Visual assessments of Postural Orientation Errors using ensembles of Deep Neural Networks

LUND UNIVERSITY

LTH

FACULTY OF ENGINEERING

Master's Thesis

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April 14, 2021

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Agenda

1. Introduction
2. Methods
3. Results
4. Conclusions and Future work

Introduction

Anterior Cruciate Ligament injuries

- Around 8000 yearly Anterior cruciate ligament injuries in Sweden.
- Regular injury mechanism is sudden changes in direction or velocity while knee is bearing weight.
- Rehabilitation typically up to 2 years.
- Increased long and short term risk of, e.g., osteoarthritis, joint instability, and re-injury.

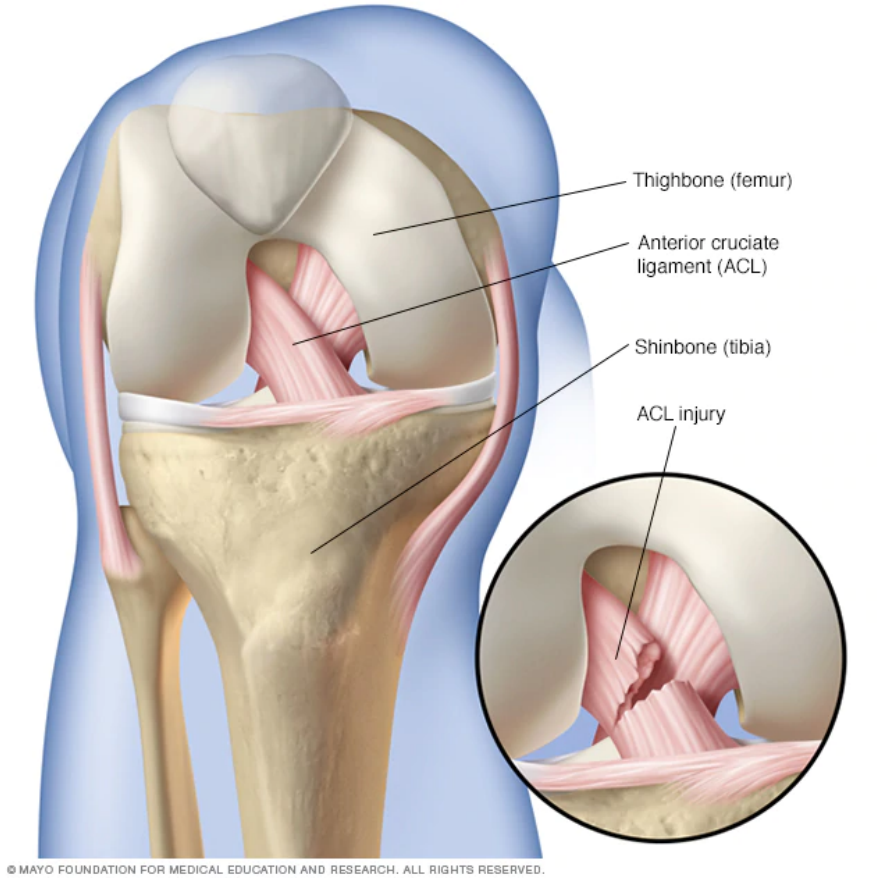


Figure 1: Illustration of ACL in the knee[1].

[1] Mayo Clinic, https://www.mayoclinic.org/diseases-conditions/acl-injury/symptoms-causes/syc-20350738

Postural Orientation

Figure 2: Examples of maintained (left) and altered postural orientation (right) during a single leg squat.

- Ability to uphold alignment of body parts.
- Altered PO - seen to increase risk of re-injury.
- No established and feasible method to assess for clinical use.
- When used, found from motion capture systems.

Postural Orientation Errors

- Proposed methods where experts assess motions from videos[2].
- Scoring on ordinal scale, 0 (Good) - 2 (Poor).
- Patient score calculated as median of 4-5 repetition scores.
- Assessments are time consuming, can they be automated?
- Trunk, Pelvis, Femoral valgus, and KMFP POEs evaluated in this work for Single leg squat.

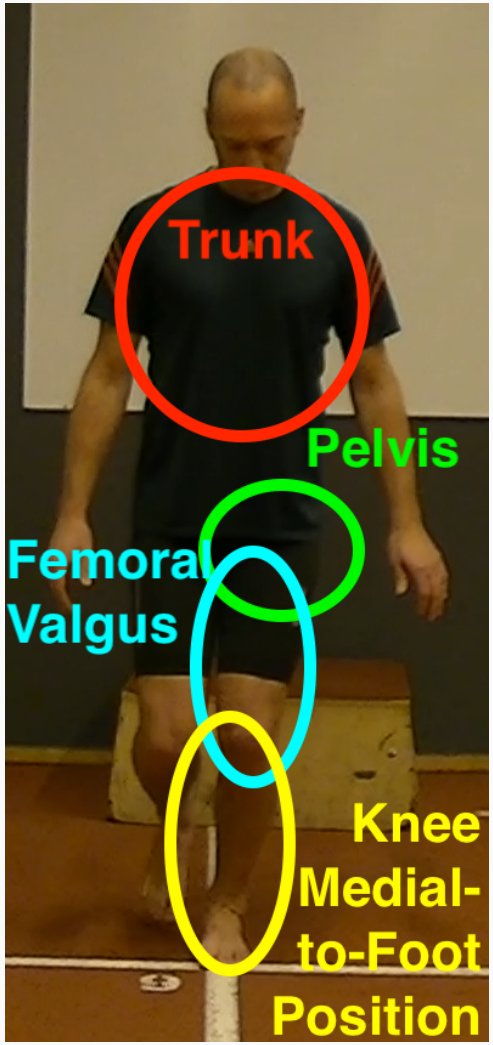


Figure 3: Evaluated POEs.

[2] Nae et al., Extended Version of a Test Battery for Visual Assessment of Postural Orientation Errors: Face Validity, Internal Consistency, and Reliability. 2020

Methods

System overview

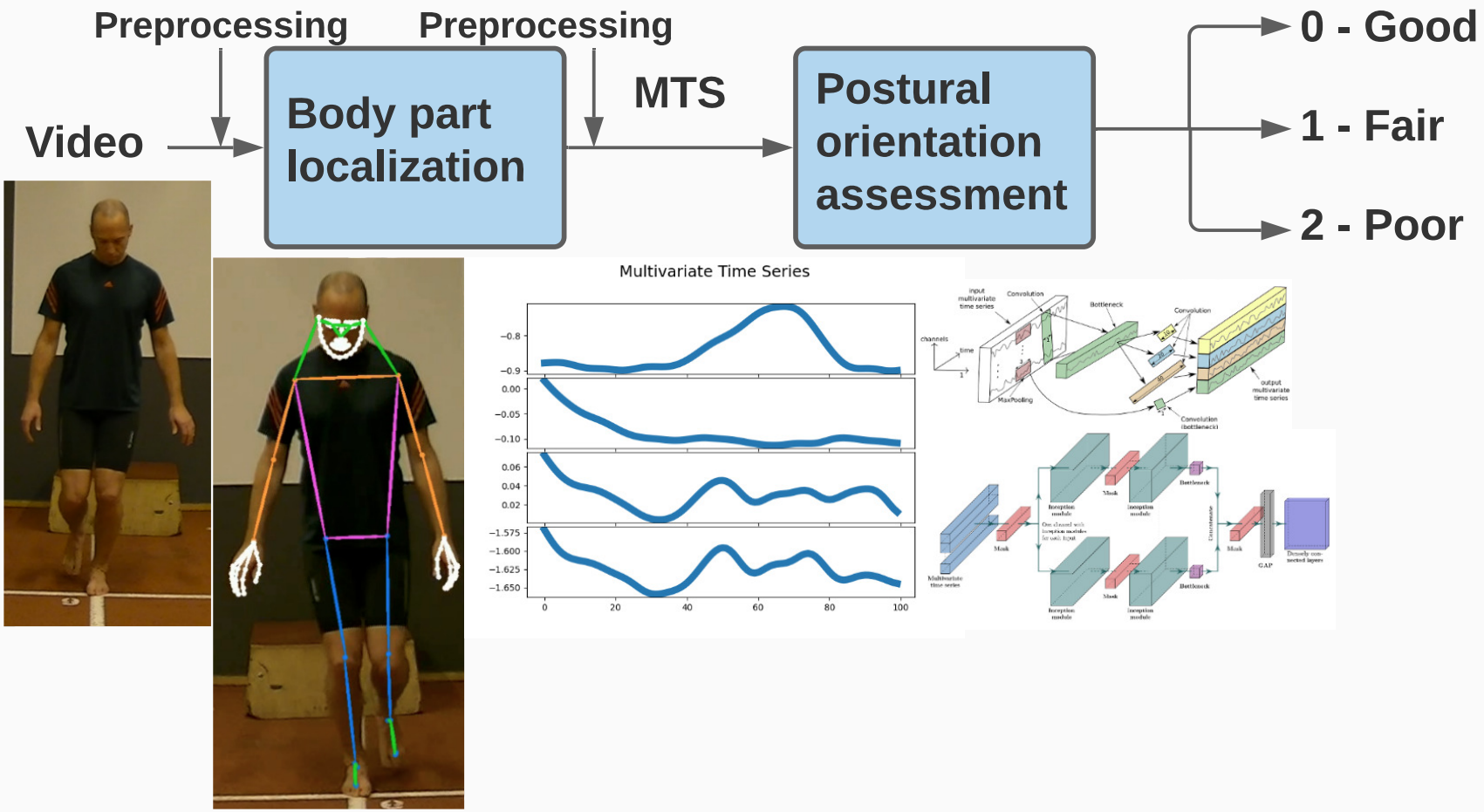
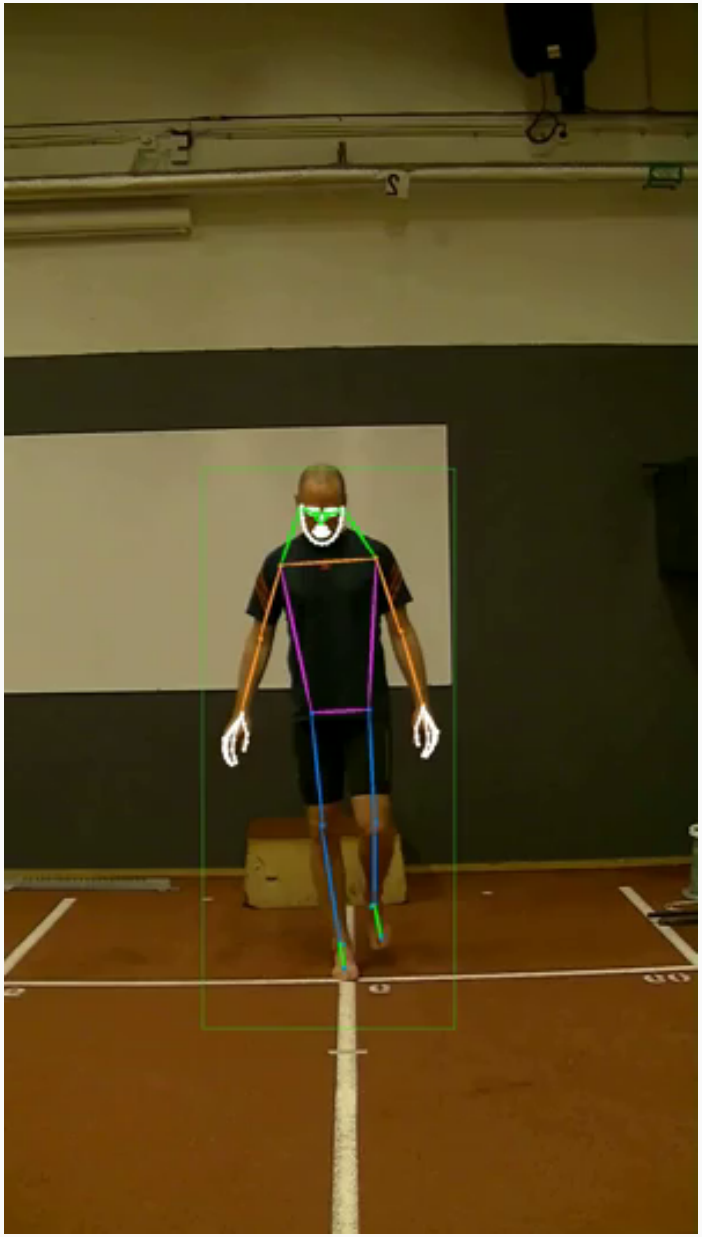


Figure 4: POE assessment system overview.

Body part localization



- Built upon MMPose framework[3].
- HRNet[4]with DARK-pose[5]trained on COCO-wholebody dataset used for pose estimation.
- Outputs 133 keypoint coordinates.

[3] MMPose - OpenMMLab, `https://github.com/open-mmlab/mmpose`

[4] Sun et al., Deep high-resolution representation learning for human pose estimation. 2019

[5] Zhang et al., Distribution-Aware Coordinate Representation for Human Pose Estimation. 2020

Time series classification - Network architectures

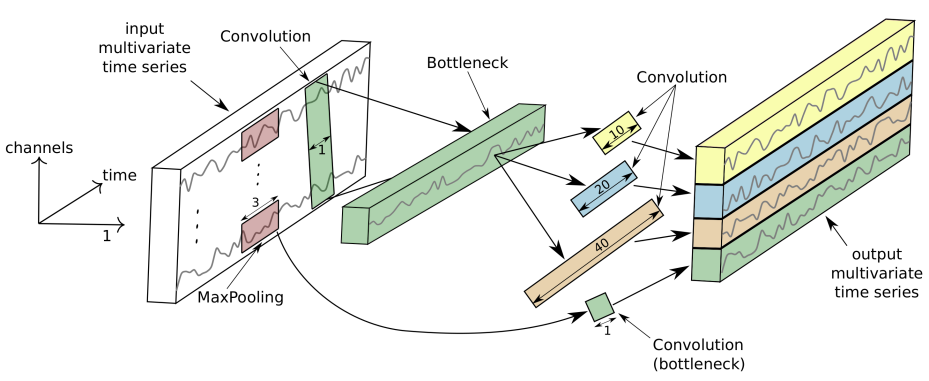


Figure 5: InceptionTime module[6].

IncetionTime[6]
Modules with convolutions of different lengths, global average pooling, and densely connected layers for classification.

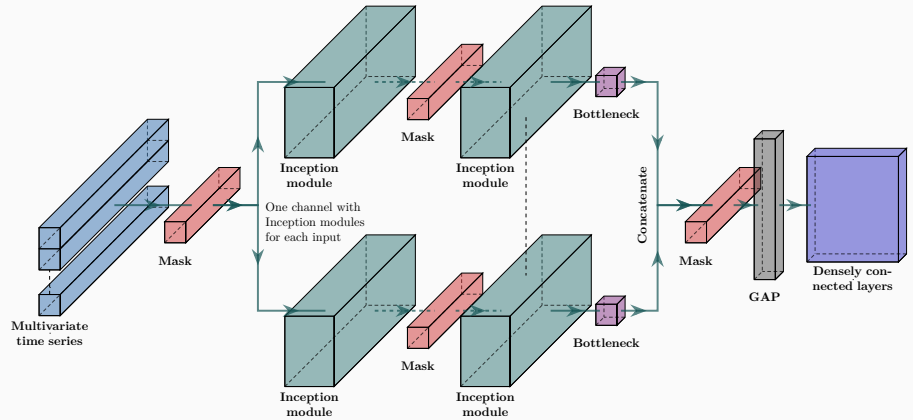


Figure 6: X-InceptionTime.

X-IncetionTime
Like InceptionTime, but input channels are kept separate.

[6] Fawaz et al., InceptionTime: Finding AlexNet for time series classification. 2020

Inputs to classification

Table 1: Input variables for the different POEs. Videos have been mirrored such that action is performed with right leg, if applicable.

Trunk	**Pelvis**	**Femoral Valgus**	**KMFP**
Left shoulder - x	Right shoulder - x	Right shoulder - x	Left shoulder - y
Right shoulder - x	Right shoulder - y	Right hip - x	Right hip - y
Right shoulder - y	Right hip - x	Right knee - y	Angle: right ankle and toes
Left hip - x	Right hip - y	Angle: right knee and ankle	Difference: right hip and knee - x
Left hip - y	Left hip - y		Difference: right knee and ankle - x
Right hip - x	Difference: right hip and knee - x		
Difference: right hip and knee - x	Difference: right knee and toes - x		

Time series classification - Ensembles

- Each classification is obtained from ensembles of 5 classifier models.
- 2 models perform well over all classes - CORAL[7] ordinal classifiers.
- Remaining models optimized for low false positive rates for one class each - class weights or modified cross-entropy loss.

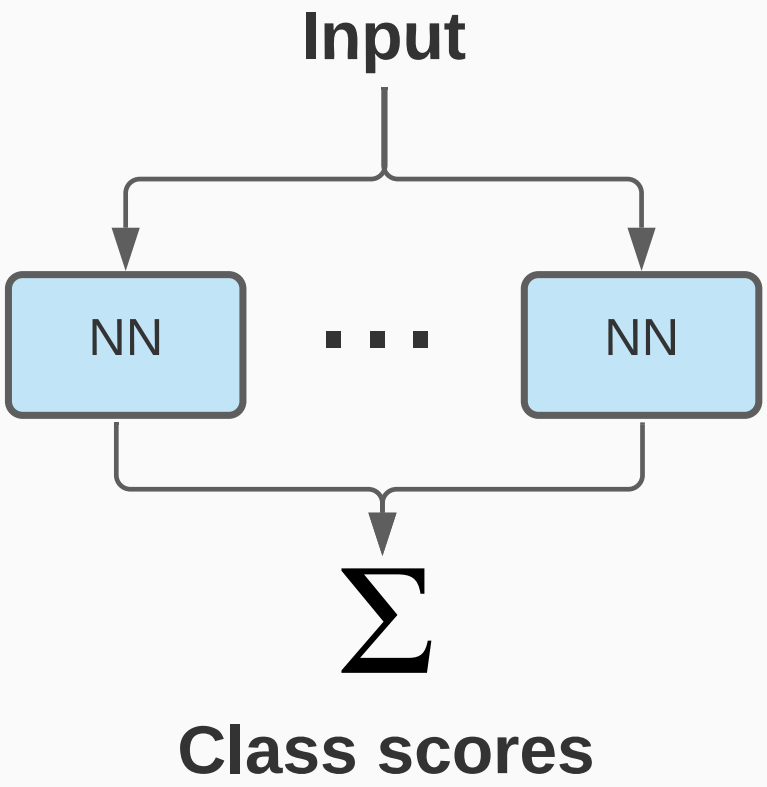


Figure 7: Ensemble struture used for classification.

[7] Cao et al., Rank consistent ordinal regression for neural networks with application to age estimation. 2019

Results

Data

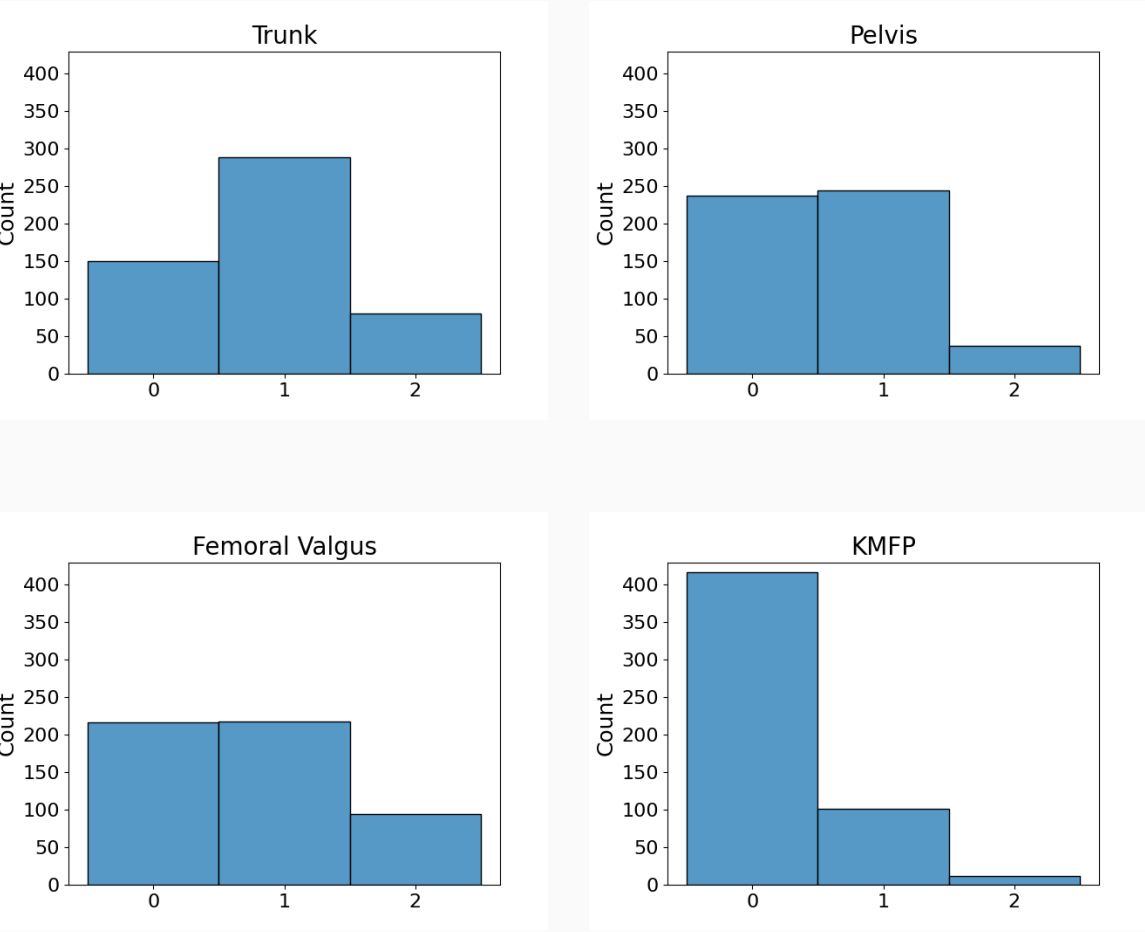


Figure 8: Class distributions for the different POEs.

- Videos with 4-5 repetitions.
- 103 unique subjects.
- Assessments for right and left leg for some subjects/POEs - 105-107 assessed videos, 519-530 repetitions.
- 20% (22 unique subjects, 110 repetitions) test set.
- 10-fold cross-validation used. Results shown are mean ($\pm$ std) of the 10 resulting models on test set.

Trunk

Accuracy (%): 73.7±4.5 75.0±7.9

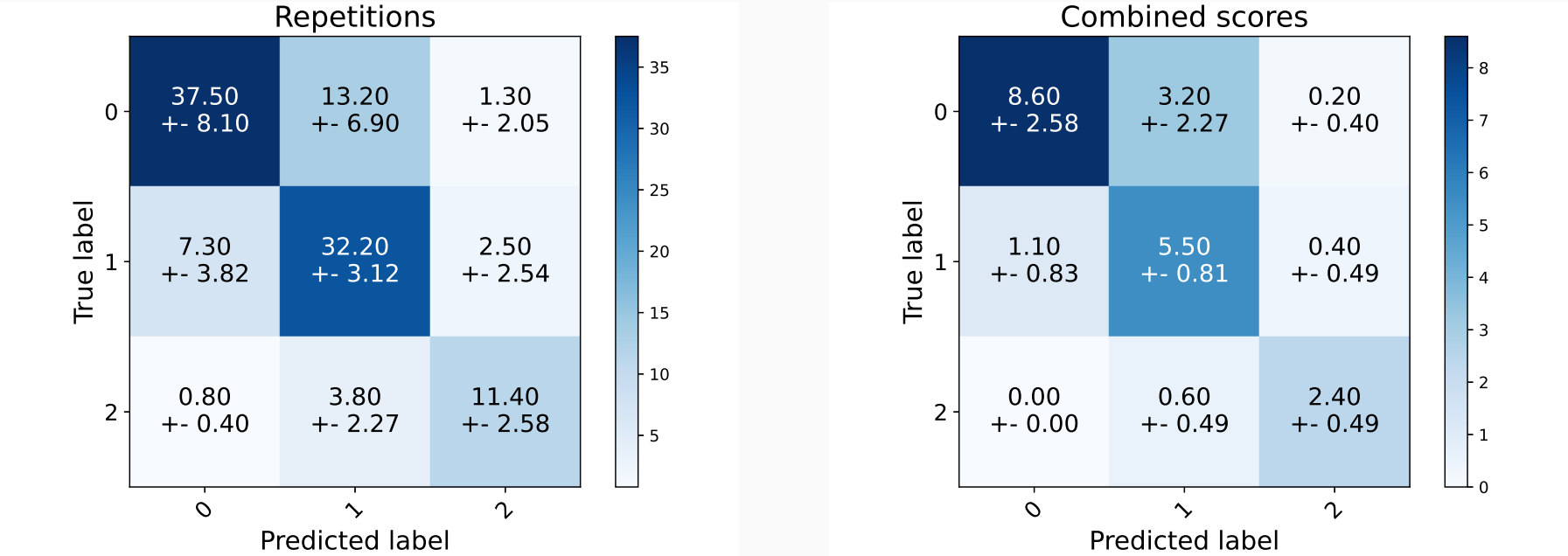


Figure 9: Confusion matrices for the classification of the repetitions (left) and the combined scores (right).

Pelvis

Accuracy (%): 63.6±10.7 69.1±10.1

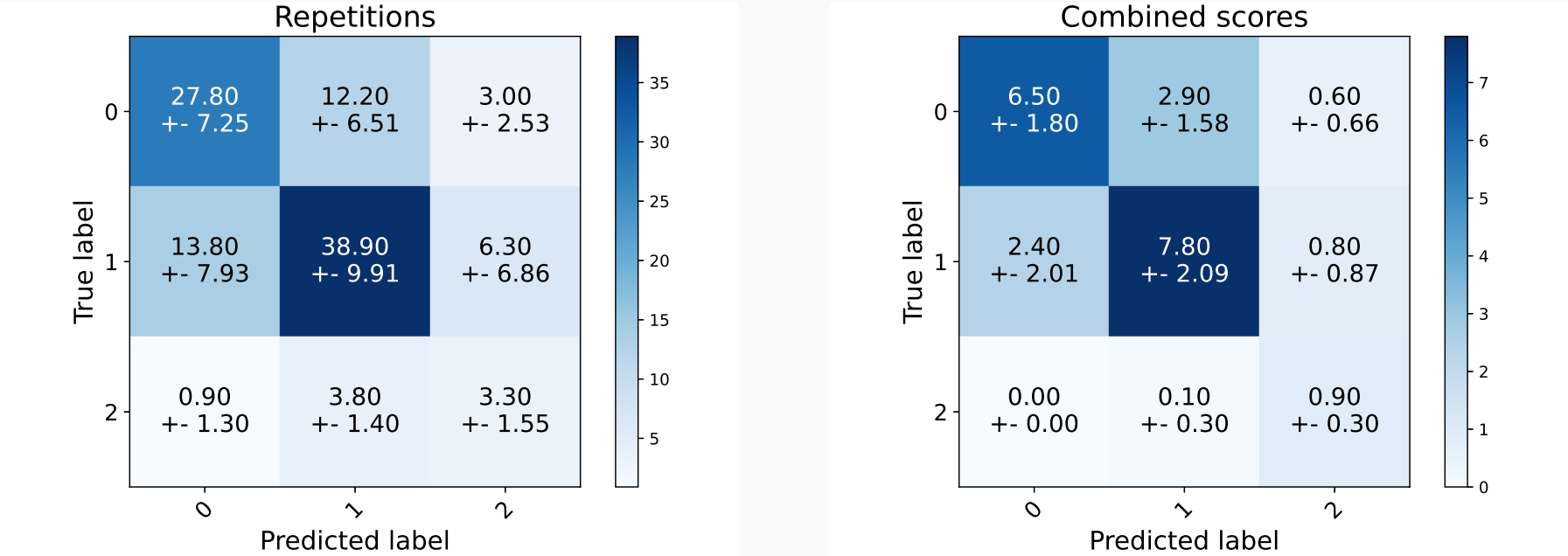


Figure 10: Confusion matrices for the classification of the repetitions (left) and the combined scores (right).

Femoral Valgus

Accuracy (%): 69.6±6.8 79.1±9.3

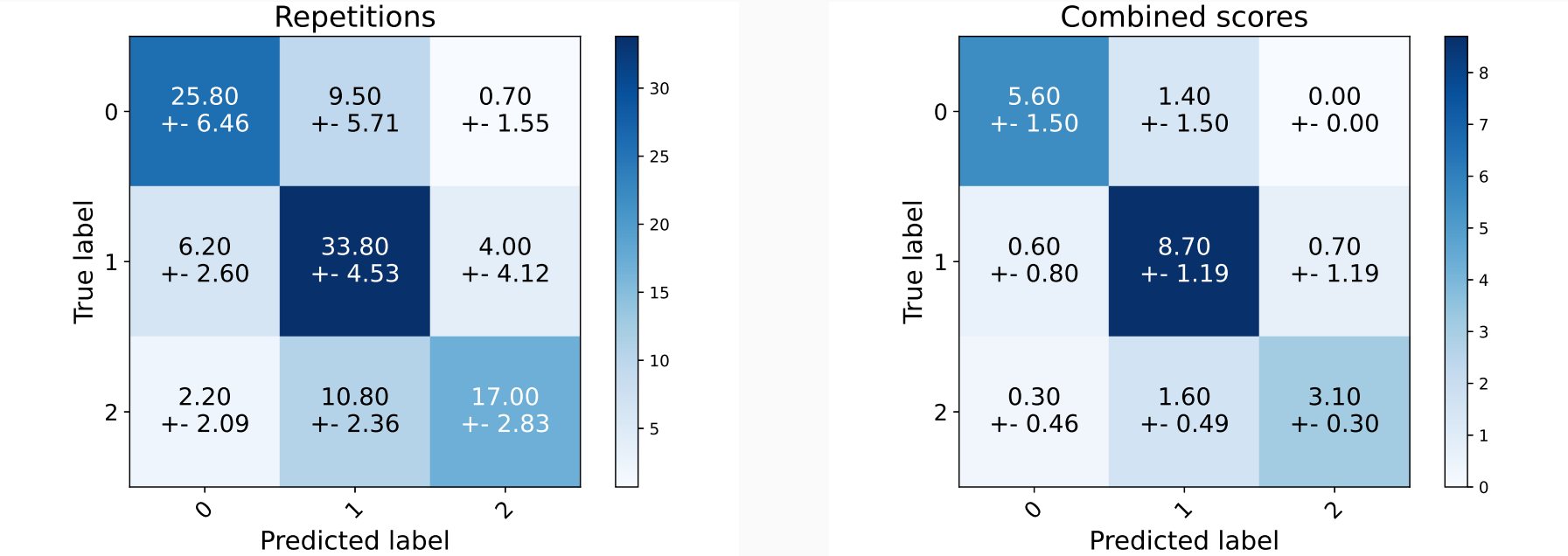
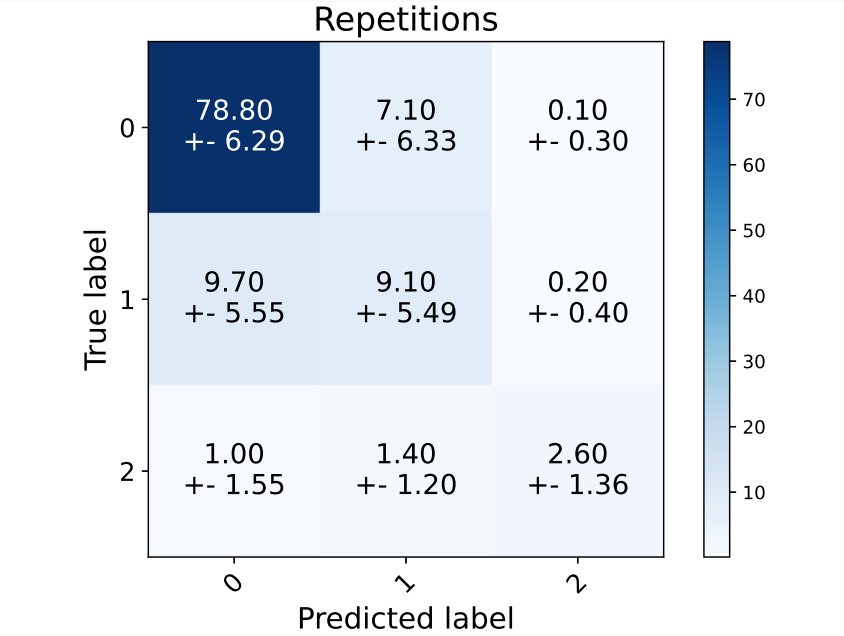


Figure 11: Confusion matrices for the classification of the repetitions (left) and the combined scores (right).

Knee Medial-to-Foot Position

Accuracy (%): 82.3±3.1 89.5±4.5



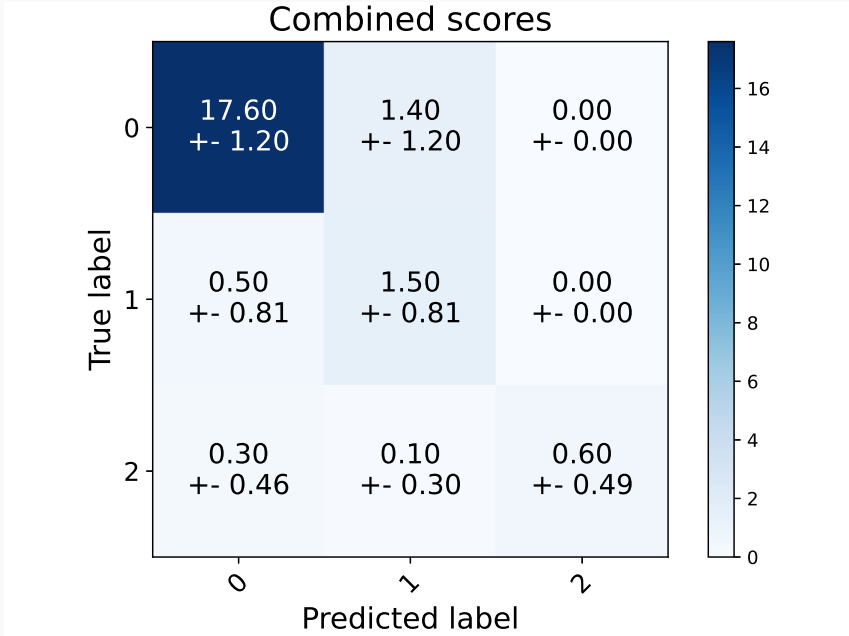


Figure 12: Confusion matrices for the classification of the repetitions (left) and the combined scores (right).

Summary

Table 2: Summary of results, here the combined scores with thresholds removing samples the models are uncertain about.

	Trunk	**Pelvis**	**Femoral Valgus**	**KMFP**
Accuracy (%)	80.0±7.8	73.3±18.9	82.3±6.0	90.3±4.3
F1 score (%)	79.9±8.9	73.6±22.3	81.0±5.2	74.0±22.3
Recall (%)	81.6±7.2	77.9±14.9	79.5±5.5	81.1±24.7
Precision (%)	83.0±6.8	74.9±23.8	86.5±5.6	71.4±22.6

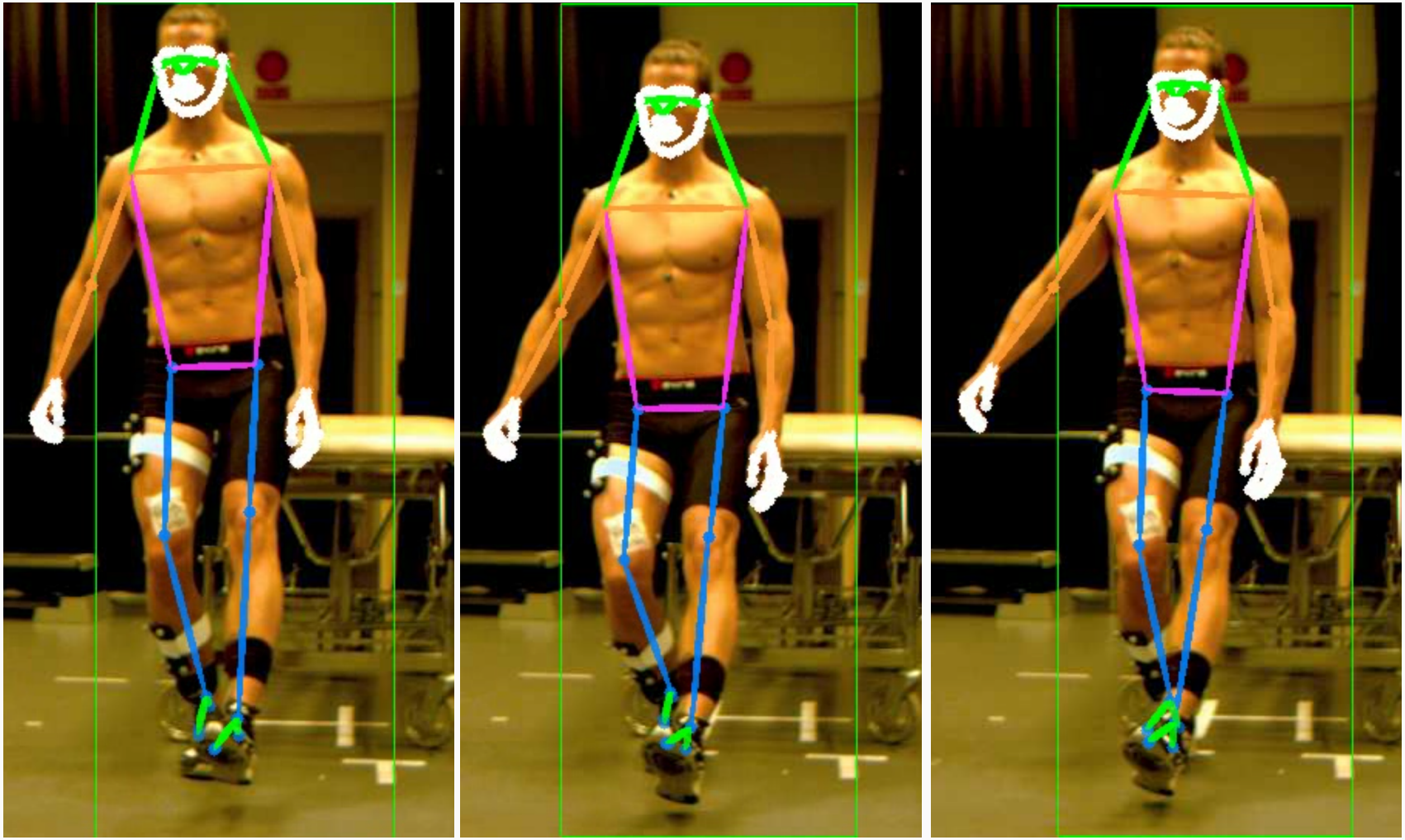
Conclusions and Future work

Conclusions and Future work

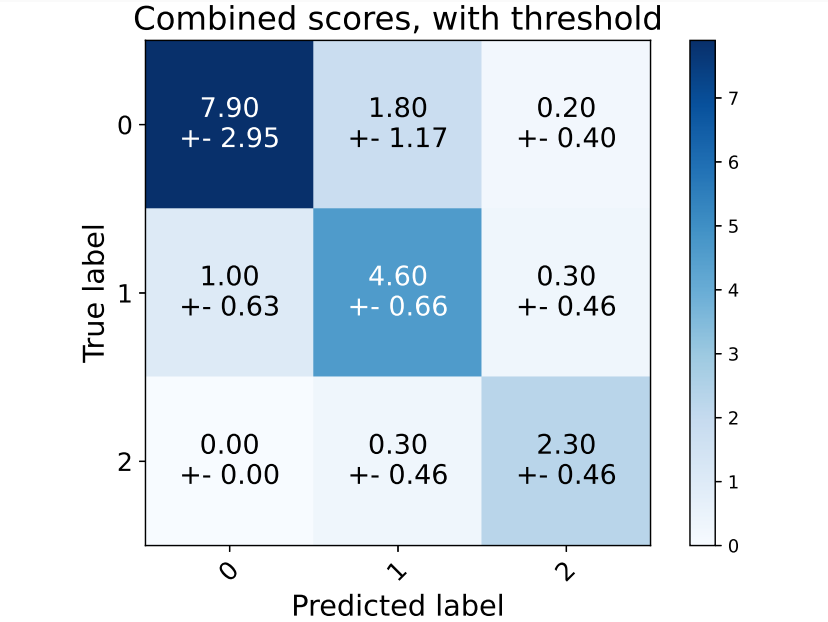
- The results suggests the proposed method could automate assessments.
- Large variance in results suggests more data needed.
- Future work:
  - Label videos differently.
  - Evaluate 3D coordinates.
  - Assess more POEs and motions.

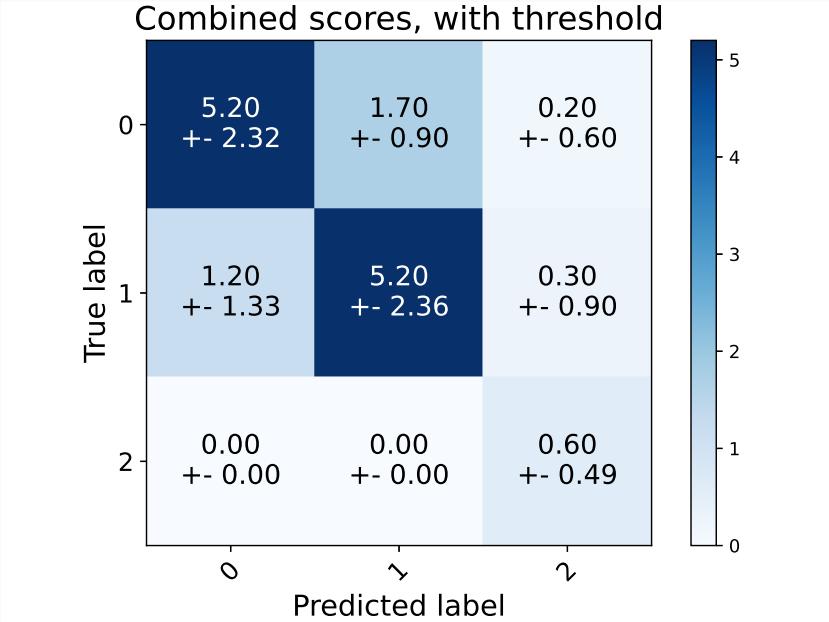
Thank you

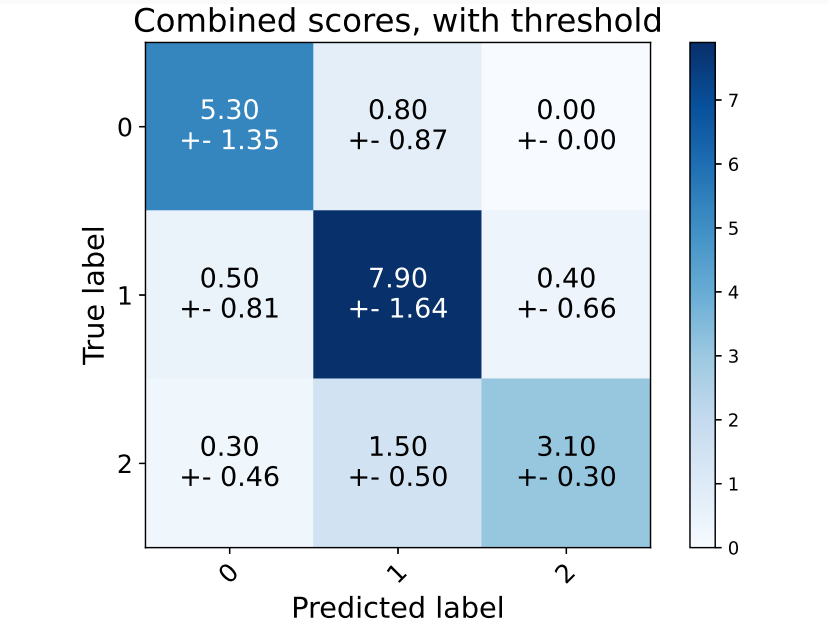
Occluded body parts

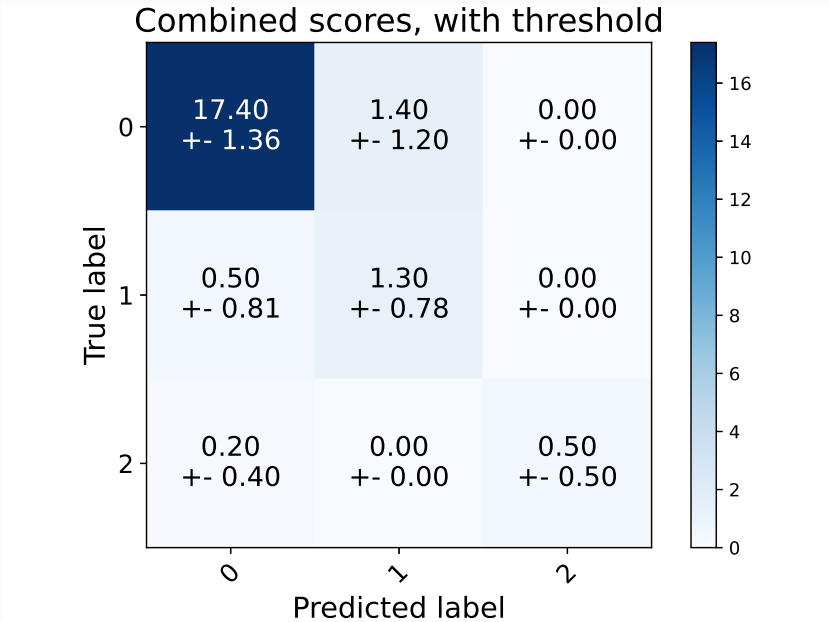


Confusion matrices for patient scores with thresholds

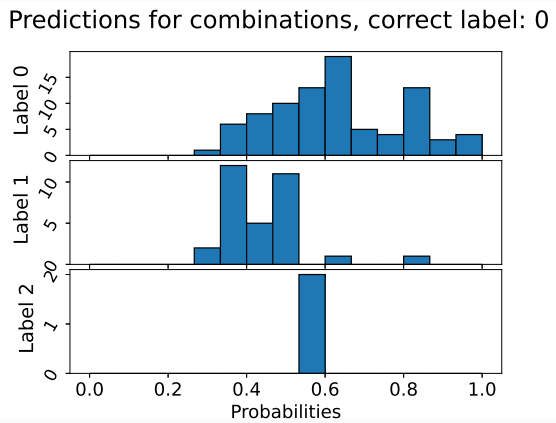


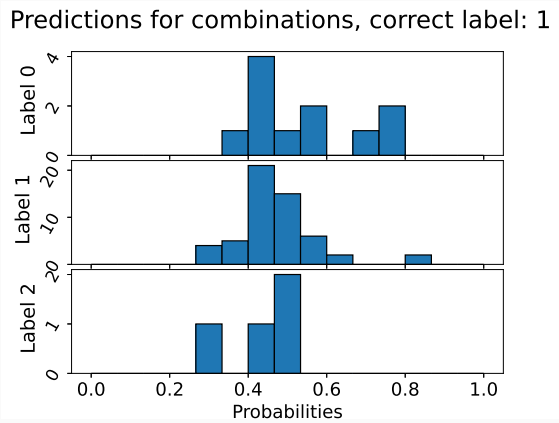


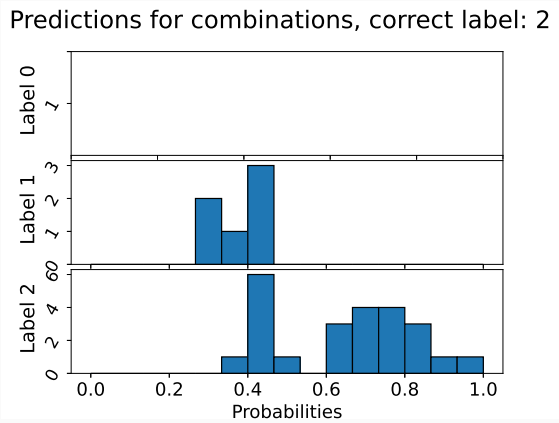




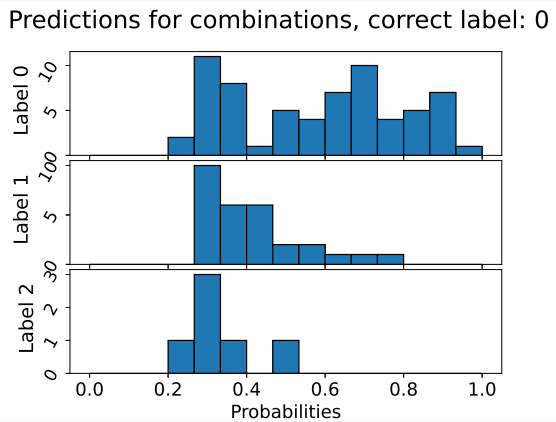
Ensemble's confidence in predicted classes - Trunk

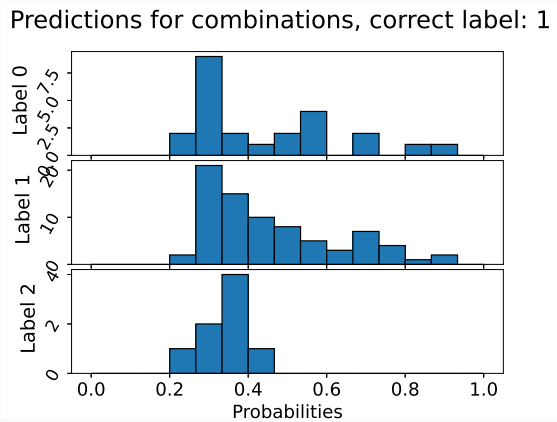


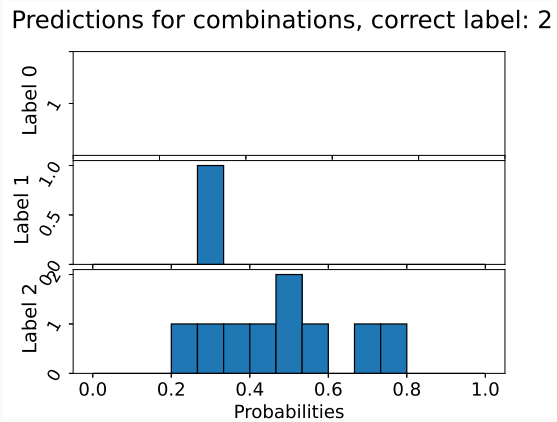




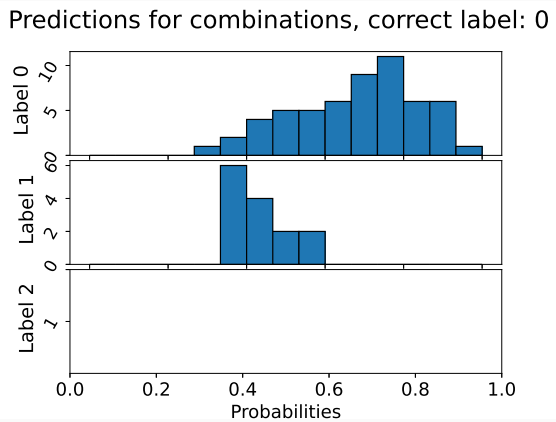
Ensemble's confidence in predicted classes - Pelvis

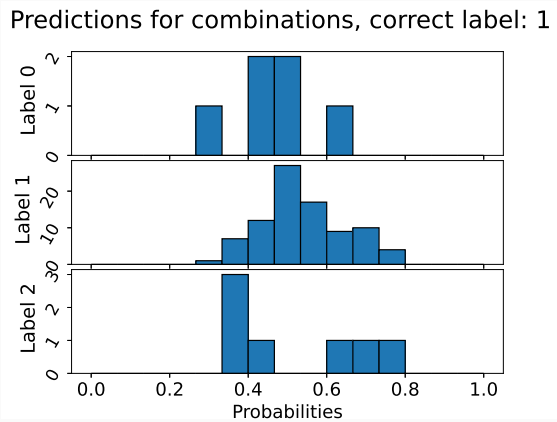


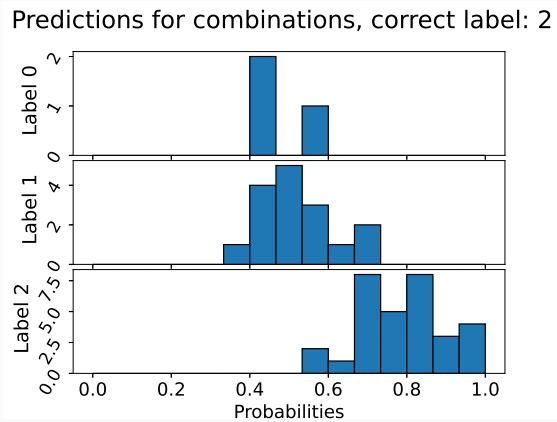




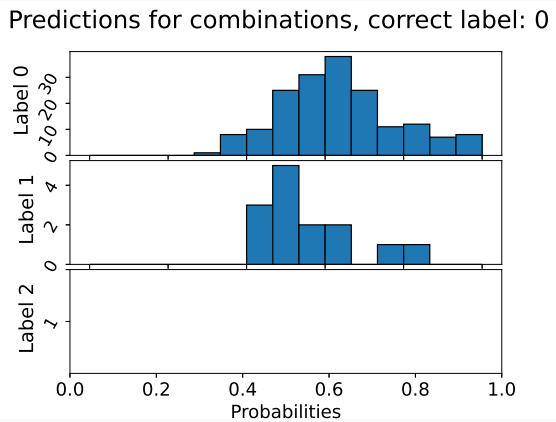
Ensemble's confidence in predicted classes - Femoral Valgus

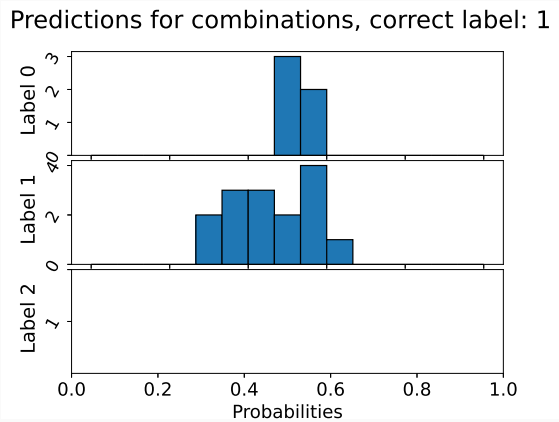


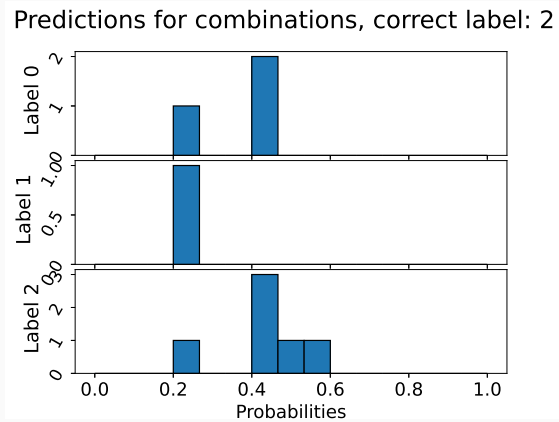




Ensemble's confidence in predicted classes - KMFP







Descriptions for the visual assessments

Segment-specific POEs	Scoring of 0: Good (no POE)	Scoring of 1: Fair (minor POE)	Scoring of 2: Poor (major POE)
Deviation of trunk in any plane	The absence of a trunk position into forward lean, lateral lean and/or rotation indicates no POE	A slight position of the trunk into forward lean, lateral lean and/or rotation indicates minor POE	A clear position of the trunk into forward lean, lateral lean and/or rotation indicates major POE
Deviation of pelvis in any plane	The absence of pelvis into lateral deviation, pelvic tilt and/or rotation of pelvis respectively indicates no POE	A slight position of the pelvis into lateral deviation, pelvic tilt and/or rotation of pelvis respectively indicates minor POE	A clear position of the pelvis into lateral deviation, pelvic tilt and/or rotation of pelvis respectively indicates major POE
Femoral valgus	The absence of femoral valgus indicates no POE	A slight position of femoral valgus indicates minor POE	A clear position of femoral valgus indicates major POE
Knee Medial-to-Foot Position	Mid-point of patella is in line with or lateral to the second toe	Mid-point of patella is placed medial to the second toe	Mid-point of patella is clearly placed medial to the big toe

Loss functions

CORAL:

$$\mathcal{L}(\boldsymbol{x}, \boldsymbol{W}, \boldsymbol{b}) = -\sum_{n=1}^{N}\sum_{k=1}^{K-1} \lambda^{(k)}[\log(\sigma(g(\boldsymbol{x}_n, \boldsymbol{W}) + b_k))y_n^{(k)} + \log(1 - \sigma(g(\boldsymbol{x}_n, \boldsymbol{W}) + b_k))(1 - y_n^{(k)})] \tag{1}$$

Confusion-entropy:

$$\mathcal{L}(\boldsymbol{x}, \boldsymbol{W}, U) = -\sum_{i=1}^{K}\sum_{j=1}^{K} u_{ij} \log \sum_{n=1}^{N} y_n^{(i)} \hat{y}_n^{(j)}(x_n, \boldsymbol{W}) \tag{2}$$

with U, e.g., $\begin{bmatrix} 0.6 & 0.05 & 0.05 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \end{bmatrix}$

Data available for the different POEs

POE	Number of unique subjects	Number of repetition sequences	Number of repetitions
Trunk	103	105	520
Pelvis	103	105	519
Femoral Valgus	103	107	530
KMFP	103	107	530

Detailed results - Trunk

	Rep.	Comb.	Thresh.	Certainties		
				1(n=15)	2(n=6)	3(n=1)
Accuracy (%)	73.7±4.5	75.0±7.9	**80.0±7.8**	**81.3±7.1**	56.7±15.2	90.0±30.0
F1 score (%)	73.1±3.4	75.0±5.8	**79.9±8.9**	**80.4±7.1**	25.8±6.3	90.0±30.0
Recall (%)	73.3±3.7	76.7±3.8	**81.6±7.2**	**81.1±5.0**	28.0±11.0	30.0±10.0
Precision (%)	76.7±4.1	78.7±5.2	**83.0±6.8**	**84.9±5.9**	28.9±6.8	30.0±10.0

Detailed results - Pelvis

	Rep.	Comb.	Thresh.	Certainties		
				1(n=14)	2(n=7)	3(n=1)
Accuracy (%)	63.6±10.7	69.1±10.1	**73.3±18.9**	67.9±15.0	**70.0±19.6**	80.0±40.0
F1 score (%)	55.7±13.4	66.5±15.0	**73.6±22.3**	58.0±20.1	**63.7±23.8**	31.7±17.4
Recall (%)	57.3±12.0	75.3±14.0	**77.9±14.9**	56.8±20.7	**64.6±22.8**	31.7±17.4
Precision (%)	58.3±14.9	67.0±14.4	**74.9±23.8**	62.5±19.7	**68.4±24.0**	31.7±17.4

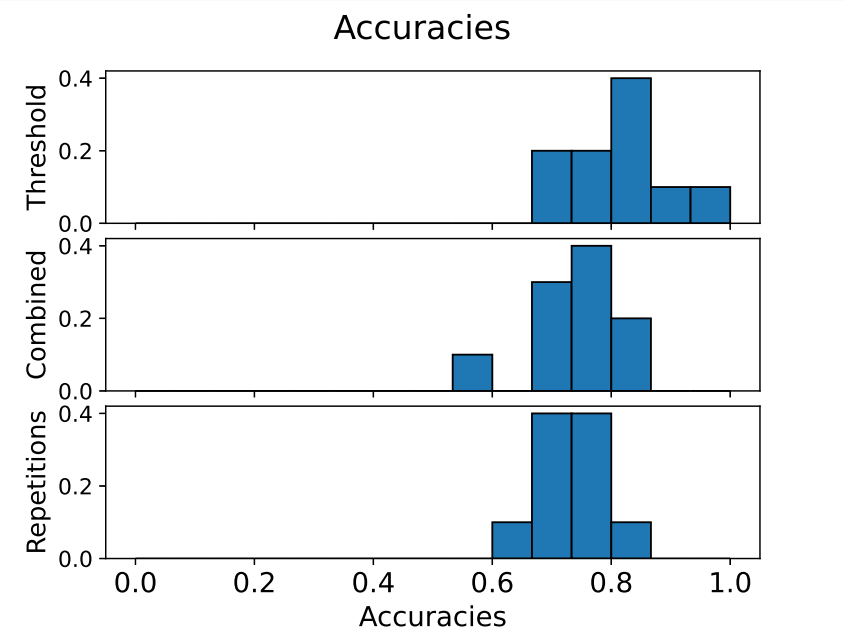
Detailed results - Femoral Valgus

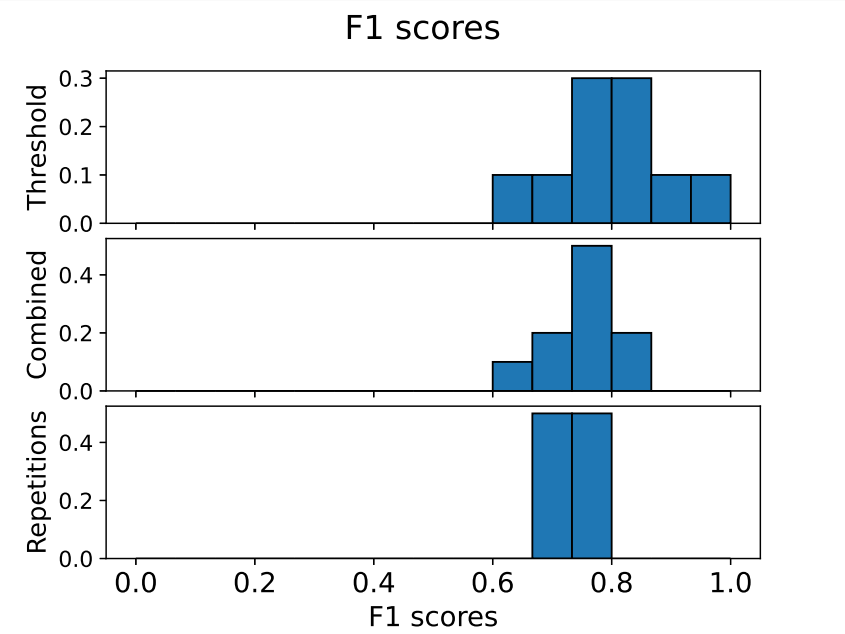
	Rep.	**Comb.**	**Thresh.**	**Certainties**		
				1(n=15)	2(n=7)	3(n=0)
Accuracy (%)	69.6±6.8	79.1±9.3	**82.3±6.0**	**82.7±9.5**	71.4±11.0	-
F1 score (%)	69.0±6.6	77.6±8.6	**81.0±5.2**	**80.8±8.6**	70.1±9.4	-
Recall (%)	68.4±6.3	76.3±8.1	**79.5±5.5**	**80.4±7.4**	71.1±9.5	-
Precision (%)	74.0±7.4	83.8±7.4	**86.5±5.6**	**85.2±7.6**	81.8±6.6	-

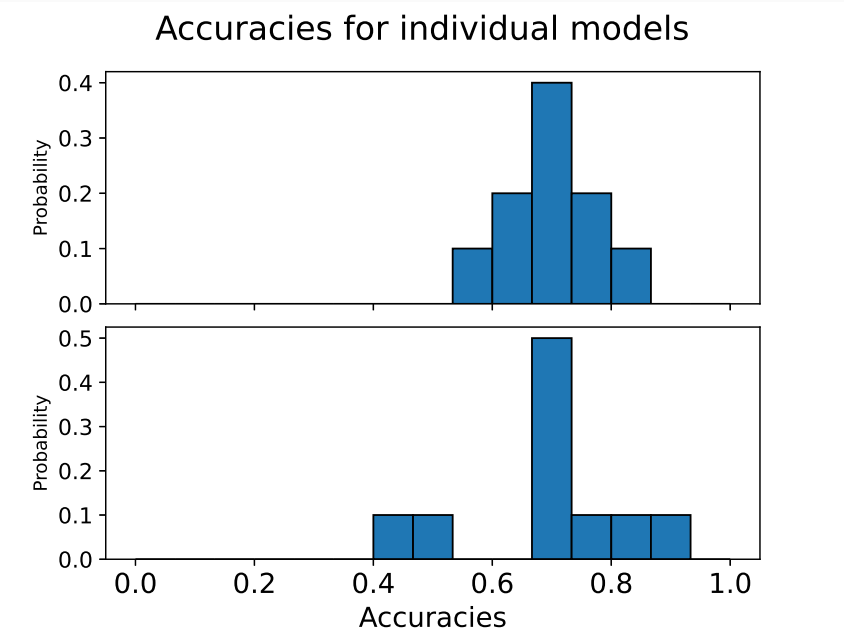
Detailed results - KMFP

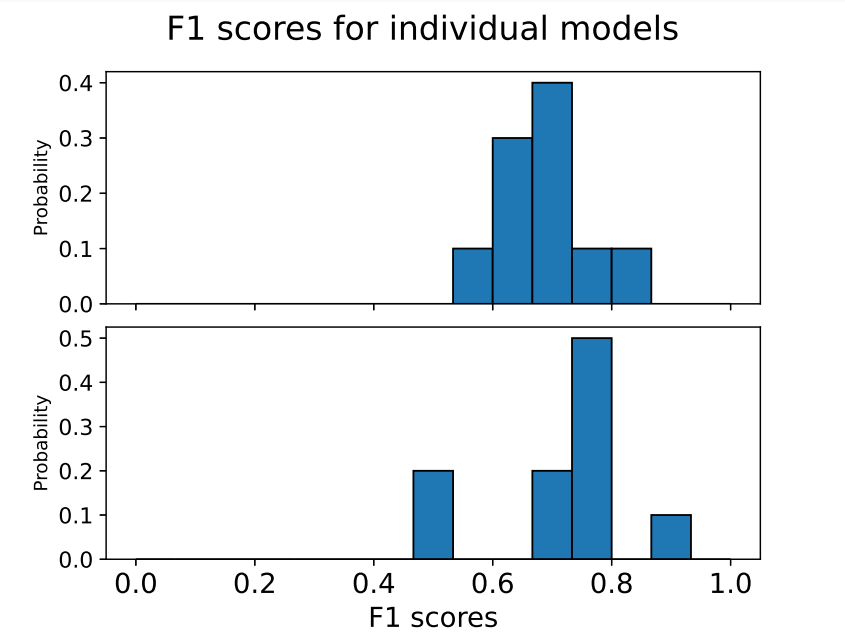
	Rep.	**Comb.**	**Thresh.**	**Certainties**		
				1(n=19)	2(n=2)	3(n=1)
Accuracy (%)	82.3±3.1	89.5±4.5	**90.3±4.3**	**92.6±5.3**	90.0±20.0	30.0±45.8
F1 score (%)	65.1±13.7	69.0±24.6	**74.0±22.3**	**69.3±28.6**	57.8±17.8	10.0±15.3
Recall (%)	63.8±14.4	75.9±26.7	**81.1±24.7**	**75.3±29.4**	60.0±13.3	10.0±15.3
Precision (%)	**78.5±8.2**	66.1±24.0	71.4±22.6	**67.2±28.9**	56.7±20.0	10.0±15.2

Histograms over accuracies and F1 scores - Trunk

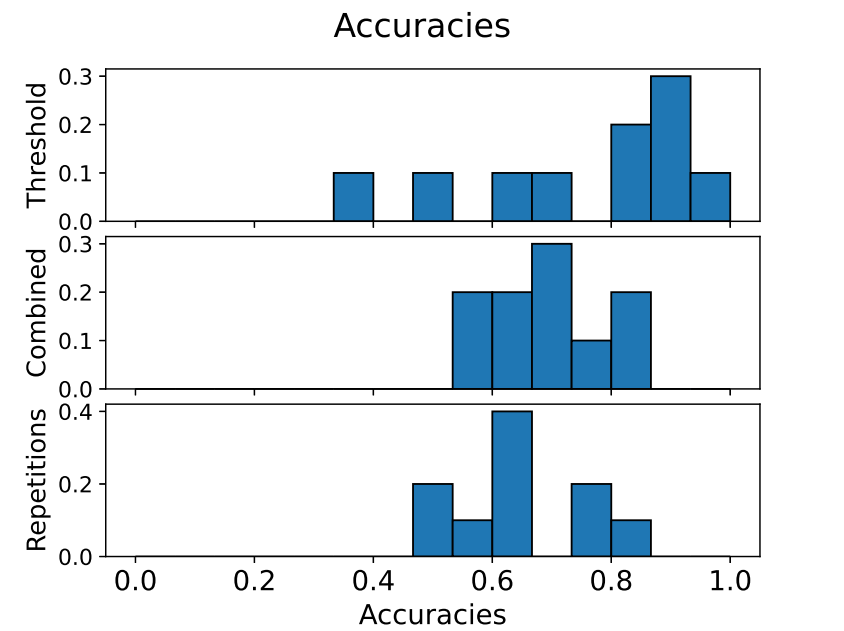


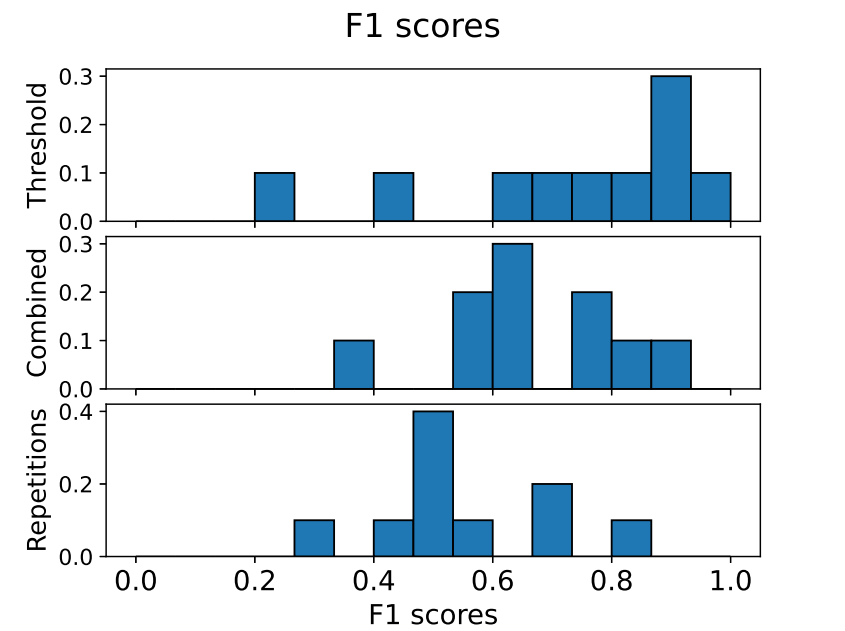


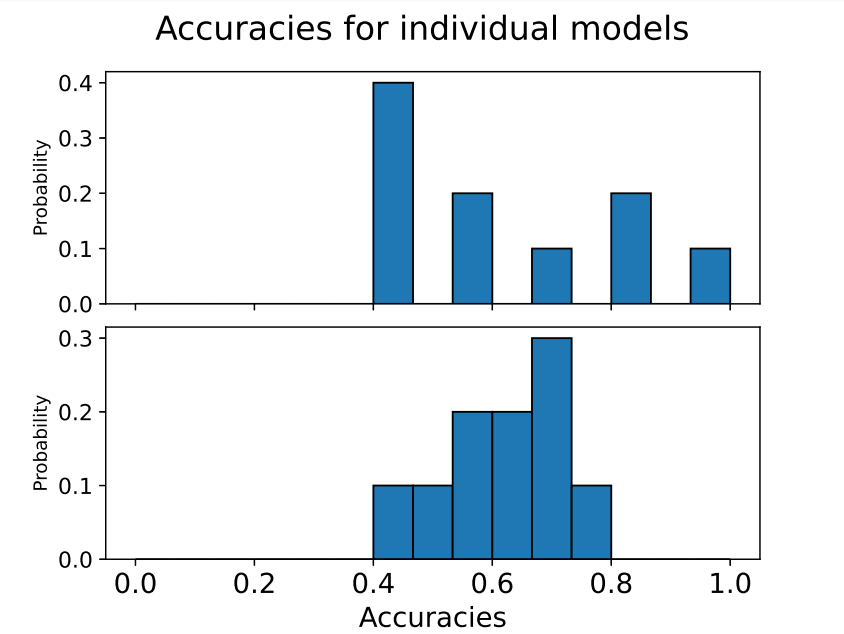


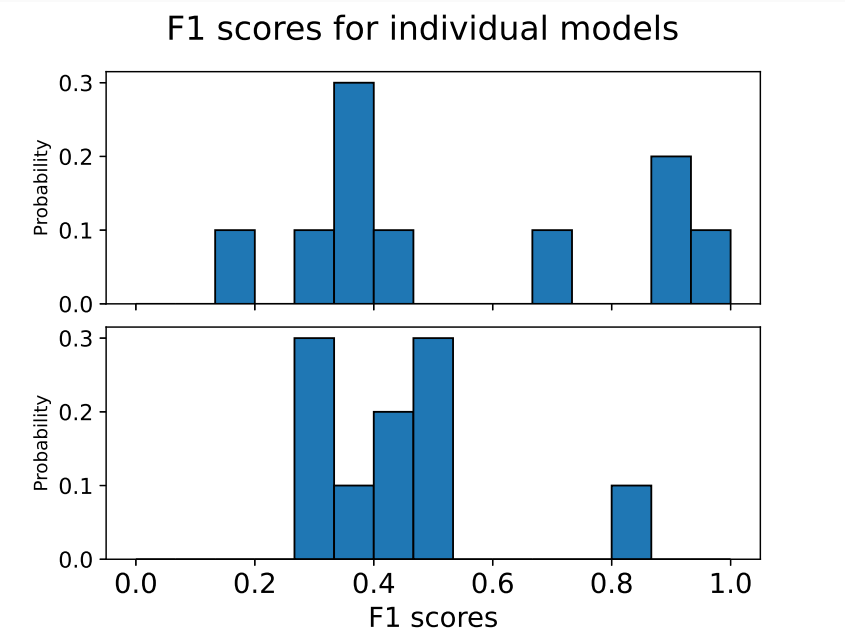


Histograms over accuracies and F1 scores - Pelvis

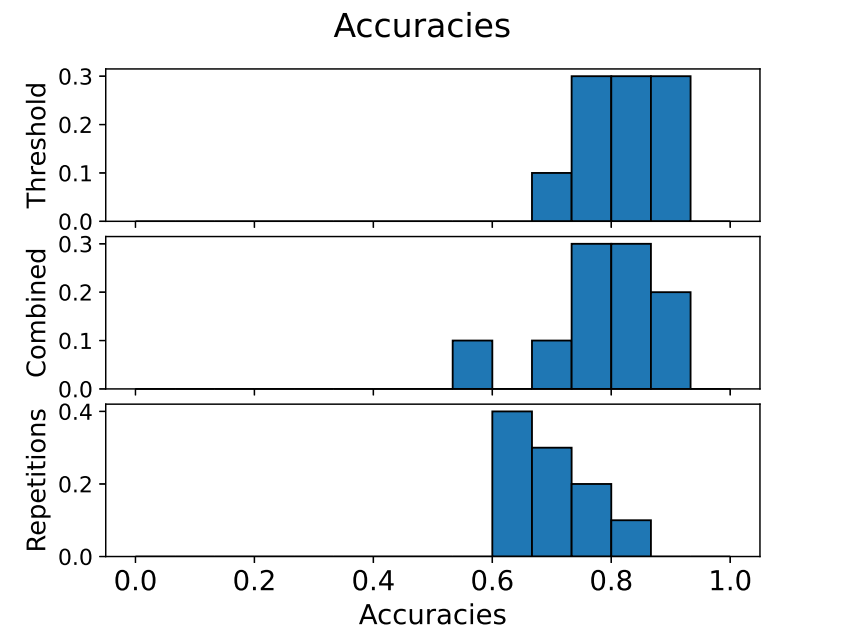


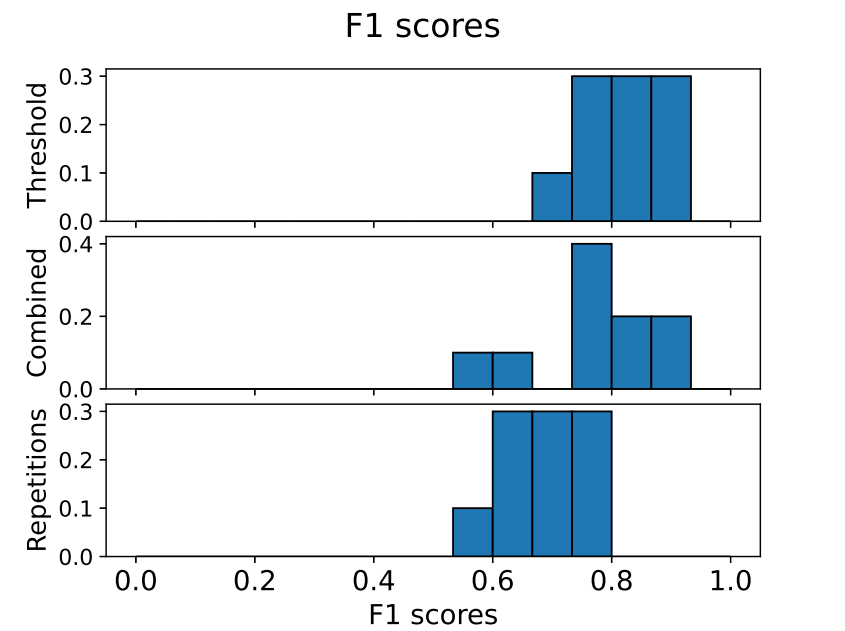


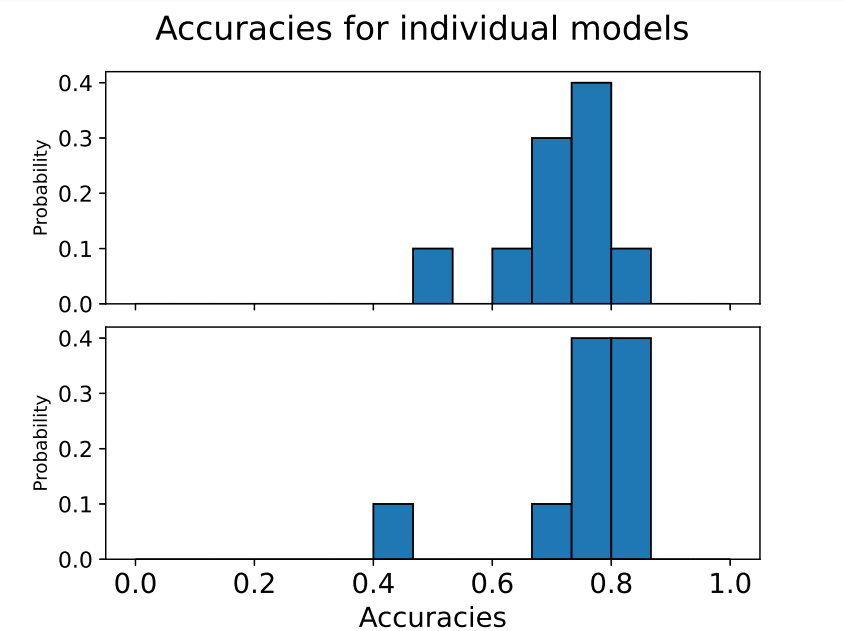


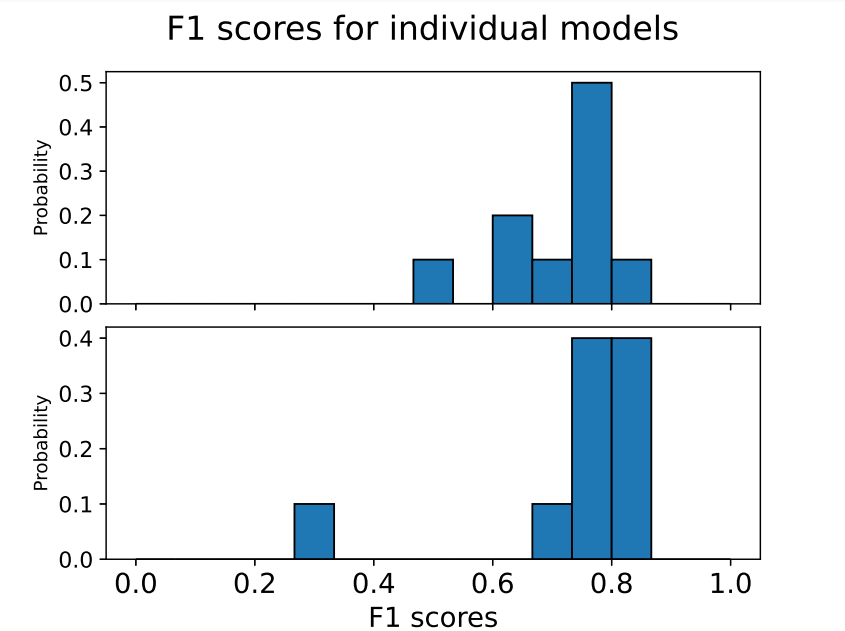


Histograms over accuracies and F1 scores - Femoral Valgus









Histograms over accuracies and F1 scores - KMFP