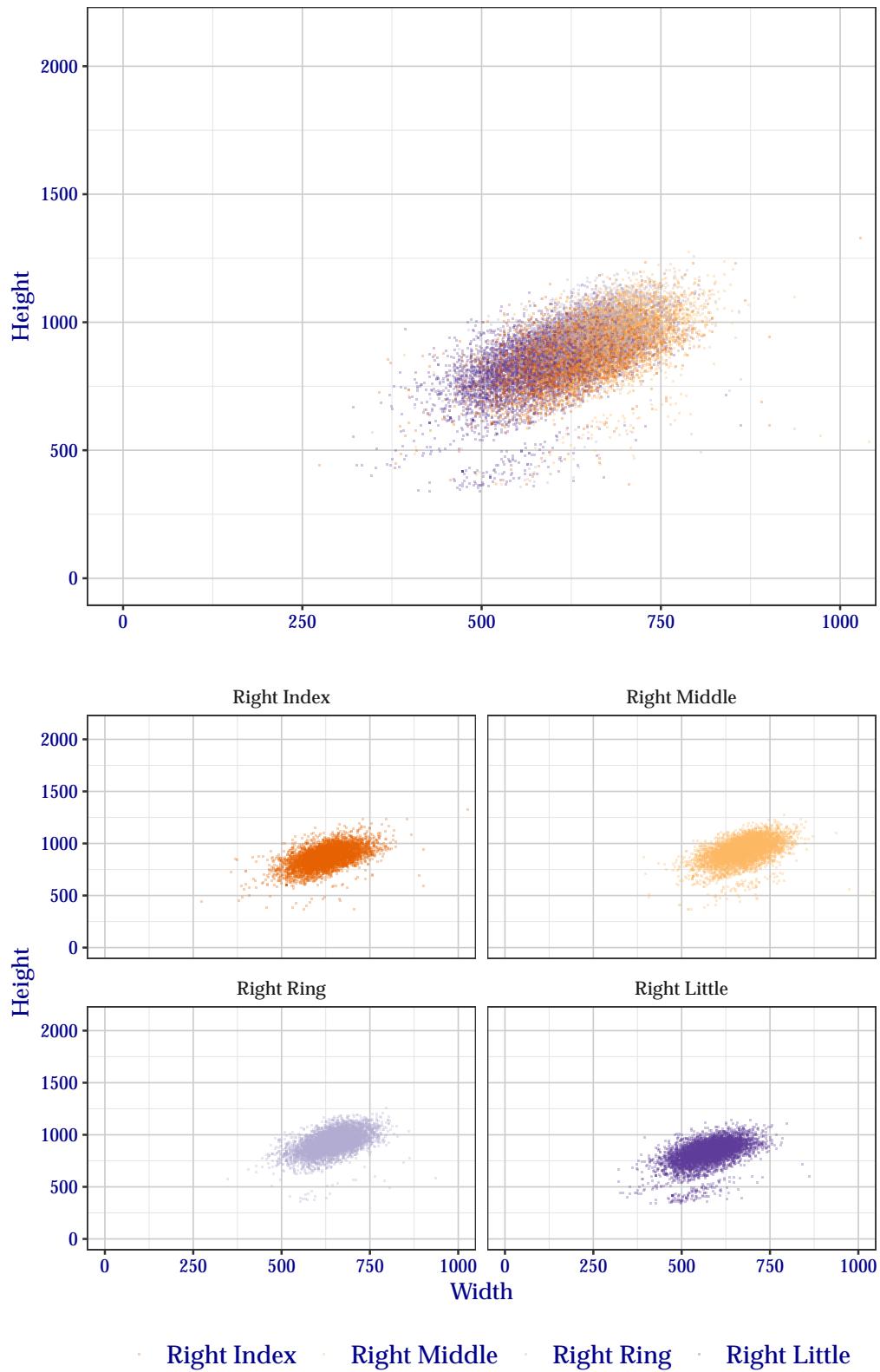
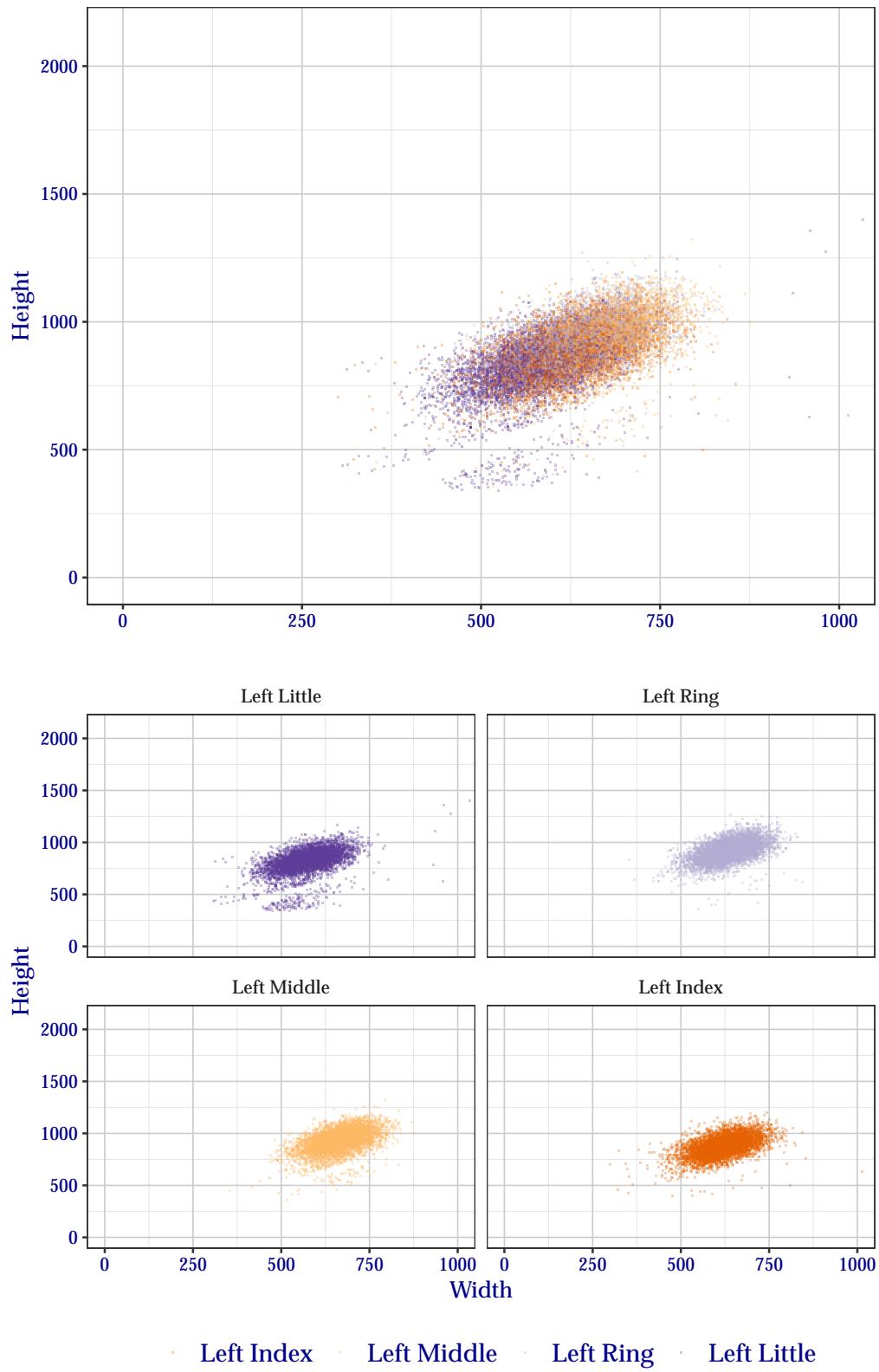


Figure 21: Segmentation position dimensions for right hand EightInch data.

Segmentation Position Dimensions

Participant: rankone/0001, FRGPs: 7, 8, 9, 10, Image Kind: Full Palm



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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 35 shows how successful rankone+0001 segmented fingers for each subject in the test corpus. Table 36 shows success for specific finger positions over the entire test corpus. Similarly, Table 37 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 38 shows success for combinations of all fingers, Table 39 for just the index and middle fingers, and Table 40 for all except the little finger.

Table 35: 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	99.5	99.5	99.5
2	99.0	99.2	99.2
3	98.5	98.9	98.9
4	96.7	97.5	97.6
5	93.3	95.1	95.1
6	92.1	92.8	92.8
7	88.9	91.4	91.7
8	77.5	83.7	84.9

Table 36: 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	93.8	94.5	94.6
Middle	94.5	94.9	95.2
Ring	95.9	96.8	96.8
Little	90.1	94.3	94.4
Left			
Index	94.1	94.6	94.6
Middle	94.6	94.9	94.9
Ring	95.4	95.9	96.7
Little	87.0	92.1	92.5

Table 37: 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	98.5	98.7	98.7
Both	89.4	90.3	90.5
Middle			
Either	98.3	98.5	98.6
Both	90.8	91.4	91.5
Ring			
Either	99.0	99.1	99.2
Both	92.3	93.6	94.3
Little			
Either	93.8	97.1	97.1
Both	83.3	89.2	89.8

Table 38: 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	97.4	97.5	97.5
At Least Two	95.9	96.3	96.3
At Least Three	94.8	95.9	95.9
All Four	86.2	90.8	91.3
Left			
Any	97.8	98.2	98.2
At Least Two	96.0	96.1	96.1
At Least Three	94.3	95.2	95.3
All Four	83.1	88.0	89.2

Table 39: 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	96.1	96.4	96.4
Both Index and Middle	92.2	93.0	93.3
Left			
Either Index or Middle	96.1	96.2	96.2
Both Index and Middle	92.6	93.3	93.3

Table 40: 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	97.1	97.5	97.5
At Least Two	95.6	96.2	96.2
All Three	91.4	92.5	92.9
Left			
Any	97.7	97.9	97.9
At Least Two	95.6	95.7	95.7
All Three	90.8	91.7	92.5

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.

rankone+0001 did **not** report any capture failures.

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.

rankone+0001 did not attempt any recovery segmentations.

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 rankone+0001 are enumerated in Table 41.

Table 41: Count of self-reported segmentation failure reasoning.

Failure Reason	Fingers
Finger Not Found	427
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 42 shows how successful rankone+0001 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 42: Performance of rankone+0001 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 43 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 43: 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	3.68	3.68	3.68
Right	3.10	3.33	3.45
Combined	3.39	3.51	3.56

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: 99.2%

Table 44: Percentage of accuracy when determining hand orientation of a 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	Skip
Left	98.9	1.1	0
Right	0.5	99.5	0

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 45, results are shown of how successful rankone+0001 segmented fingers for each subject in the test corpus. Table 46 shows success for specific finger positions over the entire test corpus. Similarly, Table 47 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 48 shows success for combinations of all fingers, Table 50 for the all except the little finger, and Table 49 for just the index and middle fingers.

Table 45: 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 [99.4, 99.7]	99.6 [99.5, 99.7]	99.6 [99.5, 99.7]
2	99.3 [99.1, 99.4]	99.3 [99.1, 99.5]	99.5 [99.3, 99.6]
3	98.8 [98.6, 98.9]	98.8 [98.6, 99.0]	99.2 [99.0, 99.3]
4	97.3 [97.0, 97.6]	97.6 [97.3, 97.8]	98.1 [97.9, 98.3]
5	91.2 [90.7, 91.7]	91.4 [91.0, 91.9]	92.3 [91.8, 92.8]
6	89.1 [88.6, 89.6]	89.8 [89.3, 90.3]	90.9 [90.5, 91.4]
7	84.7 [84.1, 85.3]	86.4 [85.7, 87.0]	87.9 [87.4, 88.4]
8	70.3 [69.6, 71.1]	75.8 [75.1, 76.5]	77.8 [77.0, 78.5]

Table 46: 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	90.5 [90.1, 90.8]	93.4 [93.1, 93.7]	94.0 [93.7, 94.3]
Middle	92.2 [91.9, 92.6]	92.9 [92.5, 93.2]	93.7 [93.4, 94.0]
Ring	92.0 [91.7, 92.4]	92.7 [92.3, 93.0]	93.6 [93.3, 93.9]
Little	91.5 [91.1, 91.9]	92.7 [92.4, 93.0]	94.6 [94.3, 94.9]
Left			
Index	95.7 [95.4, 96.0]	96.6 [96.3, 96.8]	96.9 [96.7, 97.1]
Middle	94.6 [94.3, 95.0]	95.5 [95.2, 95.7]	95.8 [95.5, 96.1]
Ring	95.6 [95.3, 95.9]	96.5 [96.3, 96.8]	97.1 [96.9, 97.4]
Little	94.9 [94.6, 95.2]	95.5 [95.2, 95.8]	96.4 [96.1, 96.6]

Table 47: 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	98.4 [98.2, 98.6]	98.7 [98.5, 98.9]	99.0 [98.8, 99.1]
Both	83.5 [82.8, 84.1]	86.9 [86.3, 87.5]	87.5 [87.0, 88.1]
Middle			
Either	98.4 [98.2, 98.6]	98.6 [98.4, 98.8]	98.8 [98.6, 99.0]
Both	84.4 [83.8, 85.0]	85.6 [85.0, 86.2]	86.5 [85.9, 87.1]
Ring			
Either	98.6 [98.4, 98.8]	98.8 [98.6, 98.9]	99.1 [98.9, 99.2]
Both	85.2 [84.6, 85.8]	86.6 [86.0, 87.2]	87.9 [87.4, 88.5]
Little			
Either	98.3 [98.1, 98.5]	98.5 [98.3, 98.7]	98.8 [98.7, 99.0]
Both	83.5 [82.9, 84.1]	85.1 [84.5, 85.7]	87.5 [86.9, 88.1]

Table 48: 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	96.6 [97.3, 97.6]	96.7 [97.4, 97.7]	97.3 [97.8, 98.1]
At Least Two	95.3 [96.2, 96.6]	95.6 [96.4, 96.8]	96.4 [97.1, 97.4]
At Least Three	92.7 [94.1, 94.5]	93.5 [94.7, 95.1]	94.7 [95.6, 96.0]
All Four	81.6 [84.5, 85.2]	85.9 [88.0, 88.7]	87.6 [89.4, 90.0]
Left			
Any	98.5 [97.3, 97.6]	98.6 [97.4, 97.7]	98.7 [97.8, 98.1]
At Least Two	97.7 [96.2, 96.6]	97.8 [96.4, 96.8]	98.2 [97.1, 97.4]
At Least Three	96.2 [94.1, 94.5]	96.6 [94.7, 95.1]	97.2 [95.6, 96.0]
All Four	88.4 [84.5, 85.2]	91.1 [88.0, 88.7]	92.1 [89.4, 90.0]

Table 49: 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	95.4 [96.2, 96.6]	95.7 [96.5, 96.9]	96.3 [96.9, 97.3]
Both Index and Middle	87.3 [89.6, 90.1]	90.5 [92.0, 92.5]	91.4 [92.7, 93.2]
Left			
Either Index or Middle	97.6 [96.2, 96.6]	97.8 [96.5, 96.9]	98.0 [96.9, 97.3]
Both Index and Middle	92.7 [89.6, 90.1]	94.2 [92.0, 92.5]	94.7 [92.7, 93.2]

Table 50: 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	96.2 [97.0, 97.3]	96.4 [97.2, 97.5]	96.9 [97.5, 97.8]
At Least Two	93.9 [95.1, 95.5]	94.5 [95.5, 95.9]	95.2 [96.1, 96.5]
All Three	84.6 [87.2, 87.8]	88.1 [90.1, 90.7]	89.2 [91.0, 91.6]
Left			
Any	98.3 [97.0, 97.3]	98.4 [97.2, 97.5]	98.6 [97.5, 97.8]
At Least Two	96.8 [95.1, 95.5]	97.1 [95.5, 95.9]	97.5 [96.1, 96.5]
All Three	90.8 [87.2, 87.8]	93.0 [90.1, 90.7]	93.7 [91.0, 91.6]

A.2 Jaccard Index

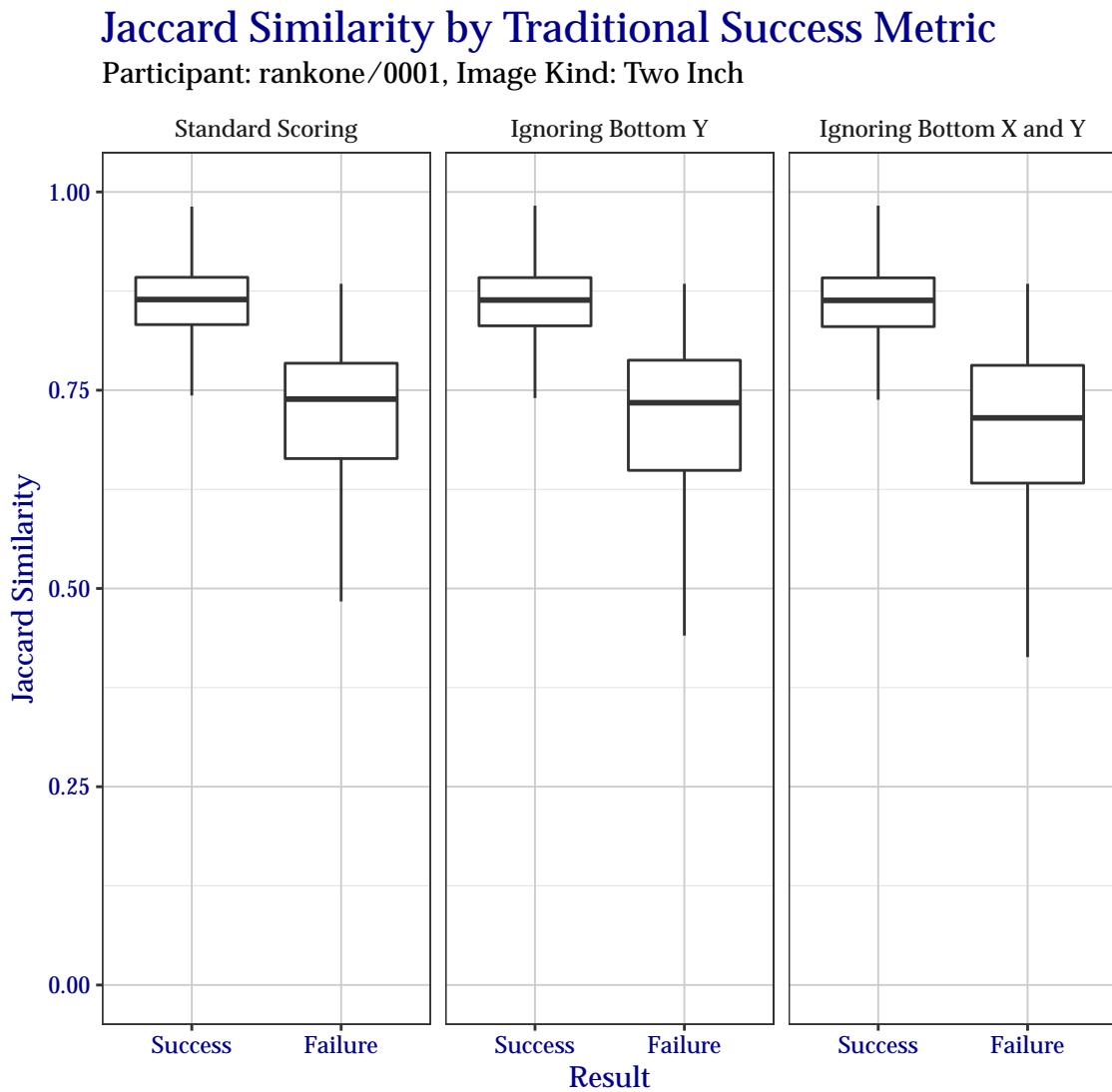
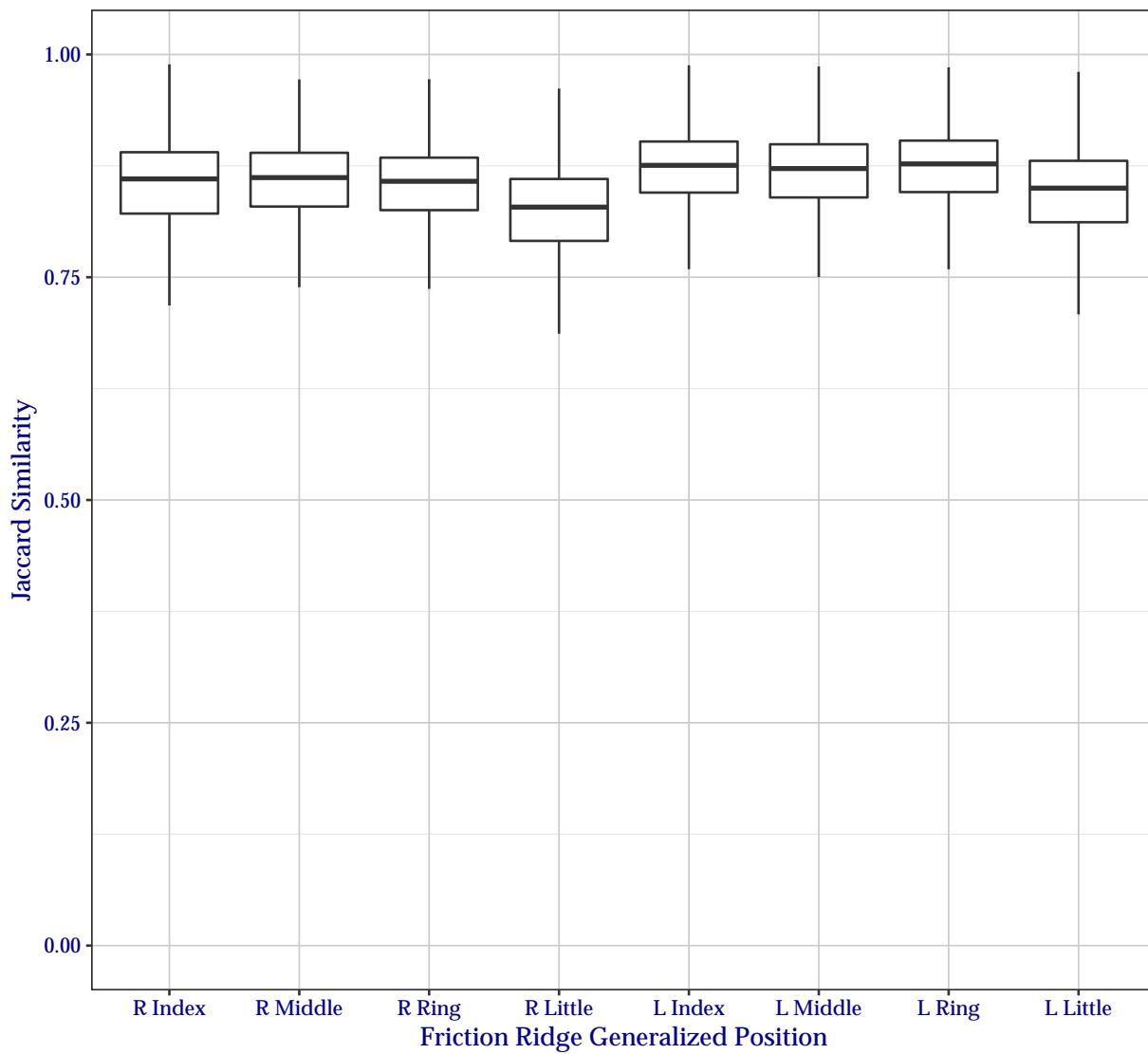


Figure 23: Boxplot of Jaccard similarity indices as compared to the traditional success metrics. Outliers have been removed for clarity.

Jaccard Similarity by Friction Ridge Generalized Position

Participant: rankone/0001, Image Kind: Two Inch



05 July 2023, 02:02:36 PM EDT

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

Table 51: 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	99.8	99.3	69.6	5.7	0.2
2	100.0	100.0	99.7	98.6	41.7	0.4	0.0
3	99.9	99.9	99.4	97.2	20.1	0.0	0.0
4	99.8	99.5	98.7	94.4	7.7	0.0	0.0
5	95.8	95.7	93.8	89.1	2.4	0	0
6	95.6	95.3	93.2	82.3	0.5	0	0
7	94.6	94.3	91.7	66.5	0.1	0	0
8	92.8	91.0	84.1	37.0	0.0	0	0

Table 52: 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	0.8	0.2	2.2	13.4	65.5	17.9
Middle	0.8	0.2	2.1	9.7	70.3	16.9
Ring	0.1	0.3	2.3	10.8	73.2	13.3
Little	0.6	1.3	2.9	25.2	65.0	5.0
Left						
Index	0.7	0.2	0.8	6.3	65.0	27.0
Middle	0.7	0.2	1.4	8.1	65.3	24.3
Ring	0.2	0.2	1.1	6.9	63.6	28.0
Little	1.3	0.5	1.9	16.3	67.8	12.2

Table 53: 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	99.9	98.3	96.5	37.6	1.5	0.0
At Least Two	99.9	99.7	98.0	93.7	12.6	0.0	0.0
At Least Three	99.2	99.0	97.2	84.0	2.6	0.0	0.0
All Four	98.6	97.1	92.8	53.0	0.3	0.0	0.0
Left							
Any	99.9	99.9	99.3	98.6	55.1	4.3	0.1
At Least Two	99.8	99.6	99.0	97.0	26.7	0.3	0.0
At Least Three	99.3	99.2	98.4	91.4	8.5	0.0	0.0
All Four	98.1	97.4	94.1	66.4	1.2	0.0	0.0

Table 54: 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	99.3	99.2	97.8	94.4	29.5	1.1	0.0
Both Index and Middle	99.1	98.8	95.9	76.3	5.3	0.0	0.0
Left							
Either Index or Middle	99.4	99.3	98.8	97.0	41.4	2.5	0.1
Both Index and Middle	99.2	98.9	97.2	84.7	9.9	0.1	0.0

Table 55: 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	99.9	99.8	98.2	96.1	35.8	1.4	0.0
At Least Two	99.2	99.1	97.5	91.0	10.6	0.0	0.0
All Three	99.1	98.6	95.3	70.1	1.7	0.0	0.0
Left							
Any	99.9	99.8	99.3	98.3	52.0	3.9	0.1
At Least Two	99.4	99.2	98.6	94.9	22.3	0.2	0.0
All Three	99.2	98.8	96.7	80.1	5.0	0.0	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 56, results are shown of how successful rankone+0001 segmented fingers for each subject in the test corpus. Table 57 shows success for specific finger positions over the entire test corpus. Similarly, Table 58 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 59 shows success for combinations of all fingers, Table 61 for the all except the little finger, and Table 60 for just the index and middle fingers.

Table 56: 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, 100.0]	99.9 [99.9, 100.0]	99.9 [99.9, 100.0]
2	99.6 [99.5, 99.7]	99.6 [99.5, 99.7]	99.6 [99.5, 99.7]
3	98.5 [98.3, 98.7]	98.5 [98.4, 98.7]	98.5 [98.4, 98.6]
4	98.2 [98.1, 98.4]	98.3 [98.1, 98.4]	98.3 [98.1, 98.4]
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, 96.1]	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	95.7 [95.4, 96.0]	95.7 [95.5, 96.0]	95.8 [95.5, 96.0]
9	94.2 [94.0, 94.5]	94.5 [94.2, 94.7]	94.8 [94.5, 95.1]
10	85.7 [85.3, 86.1]	87.0 [86.6, 87.4]	89.5 [89.1, 89.9]

Table 57: 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	96.5 [96.3, 96.7]	97.0 [96.8, 97.2]	97.5 [97.3, 97.7]
Index	99.5 [99.4, 99.6]	99.5 [99.4, 99.6]	99.6 [99.5, 99.7]
Middle	99.2 [99.1, 99.3]	99.3 [99.2, 99.4]	99.7 [99.6, 99.7]
Ring	98.7 [98.6, 98.9]	98.9 [98.7, 99.0]	99.3 [99.2, 99.4]
Little	99.0 [98.9, 99.2]	99.1 [98.9, 99.2]	99.1 [99.0, 99.2]
Left			
Thumb	96.6 [96.4, 96.8]	97.2 [97.0, 97.4]	97.7 [97.5, 97.9]
Index	99.2 [99.1, 99.3]	99.2 [99.1, 99.3]	99.3 [99.2, 99.4]
Middle	99.0 [98.9, 99.1]	99.1 [99.0, 99.2]	99.5 [99.5, 99.6]
Ring	99.2 [99.0, 99.3]	99.3 [99.2, 99.4]	99.7 [99.7, 99.8]
Little	99.2 [99.1, 99.3]	99.3 [99.2, 99.4]	99.4 [99.3, 99.5]

Table 58: 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	99.1 [99.0, 99.2]	99.2 [99.1, 99.3]	99.3 [99.2, 99.4]
Both	94.0 [93.7, 94.3]	95.1 [94.8, 95.3]	96.0 [95.7, 96.2]
Index			
Either	99.9 [99.8, 99.9]	99.9 [99.8, 99.9]	99.9 [99.8, 99.9]
Both	96.1 [95.9, 96.4]	96.2 [95.9, 96.4]	96.4 [96.1, 96.6]
Middle			
Either	99.8 [99.7, 99.8]	99.8 [99.8, 99.9]	99.9 [99.8, 99.9]
Both	95.8 [95.5, 96.0]	95.8 [95.6, 96.1]	96.6 [96.4, 96.9]
Ring			
Either	99.8 [99.8, 99.9]	99.9 [99.8, 99.9]	99.9 [99.9, 99.9]
Both	95.3 [95.1, 95.6]	95.6 [95.3, 95.8]	96.4 [96.2, 96.6]
Little			
Either	99.8 [99.7, 99.8]	99.8 [99.7, 99.8]	99.8 [99.7, 99.8]
Both	95.9 [95.6, 96.1]	95.9 [95.7, 96.2]	96.0 [95.8, 96.3]

Table 59: 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	99.7 [99.7, 99.8]	99.7 [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	98.4 [98.3, 98.5]	98.4 [98.3, 98.5]	98.4 [98.3, 98.5]
At Least Four	97.9 [97.8, 98.0]	98.0 [97.8, 98.1]	98.1 [98.0, 98.2]
All Five	89.3 [89.1, 89.6]	90.0 [89.8, 90.4]	91.4 [91.2, 91.7]
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	98.4 [98.3, 98.5]	98.4 [98.3, 98.5]	98.4 [98.3, 98.5]
At Least Four	97.9 [97.8, 98.0]	98.0 [97.8, 98.1]	98.1 [98.0, 98.2]
All Five	89.4 [89.1, 89.6]	90.2 [89.8, 90.4]	91.6 [91.2, 91.7]

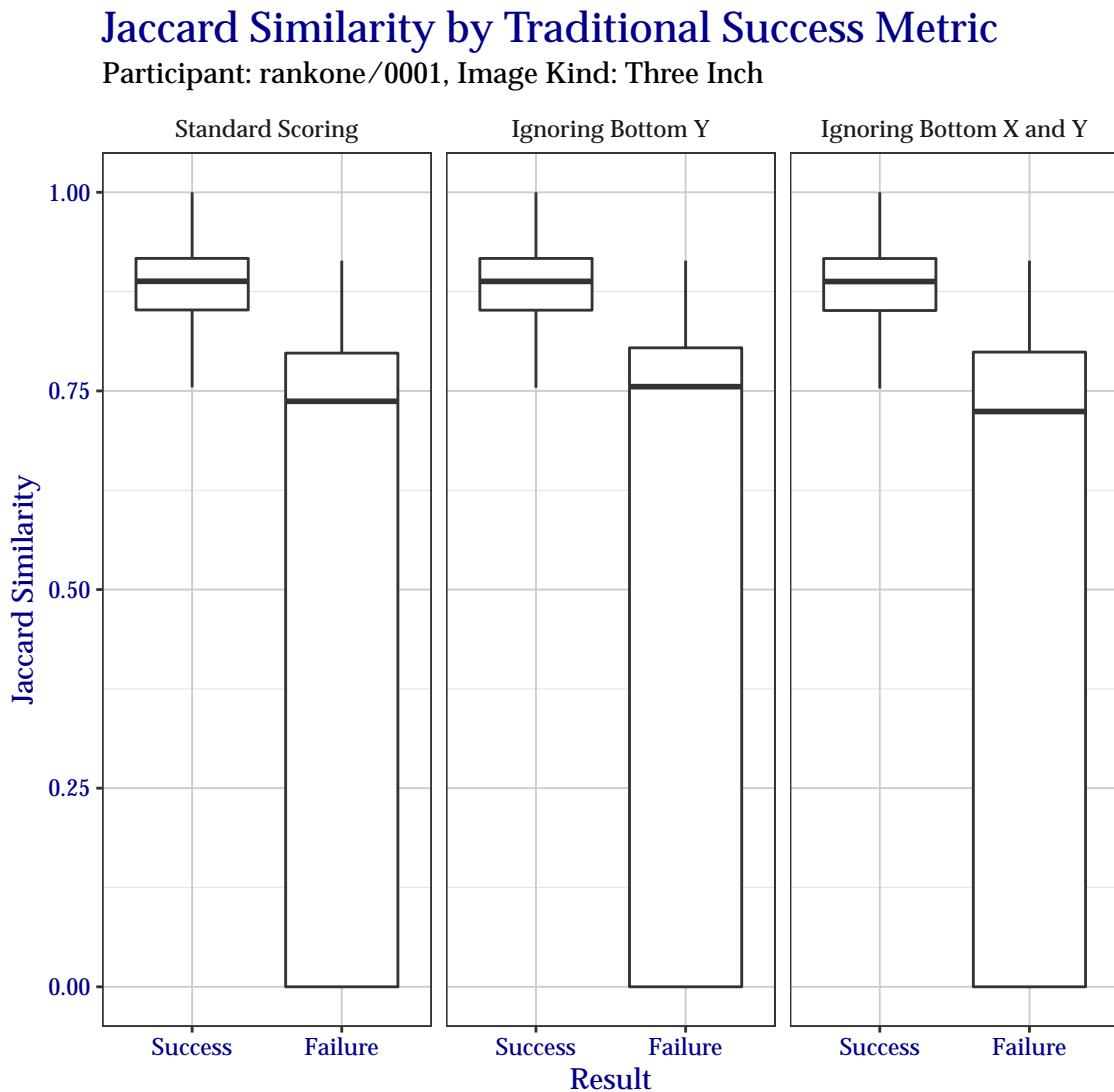
Table 60: Percentage of segmentation success by hand when only considering combinations of index and middle fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values 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	99.9 [99.9, 99.9]	99.9 [99.9, 99.9]	99.9 [99.9, 99.9]
Both Index and Middle	98.8 [98.5, 98.7]	98.9 [98.6, 98.8]	99.4 [99.1, 99.2]
Left			
Either Index or Middle	99.9 [99.9, 99.9]	99.9 [99.9, 99.9]	99.9 [99.9, 99.9]
Both Index and Middle	98.3 [98.5, 98.7]	98.4 [98.6, 98.8]	99.0 [99.1, 99.2]

Table 61: 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, 100.0]	99.9 [99.9, 100.0]	99.9 [99.9, 100.0]
At Least Two	99.8 [99.7, 99.8]	99.8 [99.8, 99.8]	99.8 [99.8, 99.9]
All Three	97.7 [97.5, 97.8]	97.9 [97.7, 98.0]	98.8 [98.7, 98.9]
Left			
Any	100.0 [99.9, 100.0]	100.0 [99.9, 100.0]	100.0 [99.9, 100.0]
At Least Two	99.8 [99.7, 99.8]	99.8 [99.8, 99.8]	99.8 [99.8, 99.9]
All Three	97.6 [97.5, 97.8]	97.8 [97.7, 98.0]	98.8 [98.7, 98.9]

B.2 Jaccard Index

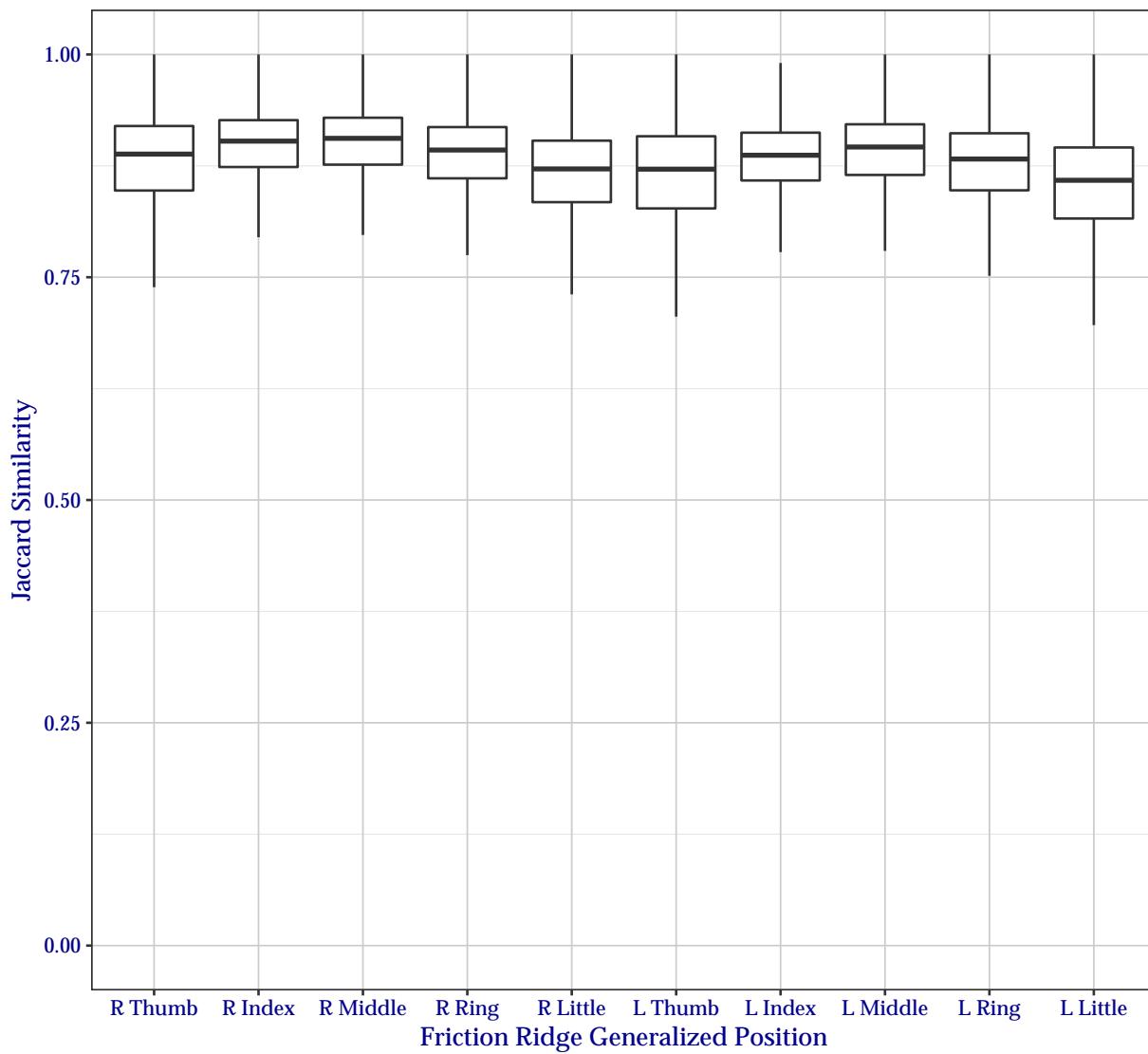


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Figure 25: Boxplot of Jaccard similarity indices as compared to the traditional success metrics. Outliers have been removed for clarity.

Jaccard Similarity by Friction Ridge Generalized Position

Participant: rankone/0001, Image Kind: Three Inch



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

Table 62: 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	96.8	36.4	1.6
2	99.9	99.9	99.9	99.4	89.4	8.2	0.0
3	98.5	98.5	98.5	97.9	76.0	1.3	0.0
4	98.4	98.4	98.1	97.0	56.6	0.1	0.0
5	95.9	95.9	95.9	95.8	35.4	0.0	0.0
6	95.9	95.9	95.9	95.1	18.1	0	0
7	95.9	95.9	95.9	93.2	6.9	0	0
8	95.8	95.8	95.6	88.6	1.9	0	0
9	95.3	95.3	94.4	76.2	0.4	0	0
10	93.5	93.1	88.1	47.1	0.1	0	0

Table 63: 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	1.0	0.1	0.8	8.2	49.0	40.9
Index	0.1	0.0	0.4	3.7	42.8	53.0
Middle	0.1	0.0	0.4	3.7	39.8	56.0
Ring	0.1	0.1	0.6	5.0	51.3	42.9
Little	0.2	0.1	1.0	10.6	60.7	27.4
Left						
Thumb	1.6	0.1	1.3	12.0	54.7	30.3
Index	0.1	0.0	0.1	3.6	59.6	36.6
Middle	0.2	0.0	0.3	4.2	49.0	46.3
Ring	0.1	0.1	0.5	7.3	56.9	35.1
Little	0.3	0.1	1.4	16.5	59.7	22.0

Table 64: 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	99.9	99.9	99.9	99.7	90.3	24.4	0.9
At Least Two	98.5	98.5	98.5	97.7	68.6	3.3	0.0
At Least Three	98.5	98.5	98.4	96.1	39.8	0.3	0.0
At Least Four	98.4	98.3	97.8	91.6	15.0	0.0	0.0
All Five	93.9	93.7	91.2	70.2	2.5	0.0	0.0
Left							
Any	100.0	99.9	99.9	99.7	83.6	16.5	0.7
At Least Two	98.5	98.5	98.5	97.8	52.9	1.6	0.0
At Least Three	98.4	98.4	98.3	96.0	23.5	0.1	0.0
At Least Four	98.3	98.3	97.7	88.3	6.4	0.0	0.0
All Five	93.2	93.0	90.1	60.1	0.8	0.0	0.0

Table 65: 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	99.8	98.5	75.4	13.7	0.4
Both Index and Middle	99.8	99.8	99.1	93.0	33.6	0.9	0.0
Left							
Either Index or Middle	99.9	99.9	99.9	99.0	63.1	8.2	0.2
Both Index and Middle	99.8	99.8	99.3	92.4	19.7	0.3	0

Table 66: 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	100.0	100.0	99.9	99.2	82.6	17.6	0.5
At Least Two	99.9	99.9	99.7	97.1	51.6	1.7	0.0
All Three	99.8	99.7	98.5	89.4	17.7	0.1	0.0
Left							
Any	100.0	100.0	100.0	99.5	73.5	11.1	0.3
At Least Two	99.9	99.9	99.8	97.5	35.8	0.8	0
All Three	99.8	99.6	98.7	86.3	8.7	0.0	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 67, results are shown of how successful rankone+0001 segmented fingers for each subject in the test corpus. Table 68 shows success for specific finger positions over the entire test corpus. Similarly, Table 69 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 70 shows success for combinations of all fingers, Table 72 for the all except the little finger, and Table 71 for just the index and middle fingers.

Table 67: 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	99.1 [98.3, 99.7]	99.6 [99.1, 100.0]	99.6 [99.1, 100.0]
2	97.8 [96.6, 98.7]	98.4 [97.5, 99.2]	98.7 [97.8, 99.5]
3	96.2 [94.7, 97.5]	96.4 [95.0, 97.6]	96.8 [95.4, 98.0]
4	92.6 [90.6, 94.5]	93.7 [92.0, 95.4]	93.8 [92.0, 95.4]
5	85.5 [82.9, 88.0]	86.4 [83.8, 88.8]	86.8 [84.3, 89.2]
6	77.7 [74.8, 80.8]	78.9 [75.9, 81.8]	80.0 [77.2, 82.9]
7	63.0 [59.8, 66.3]	64.6 [61.0, 68.0]	65.9 [62.7, 69.4]
8	41.2 [37.7, 44.8]	45.2 [41.4, 48.9]	47.4 [43.9, 51.0]

Table 68: 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	85.2 [82.7, 87.8]	85.8 [83.2, 88.3]	85.8 [83.4, 88.3]
Middle	78.1 [75.0, 81.0]	78.6 [75.9, 81.5]	79.3 [76.1, 82.2]
Ring	86.2 [83.6, 88.6]	87.4 [84.8, 89.6]	87.6 [85.1, 89.9]
Little	83.5 [81.0, 86.2]	85.9 [83.4, 88.3]	86.6 [83.9, 89.0]
Left			
Index	82.4 [79.6, 84.9]	83.6 [81.0, 86.3]	84.0 [81.2, 86.6]
Middle	78.0 [74.9, 81.2]	78.5 [75.5, 81.4]	79.0 [76.3, 82.0]
Ring	86.7 [84.2, 89.0]	87.8 [85.4, 90.2]	89.0 [86.6, 91.2]
Little	78.2 [75.3, 81.0]	81.0 [78.3, 83.7]	83.2 [80.2, 85.7]

Table 69: 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	93.9 [92.4, 95.7]	94.9 [93.3, 96.4]	94.9 [93.3, 96.4]
Both	72.3 [69.0, 75.5]	73.1 [70.0, 76.4]	73.5 [70.2, 76.7]
Middle			
Either	91.2 [89.2, 93.1]	91.8 [89.9, 93.5]	92.1 [90.3, 94.1]
Both	63.6 [60.3, 67.1]	64.0 [60.7, 67.7]	65.0 [61.8, 68.4]
Ring			
Either	95.1 [93.7, 96.6]	96.0 [94.6, 97.5]	96.0 [94.6, 97.4]
Both	76.4 [73.5, 79.3]	77.7 [74.7, 80.5]	79.2 [76.4, 82.1]
Little			
Either	92.8 [90.8, 94.5]	94.5 [92.8, 96.0]	94.9 [93.2, 96.3]
Both	67.7 [64.4, 71.0]	71.1 [67.9, 74.4]	73.5 [70.2, 76.5]

Table 70: 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	96.3 [95.8, 97.6]	96.7 [96.5, 98.1]	96.7 [96.8, 98.3]
At Least Two	91.4 [89.8, 92.7]	91.8 [90.2, 93.2]	91.9 [90.8, 93.6]
At Least Three	81.9 [78.8, 82.9]	82.6 [79.7, 83.5]	82.7 [80.1, 84.0]
All Four	63.4 [57.6, 62.9]	66.6 [61.0, 66.1]	68.0 [62.9, 67.6]
Left			
Any	97.2 [95.8, 97.6]	98.0 [96.5, 98.1]	98.4 [96.8, 98.3]
At Least Two	91.2 [89.8, 92.7]	91.6 [90.2, 93.2]	92.4 [90.8, 93.6]
At Least Three	79.8 [78.8, 82.9]	80.8 [79.7, 83.5]	81.7 [80.1, 84.0]
All Four	57.0 [57.6, 62.9]	60.5 [61.0, 66.1]	62.6 [62.9, 67.6]

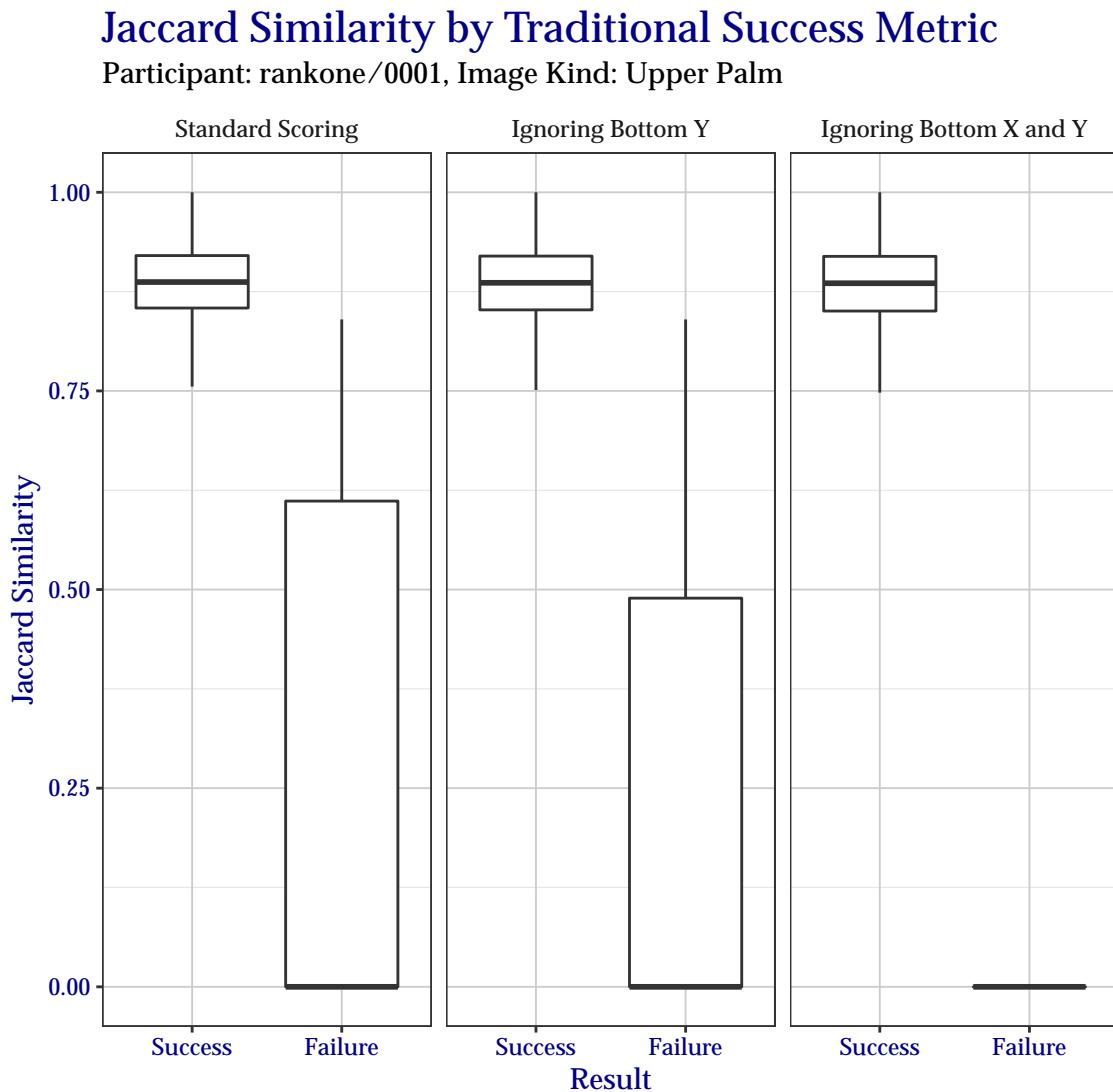
Table 71: Percentage of segmentation success by hand when only considering combinations of index and middle fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values 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	90.2 [88.0, 91.0]	90.4 [88.2, 91.4]	90.4 [88.6, 91.6]
Both Index and Middle	73.1 [69.9, 74.6]	73.9 [71.1, 75.5]	74.6 [71.8, 76.0]
Left			
Either Index or Middle	89.0 [88.0, 91.0]	89.4 [88.2, 91.4]	89.9 [88.6, 91.6]
Both Index and Middle	71.4 [69.9, 74.6]	72.7 [71.1, 75.5]	73.1 [71.8, 76.0]

Table 72: 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	94.8 [93.9, 96.1]	95.2 [94.6, 96.6]	95.2 [95.0, 97.0]
At Least Two	85.6 [83.2, 86.7]	86.2 [83.3, 87.0]	86.3 [83.5, 87.1]
All Three	69.0 [66.1, 70.5]	70.3 [67.5, 72.0]	71.1 [68.5, 73.2]
Left			
Any	95.2 [93.9, 96.1]	96.2 [94.6, 96.6]	96.8 [95.0, 97.0]
At Least Two	84.2 [83.2, 86.7]	84.5 [83.3, 87.0]	84.6 [83.5, 87.1]
All Three	67.6 [66.1, 70.5]	69.2 [67.5, 72.0]	70.6 [68.5, 73.2]

C.2 Jaccard Index

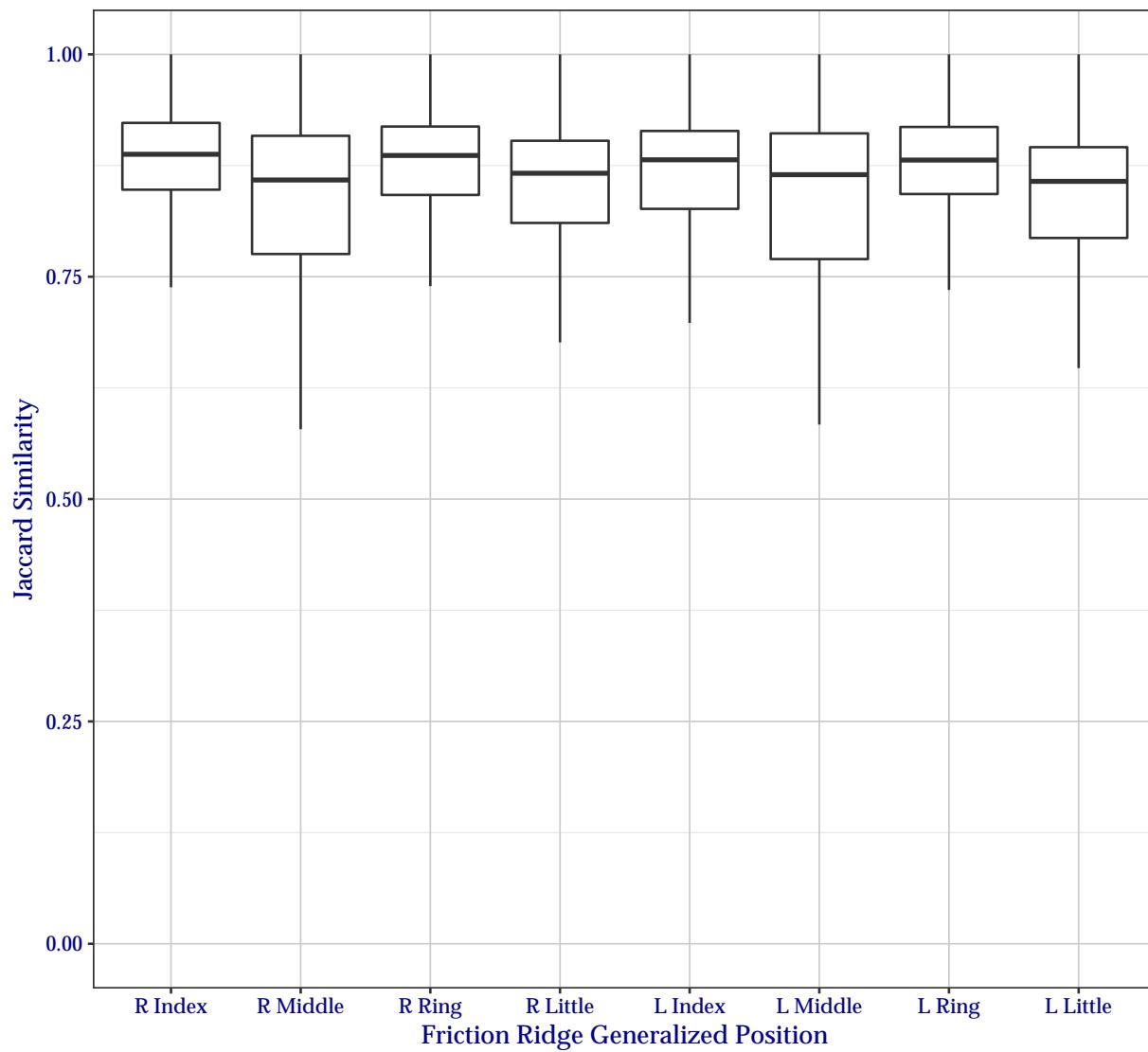


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Figure 27: Boxplot of Jaccard similarity indices as compared to the traditional success metrics. Outliers have been removed for clarity.

Jaccard Similarity by Friction Ridge Generalized Position

Participant: rankone/0001, Image Kind: Upper Palm



05 July 2023, 01:48:21 PM EDT

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

Table 73: 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	99.6	99.6	99.3	99.2	87.6	31.5	22.0
2	98.6	98.4	98.2	97.2	70.1	18.3	17.4
3	97.1	97.0	96.0	94.7	47.0	14.8	14.2
4	95.0	94.3	92.8	89.3	24.4	9.6	9.5
5	88.3	87.5	85.8	81.3	12.6	7.0	6.9
6	82.2	81.4	79.3	71.0	6.9	5.4	5.4
7	71.4	69.8	66.9	53.1	3.8	3.7	3.7
8	62.6	60.1	52.7	30.7	2.1	1.8	1.8

Table 74: 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	12.6	0.5	1.1	3.7	41.0	41.1
Middle	15.2	1.6	3.0	9.4	42.7	28.1
Ring	10.9	1.1	1.3	4.0	44.5	38.2
Little	11.3	0.7	1.8	8.5	51.1	26.6
Left						
Index	15.1	0.4	1.7	3.7	43.3	35.8
Middle	15.5	0.9	2.7	9.8	41.4	29.7
Ring	9.1	0.3	1.7	4.1	49.1	35.7
Little	10.0	1.2	3.8	11.5	52.0	21.5

Table 75: 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	96.8	96.8	96.4	95.6	73.1	22.3	17.2
At Least Two	92.4	92.0	91.2	89.6	38.6	13.0	12.5
At Least Three	84.8	84.0	82.7	77.5	16.4	7.6	7.6
All Four	75.9	73.3	68.5	50.4	5.9	4.3	4.3
Left							
Any	98.4	98.4	97.6	96.8	70.6	23.1	17.6
At Least Two	93.5	93.4	91.9	89.8	34.2	11.8	11.7
At Least Three	83.8	83.4	81.4	75.2	13.9	7.4	7.4
All Four	74.5	72.3	66.6	46.6	4.0	3.3	3.3

Table 76: 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	91.0	91.0	90.6	89.0	53.1	18.5	15.3
Both Index and Middle	81.2	79.1	75.4	63.8	16.1	7.6	7.4
Left							
Either Index or Middle	89.7	89.5	89.3	87.9	52.0	17.9	15.4
Both Index and Middle	79.7	78.5	74.4	62.2	13.5	7.4	7.4

Table 77: 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	95.5	95.5	94.9	94.0	66.0	20.9	16.5
At Least Two	87.8	87.0	85.8	82.8	31.5	11.8	11.4
All Three	78.1	75.7	71.9	58.6	9.8	6.0	6.0
Left							
Any	96.9	96.8	95.6	94.2	64.9	21.0	16.6
At Least Two	85.5	85.4	84.5	82.4	27.3	11.1	11.1
All Three	77.7	76.4	72.4	58.4	9.0	6.5	6.5

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 78, results are shown of how successful rankone+0001 segmented fingers for each subject in the test corpus. Table 79 shows success for specific finger positions over the entire test corpus. Similarly, Table 80 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 81 shows success for combinations of all fingers, Table 83 for the all except the little finger, and Table 82 for just the index and middle fingers.

Table 78: 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	99.5 [99.1, 100.0]	99.5 [99.1, 99.9]	99.5 [99.1, 100.0]
2	99.0 [98.2, 99.7]	99.2 [98.6, 99.7]	99.2 [98.5, 99.8]
3	98.5 [97.6, 99.2]	98.9 [98.2, 99.5]	98.9 [98.0, 99.5]
4	96.7 [95.3, 97.7]	97.5 [96.4, 98.5]	97.6 [96.6, 98.5]
5	93.3 [91.7, 94.8]	95.1 [93.5, 96.4]	95.1 [93.6, 96.4]
6	92.1 [90.1, 93.8]	92.8 [91.0, 94.5]	92.8 [91.0, 94.6]
7	88.9 [86.7, 90.8]	91.4 [89.3, 93.2]	91.7 [89.9, 93.4]
8	77.5 [74.7, 80.2]	83.7 [81.3, 86.0]	84.9 [82.5, 87.4]

Table 79: 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	93.8 [92.2, 95.4]	94.5 [92.9, 96.0]	94.6 [93.1, 96.1]
Middle	94.5 [92.9, 95.9]	94.9 [93.3, 96.4]	95.2 [93.7, 96.6]
Ring	95.9 [94.5, 97.1]	96.8 [95.6, 97.9]	96.8 [95.5, 97.8]
Little	90.1 [88.3, 92.0]	94.3 [92.5, 95.7]	94.4 [92.9, 95.9]
Left			
Index	94.1 [92.5, 95.6]	94.6 [92.9, 96.1]	94.6 [93.0, 96.1]
Middle	94.6 [93.1, 96.1]	94.9 [93.5, 96.3]	94.9 [93.4, 96.3]
Ring	95.4 [94.0, 96.8]	95.9 [94.4, 97.0]	96.7 [95.4, 97.8]
Little	87.0 [84.8, 89.2]	92.1 [90.3, 93.8]	92.5 [90.7, 94.3]

Table 80: 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	98.5 [97.6, 99.2]	98.7 [97.9, 99.4]	98.7 [97.9, 99.4]
Both	89.4 [87.2, 91.4]	90.3 [88.4, 92.2]	90.5 [88.4, 92.4]
Middle			
Either	98.3 [97.4, 99.1]	98.5 [97.7, 99.3]	98.6 [97.8, 99.3]
Both	90.8 [88.7, 92.6]	91.4 [89.4, 93.2]	91.5 [89.7, 93.4]
Ring			
Either	99.0 [98.2, 99.7]	99.1 [98.4, 99.7]	99.2 [98.6, 99.8]
Both	92.3 [90.6, 94.0]	93.6 [92.0, 95.2]	94.3 [92.5, 95.7]
Little			
Either	93.8 [92.1, 95.3]	97.1 [95.9, 98.2]	97.1 [95.9, 98.2]
Both	83.3 [81.0, 86.0]	89.2 [87.0, 91.1]	89.8 [87.6, 91.7]

Table 81: 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	97.4 [96.8, 98.3]	97.5 [97.0, 98.5]	97.5 [97.1, 98.5]
At Least Two	95.9 [94.9, 96.8]	96.3 [95.3, 97.1]	96.3 [95.3, 97.1]
At Least Three	94.8 [93.4, 95.6]	95.9 [94.5, 96.4]	95.9 [94.6, 96.5]
All Four	86.2 [82.9, 86.3]	90.8 [88.0, 90.9]	91.3 [88.9, 91.6]
Left			
Any	97.8 [96.8, 98.3]	98.2 [97.0, 98.5]	98.2 [97.1, 98.5]
At Least Two	96.0 [94.9, 96.8]	96.1 [95.3, 97.1]	96.1 [95.3, 97.1]
At Least Three	94.3 [93.4, 95.6]	95.2 [94.5, 96.4]	95.3 [94.6, 96.5]
All Four	83.1 [82.9, 86.3]	88.0 [88.0, 90.9]	89.2 [88.9, 91.6]

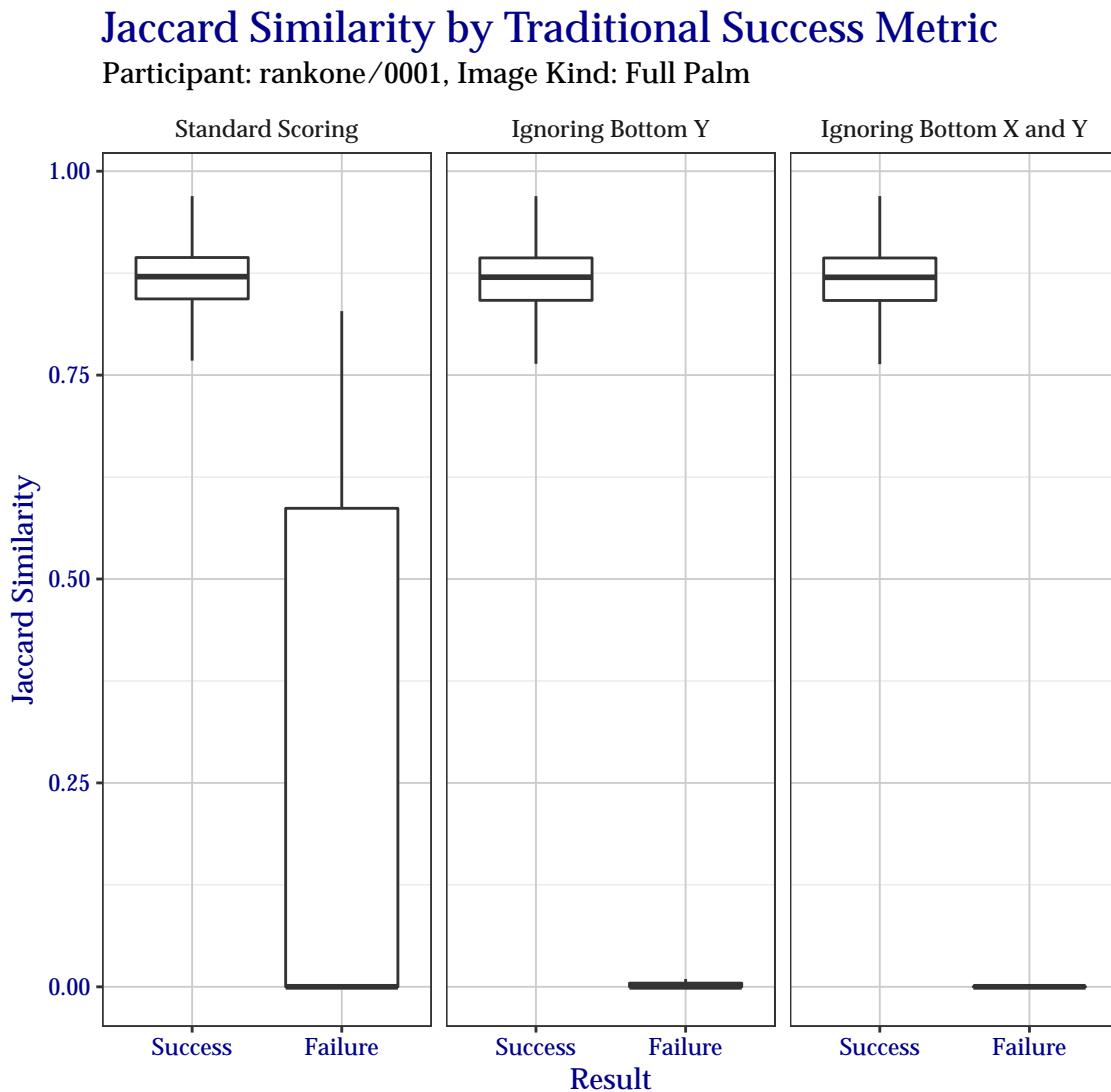
Table 82: Percentage of segmentation success by hand when only considering combinations of index and middle fingers. In *Ignoring Bottom Y*, the bottom left and bottom right Y coordinates are ignored. *Ignoring Bottom X and Y* only checks the locations of the top left and top right coordinates. Values 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	96.1 [95.1, 97.0]	96.4 [95.4, 97.2]	96.4 [95.4, 97.1]
Both Index and Middle	92.2 [91.1, 93.5]	93.0 [92.0, 94.4]	93.3 [92.1, 94.5]
Left			
Either Index or Middle	96.1 [95.1, 97.0]	96.2 [95.4, 97.2]	96.2 [95.4, 97.1]
Both Index and Middle	92.6 [91.1, 93.5]	93.3 [92.0, 94.4]	93.3 [92.1, 94.5]

Table 83: 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	97.1 [96.7, 98.2]	97.5 [97.0, 98.4]	97.5 [97.0, 98.3]
At Least Two	95.6 [94.7, 96.6]	96.2 [94.9, 96.9]	96.2 [95.1, 96.9]
All Three	91.4 [89.7, 92.4]	92.5 [90.9, 93.3]	92.9 [91.4, 94.0]
Left			
Any	97.7 [96.7, 98.2]	97.9 [97.0, 98.4]	97.9 [97.0, 98.3]
At Least Two	95.6 [94.7, 96.6]	95.7 [94.9, 96.9]	95.7 [95.1, 96.9]
All Three	90.8 [89.7, 92.4]	91.7 [90.9, 93.3]	92.5 [91.4, 94.0]

D.2 Jaccard Index

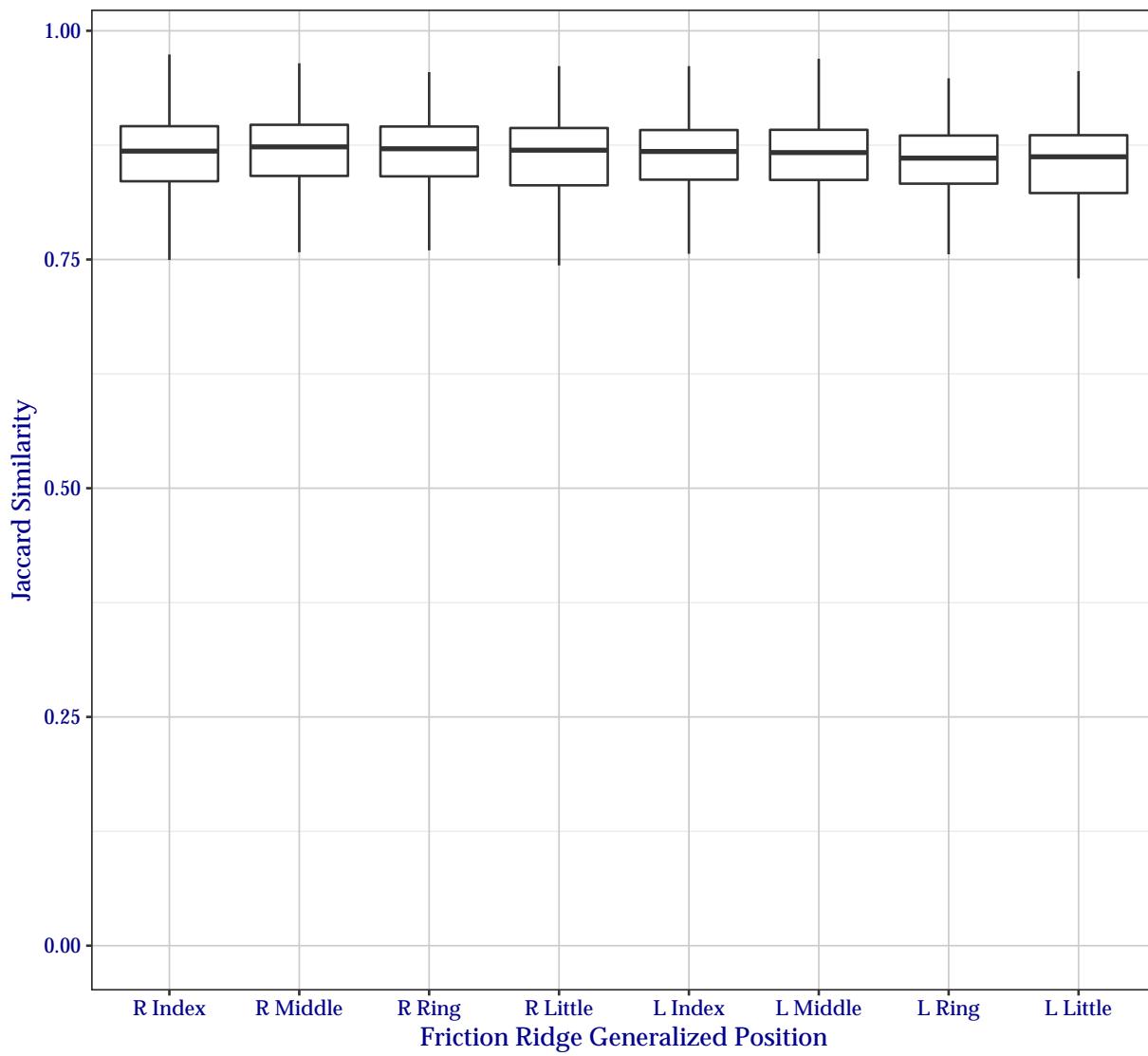


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Figure 29: Boxplot of Jaccard similarity indices as compared to the traditional success metrics. Outliers have been removed for clarity.

Jaccard Similarity by Friction Ridge Generalized Position

Participant: rankone/0001, Image Kind: Full Palm



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

Table 84: 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
1	99.5	99.5	99.4	99.3	67.1	3.6
2	99.1	99.1	98.9	98.3	40.2	0.1
3	99.0	98.9	98.6	97.2	20.5	0
4	98.0	97.7	97.4	94.5	10.2	0
5	94.8	94.0	93.6	89.9	4.8	0
6	92.9	92.6	92.0	85.5	1.8	0
7	91.8	91.0	89.4	75.6	0.6	0
8	87.6	84.8	78.9	52.6	0	0

Table 85: 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	5.0	0.5	0.6	6.2	66.8	20.9
Middle	4.1	0.3	0.4	7.7	65.4	22.1
Ring	3.1	0.2	1.3	5.5	69.0	20.9
Little	5.7	1.6	2.3	6.4	65.1	18.9
Left						
Index	4.7	0.2	0.8	7.6	68.3	18.4
Middle	3.9	0.2	1.2	5.6	71.2	17.9
Ring	2.8	0.2	0.8	8.3	75.6	12.3
Little	7.8	1.7	2.4	7.7	66.5	13.9

Table 86: 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
Right						
Any	97.5	97.4	97.4	96.6	51.5	2.2
At Least Two	96.1	96.0	95.7	93.6	22.5	0.0
At Least Three	95.7	95.4	94.9	88.6	7.6	0.0
All Four	92.6	90.6	86.8	70.2	1.1	0.0
Left						
Any	98.2	97.9	97.6	96.8	42.5	1.5
At Least Two	96.1	96.1	95.7	93.3	15.2	0.0
At Least Three	95.7	95.6	94.8	88.4	3.8	0.0
All Four	90.8	88.7	85.1	65.5	1.0	0.0

Table 87: 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
Right						
Either Index or Middle	96.2	96.1	95.9	93.9	34.7	1.1
Both Index and Middle	94.6	93.9	93.2	81.3	8.3	0
Left						
Either Index or Middle	96.3	96.2	95.7	93.9	30.6	0.7
Both Index and Middle	95.1	94.7	93.2	81.8	5.7	0

Table 88: 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
Right						
Any	97.4	97.1	97.1	96.0	44.3	1.6
At Least Two	96.0	96.0	95.4	90.9	15.6	0
All Three	94.4	93.6	92.0	78.2	4.0	0
Left						
Any	97.9	97.7	97.5	96.1	35.9	0.8
At Least Two	96.0	96.0	95.3	91.8	10.9	0
All Three	94.7	94.3	92.4	75.7	1.8	0