

Supplemental

From Video to Stability: Learning Dynamics from Kinematics of Human Motion

Anonymous ECCV submission

Paper ID 4366

1 Example Poses of 24-form Taiji

To better understand what 24-form Taiji is and what movements are part of this performance, Figures 1 and 2 is provided to visualized the key poses of 24-form, in addition to the videos provided with this supplemental document.

2 Ordinary Activities

Table 1: Comparison of foot pressure error metrics on a subset of simple ordinary movements of all subjects as compared to results on the entire dataset.

Comparison of data subset using MAE, SIM, KLD, & IG (Mean/Std)												
Complete Dataset					Ordinary Movement Subset							
Model	MAE	SIM	KLD	IG	MAE	SIM	KLD	IG				
PNS2	8.95 / 2.53	0.39 / 0.12	3.01 / 2.54	-0.53 / 0.42	8.53 / 1.51	0.45 / 0.08	2.50 / 1.22	-0.66 / 0.31				
PNS3	8.48 / 2.21	0.43 / 0.11	2.25 / 1.76	-0.39 / 0.33	7.74 / 1.31	0.50 / 0.07	2.18 / 0.99	-0.58 / 0.25				
PNS3B	8.50 / 2.40	0.43 / 0.12	2.68 / 2.21	-0.52 / 0.41	7.84 / 1.40	0.49 / 0.08	2.48 / 1.06	-0.72 / 0.29				
PN3BK	NA / NA	0.42 / 0.11	1.38 / 0.51	-0.21 / 0.08	NA / NA	0.47 / 0.07	1.22 / 0.29	-0.26 / 0.05				

Table 2: Comparison of CoP and BoS metrics on a subset of simple ordinary movements of all subjects as compared to results on the entire dataset.

Comparison of data subset using IoU & CoP (Med/rStd)				
Complete Dataset			Ordinary Movement Subset	
Model	CoP	IoU(BoS)	CoP	IoU(BoS)
PNS2	0.68 / 0.16	39.85 / 27.98	0.65 / 0.20	47.10 / 35.02
PNS3	0.69 / 0.18	29.87 / 21.30	0.67 / 0.20	39.05 / 31.00
PNS3B	0.73 / 0.14	32.52 / 21.81	0.67 / 0.20	41.81 / 32.56
PN3BK	0.72 / 0.15	35.87 / 25.94	0.66 / 0.21	44.72 / 35.72



Fig. 1: A visualization of the first half of key poses in 24-form Taiji [4]. The forms follow the order of left to right, top to bottom, starting from the opening pose in the top left. Images include illustration, Subject 7 and Subject 10.

As indicated in Section 5, lines 609-611 in the main paper, quantitative evaluations on a subset of ordinary poses shows that networks trained on Taiji movements can be generalized to non-Taiji-specific poses. Tables 1 and 2 present quantitative results when a subject is performing a subset of movements that are part of ordinary activities. The following movements are part of the subset: 1 - standing with right hand behind, 2 - standing with two arms down, 3 - left side stepping, 4 - BUMP (arm) to left, 5 - BUMP (arm) to right, 6 - pushing to left, 7 - pushing to the right, 8 - left kick, and 9 - right kick. These results are compared to the full dataset showing that the full dataset is representative of ordinary movements. Figure 3 provides example poses for each of the ordinary movements as recorded for Subject 2.

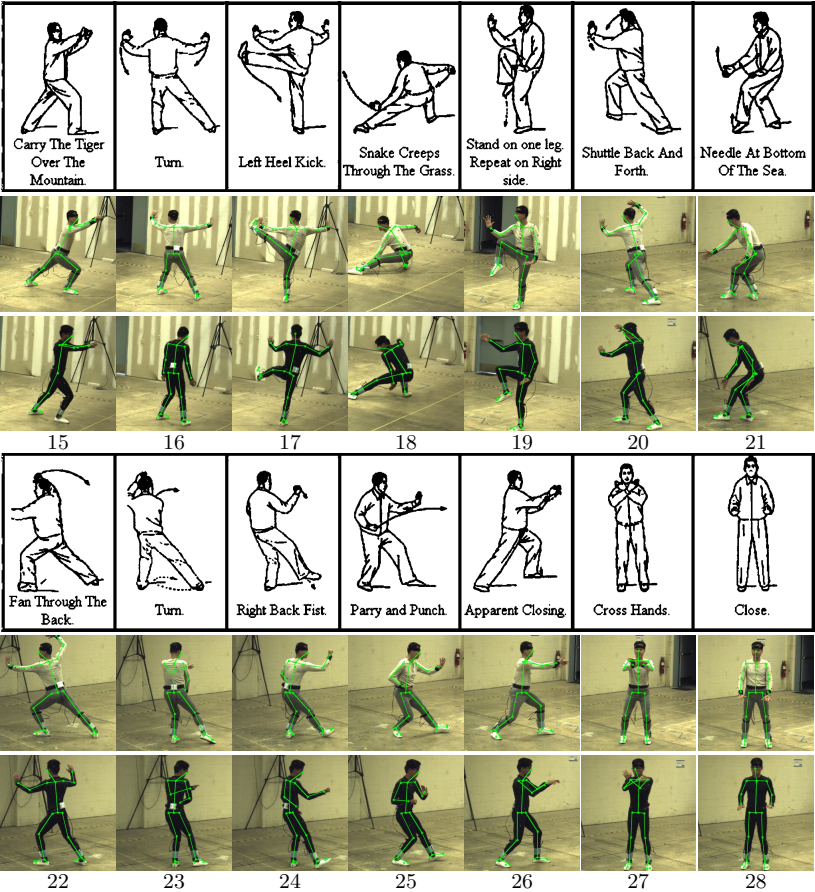


Fig. 2: A visualization of the second half of key poses in 24-form Taiji [4]. The forms follow the order of left to right, top to bottom, starting with Figure 1. Images include illustration, Subject 7 and Subject 10.

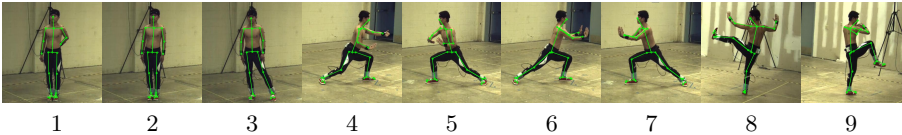


Fig. 3: Example poses from Subject 2 - Session 1 - Take 1 used as part of the subset of ordinary movements used in the quantitative evaluation provided in Table 1. The movemetns are as follows: 1 - standing with right hand behind, 2 - standing with two arms down, 3 - left side stepping, 4 - BUMP (arm) to left, 5 - BUMP (arm) to right, 6 - pushing to left, 7 - pushing to the right, 8 - left kick, and 9 - right kick.

3 Example Videos

Included with this supplemental document are result videos for two of the 10 subjects. Subject 1 (Best) and Subject 2 (Worst) are included to visualize the basic range of performance of select network configurations. Similar to the frames provided in Figure 8, lines 495-518 in the main paper, each video contains a composite of the input video with pose overlay from View 1, ground truth measured foot pressure, PNS2, PNS3, and PNS3B foot pressures, and the resulting BoS and CoP from each pressure source. The videos show a consistency in BoS and CoP temporally as well as an ability to adapt to different subjects.

4 Pose Data Variations

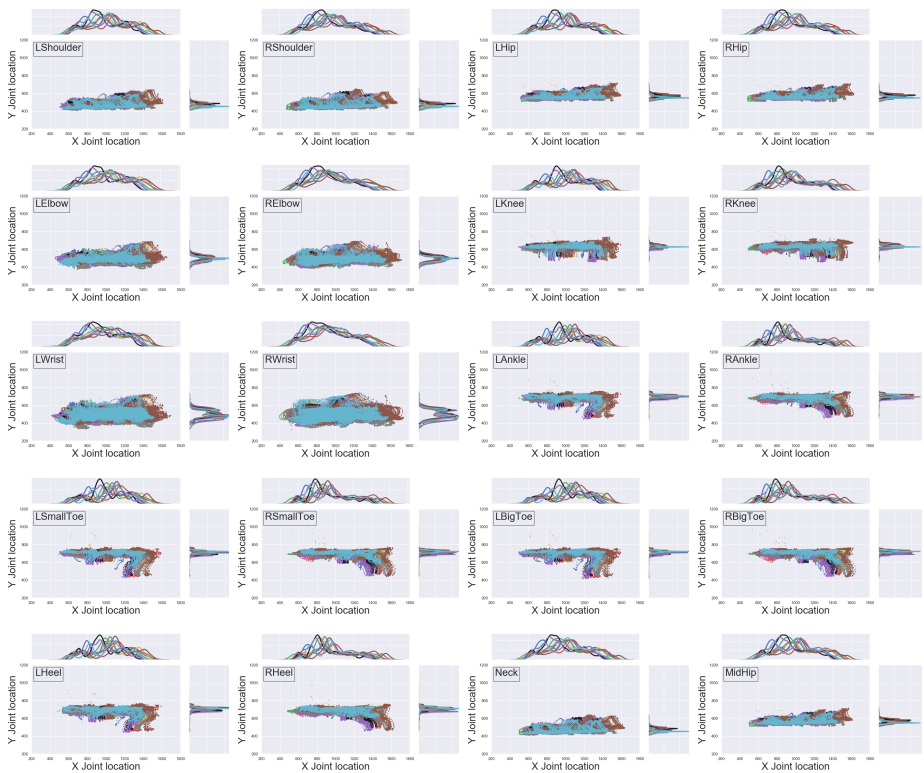


Fig. 4: Per body joint Kernel Density and scatter plots of OpenPose [2] data for all subjects showing spatial similarity of joints between subjects in the dataset. The data for each subject is represented with different colors. Subject Colors: 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10.

As discussed in Main Paper Section 3.1 (Lines 244-246), Kernel Density Estimation (KDE) plots are used to show pose data variations among all subjects. Figure 4 shows per body joint KDE plots from the video frames extracted by

the OpenPose [2] network. These distributions support the hypothesis that even though the subjects' movements differ from each other, their spatial similarity fall under a reasonable statistical distribution (unimodal, Gaussian) for the major joints (shoulder, hip). Meanwhile, wrists and elbows demonstrate much larger variations than others.

5 Body Joint Detection Success Rates

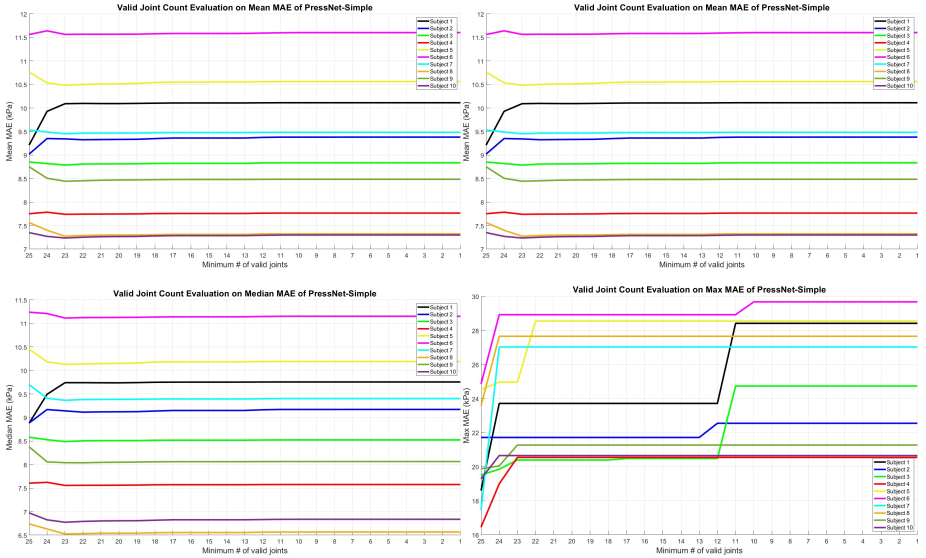


Fig. 5: Analysis of the impact of joint count on MAE of PressNet-Simple. Mean, Standard Deviation, Median, and Maximum (Left to Right, Top to Bottom) MAE are plotted based on the minimum number of valid joints, as defined by OpenPose, to visualize the impact of the accuracy of input joint accuracy on PNS2.

OpenPose does not always provide valid joint locations for all 25 joints in the Body25 model, as indicated by a confidence of 0 for joints that are not detected. Although all our pressure prediction methods can accommodate poses with any number of valid joints, our analysis in the paper focused only on frames where 25 or more valid joints were detected. Figure 5 presents the impact on PNS2 error statistics as number of detected joints decreases. Shown are the mean, standard deviation, median, and maximum MAE for each subject. While mean, standard deviation, and median errors increase noticeably when only a single joint is missing, they have minor increase as the number of missing joints increases beyond four. On the other hand, maximum errors increase sporadically as more joints get occluded, reaching a plateau when approximately half of the body joints are missing.

6 Impact of Mass, Height, Gender on Outcome

Table 3: A comparison of Mean Absolute Error (MAE) of foot pressure estimation results for KNN5, PN2, and PNS2 for each subject with subject parameter normalization. Included results are: the original MAE, normalized by subject mass (average mass / subject mass) and normalized by subject height (average height / subject height). Only outputs generated from 25 or more valid joints as input are included in the evaluation.

Mass and Height Normalization Comparison of KNN5, PN2, and PNS3 Mean Absolute Errors (kPa)															
	Original (Mean/Std)					Mass Normalized (Mean/Std)					Height Normalized (Mean/Std)				
Subject	KNN5	PN2	PNS2			KNN5	PN2	PNS2			KNN5	PN2	PNS2		
1	9.56 / 2.33	7.40	1.42	7.55 / 1.54		11.67 / 2.85	9.04	1.74	9.21 / 1.88		9.90 / 2.41	7.67	1.47	7.82 / 1.60	
2	9.98 / 3.37	9.31	2.68	9.44 / 2.93		9.54 / 3.22	8.89	2.56	9.02 / 2.80		9.62 / 3.24	8.96	2.59	9.09 / 2.82	
3	9.73 / 3.07	8.21	2.16	8.82 / 2.37		9.76 / 3.08	8.23	2.17	8.85 / 2.37		10.08 / 3.18	8.50	2.24	9.14 / 2.45	
4	10.91 / 3.03	8.91	2.41	9.38 / 2.42		9.01 / 2.51	7.36	1.99	7.75 / 2.00		10.63 / 2.96	8.68	2.35	9.15 / 2.36	
5	11.21 / 3.22	9.80	2.39	10.14 / 2.53		11.90 / 3.42	10.40	2.54	10.76 / 2.68		11.90 / 3.42	10.40	2.54	10.77 / 2.68	
6	11.06 / 3.07	9.61	2.18	9.98 / 2.35		12.81 / 3.56	11.14	2.53	11.56 / 2.72		11.90 / 3.31	10.34	2.35	10.74 / 2.53	
7	11.08 / 2.94	10.50	2.18	10.18 / 2.23		10.38 / 2.76	9.84	2.04	9.53 / 2.09		10.86 / 2.89	10.29	2.14	9.98 / 2.19	
8	8.94 / 3.87	7.64	3.59	8.31 / 3.58		8.13 / 3.53	6.95	3.27	7.56 / 3.25		8.23 / 3.57	7.03	3.30	7.65 / 3.29	
9	9.26 / 3.14	6.97	2.68	8.24 / 2.88		9.83 / 3.34	7.40	2.85	8.75 / 3.05		9.41 / 3.20	7.08	2.73	8.38 / 2.92	
10	8.82 / 3.41	6.91	2.43	7.44 / 2.51		8.71 / 3.37	6.82	2.40	7.35 / 2.48		8.46 / 3.27	6.63	2.33	7.14 / 2.41	
Female Mean	10.16 / 2.97	8.40	2.17	8.95 / 2.33		11.19 / 3.25	9.24	2.36	9.83 / 2.54		10.64 / 3.10	8.80	2.27	9.37 / 2.44	
Female Std	0.81 / 0.32	1.14	0.42	1.00 / 0.44		1.20 / 0.25	1.37	0.38	1.13 / 0.39		1.05 / 0.35	1.36	0.43	1.21 / 0.45	
Male Mean	9.95 / 3.33	8.65	2.66	8.95 / 2.73		9.15 / 3.08	7.97	2.45	8.24 / 2.52		9.56 / 3.19	8.32	2.54	8.60 / 2.61	
Male Std	0.95 / 0.33	1.26	0.49	0.96 / 0.48		0.76 / 0.38	1.19	0.46	0.87 / 0.46		1.08 / 0.24	1.34	0.41	1.05 / 0.40	
All Mean	10.06 / 3.15	8.53	2.41	8.95 / 2.53		10.17 / 3.16	8.61	2.41	9.04 / 2.53		10.10 / 3.14	8.56	2.40	8.98 / 2.52	
All Std	0.89 / 0.37	1.21	0.52	0.98 / 0.50		1.43 / 0.34	1.43	0.42	1.28 / 0.43		1.19 / 0.31	1.37	0.44	1.19 / 0.43	

As mentioned in Section 5 lines 604-606 in the main paper, the system performance is stable across subject weight, gender, height variations. Table 3 includes the Mean Absolute Error (MAE) data while additionally including results normalized by mass and by height respectively.

Mass: The mass normalization columns in Table 3 scale the MAE relative to the subject mass by calculating the ratio of average mass divided by subject mass, providing for a mass-adjusted comparison between subjects.

Gender: Mass normalization increases the difference between male and female subject's Mean Absolute Error as compared to the original data. This is expected, because female subjects tend to have lower mass, as supported by [3] and [5].

Height: Table 3 also contains results of a similar normalization using subject height rather than mass; however, this normalization does not lead to any additional insights.

7 CoP Robust Analysis

Figure 5 lines 405-421 of the main paper shows a bar chart for visual comparison of methods, reproduced here along with a line graph showing how the median CoP error changes with respect to a threshold range. Table 4 provides the corresponding numerical values at a 10 kPa pressure threshold. These are quantitative evaluations of CoP offsets using robust median analysis for each subject that help evaluate, in a statistically robust manner, the accuracy of CoP distributions in terms of the robust *Median* and robust STD (*rStd*) relative to ground truth measurements.

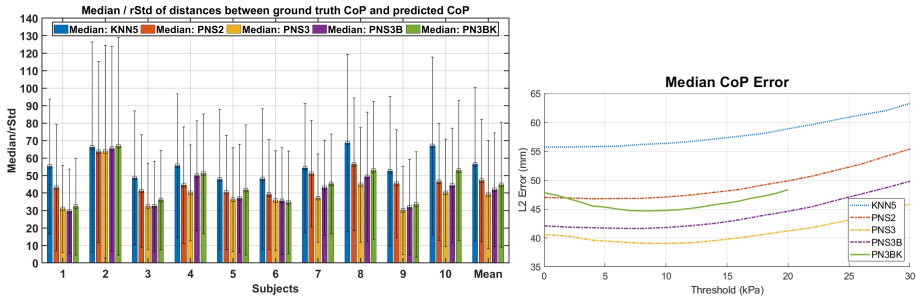


Fig. 6: A comparison of CoP offset distance errors across methods, subjects, and threshold characterized by robust estimation Median/rStd (robust STD). Table 4 contains the numerical results that relate to 10 kPa threshold.

Table 4: CoP geometric median and robust standard deviation ($rStd = 1.4826 \times$ median absolute deviation). The Median and rStd (Med/rStd) of Euclidean distances between ground truth CoP and the CoP of foot pressure maps predicted by KNN5, PNS2, PNS3, PNS3B, PN3BK, respectively.

Sub	CoP Robust Analysis - Median/rStd (mm)				
#	KNN5	PNS2	PNS3	PNS3B	PN3BK
1	55.23 / 38.53	43.09 / 36.24	30.88 / 24.83	29.57 / 24.14	32.21 / 27.67
2	66.12 / 60.24	63.53 / 51.79	63.70 / 60.73	65.33 / 58.60	66.80 / 62.23
3	48.61 / 38.31	41.14 / 32.13	32.25 / 24.53	32.45 / 25.72	36.03 / 28.51
4	55.67 / 41.02	44.50 / 33.30	40.03 / 27.43	49.91 / 31.40	51.14 / 34.11
5	47.75 / 40.14	40.34 / 32.71	36.11 / 29.74	36.93 / 30.95	41.75 / 37.23
6	48.04 / 40.14	39.15 / 31.40	35.57 / 28.61	35.42 / 30.44	34.71 / 29.33
7	54.22 / 37.09	51.01 / 30.43	37.11 / 25.26	43.04 / 27.12	45.16 / 28.57
8	68.55 / 50.70	56.42 / 37.91	44.61 / 32.81	49.28 / 37.01	52.95 / 39.39
9	52.56 / 42.76	45.38 / 30.75	30.13 / 25.26	31.89 / 27.35	33.50 / 30.14
10	66.96 / 50.75	46.39 / 33.51	40.13 / 30.80	44.27 / 32.82	52.96 / 40.05
Mean	56.37 / 43.97	47.10 / 35.02	39.05 / 31.00	41.81 / 32.56	44.72 / 35.72

8 IoU Robust Analysis

Figure 6 lines 422-434 of the main paper shows a line graph for visual comparison of methods over a range of pressure thresholds. Table 5 provides the corresponding numerical values at a 10 kPa pressure threshold. These are quantitative evaluations of BoS overlap (IoU) using robust median analysis for each subject. These results help evaluate, in a statistically robust manner, the accuracy of BoS distributions in terms of the robust *Median* and robust STD (*rStd*) relative to ground truth measurements.

9 Influence of number of subjects

Considering the goal of predicting foot pressure from pose, an evaluation was performed to determine if our dataset of 10 subjects is sufficiently large to allow for meaningful deep learning and generalization. Section 5 lines 604-606 of the main paper noted that system performance is stable with respect to the number of subjects in the training/testing dataset. Figure 7 is included to support that

Table 5: IoU median and robust standard deviation ($rStd = 1.4826 \times \text{median absolute deviation}$). The Median and $rStd$ (Med/ $rStd$) of IoU between ground truth BoS and the BoS of foot pressure maps predicted by KNN5, PNS2, PNS3, PNS3B, PN3BK, respectively.

IoU Robust Analysis of BoS - Median/ $rStd$ (mm)					
Sub #	KNN5	PNS2	PNS3	PNS3B	PN3BK
1	0.602 / 0.194	0.668 / 0.164	0.711 / 0.150	0.763 / 0.131	0.723 / 0.138
2	0.544 / 0.248	0.591 / 0.238	0.522 / 0.232	0.533 / 0.243	0.615 / 0.237
3	0.670 / 0.229	0.755 / 0.176	0.782 / 0.149	0.786 / 0.142	0.762 / 0.164
4	0.645 / 0.216	0.711 / 0.202	0.704 / 0.201	0.626 / 0.230	0.636 / 0.260
5	0.643 / 0.220	0.660 / 0.200	0.667 / 0.217	0.699 / 0.201	0.640 / 0.195
6	0.604 / 0.197	0.647 / 0.174	0.658 / 0.196	0.677 / 0.168	0.677 / 0.196
7	0.607 / 0.196	0.643 / 0.187	0.689 / 0.167	0.668 / 0.181	0.639 / 0.197
8	0.561 / 0.273	0.602 / 0.265	0.602 / 0.303	0.615 / 0.295	0.587 / 0.278
9	0.558 / 0.228	0.570 / 0.184	0.652 / 0.185	0.670 / 0.177	0.700 / 0.200
10	0.548 / 0.280	0.692 / 0.197	0.682 / 0.211	0.659 / 0.217	0.678 / 0.209
Mean	0.598 / 0.228	0.654 / 0.199	0.667 / 0.201	0.669 / 0.198	0.666 / 0.207

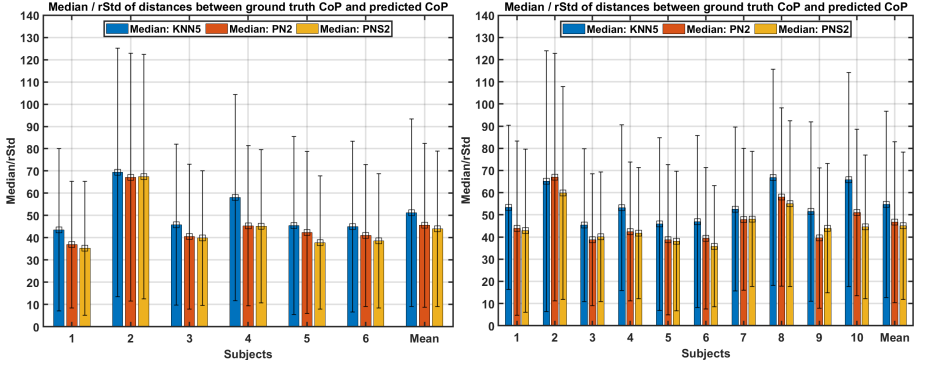


Fig. 7: A 6 subject comparison of CoP offset distance errors across methods and subjects, characterized by robust estimation Median/ $rStd$ (robust STD). The methods used are KNN5, PN2 and PNS2.

10 subjects is sufficient. The same network architecture, data normalization, and leave-one-subject-out validation was applied to a subset of the dataset containing only the first 6 subjects, using 3 network configurations (KNN5, PN2, and PNS2). Figure 7 shows that the 6-subject CoP quantitative results are comparable to the 10 subject CoP results.

10 Overview of all evaluated network and data configurations

During our research study we trained and analyzed many network architecture and dataset format configurations as shown in Figure 8. We used KNN ($K=5$), PressNet, PressNet-Simple, and PressNet-KL network architectures with 2D OpenPose (25 joints), 3D joints reconstructed from OpenPose (25 joints), 3D joints reconstructed and refined by BioPose (12 joints), a 3D hybrid from OpenPose plus core joints refined by BioPose (25 joint), and 3D from mocap (12 joints). The following is a comprehensive list of all acronyms with descriptions.

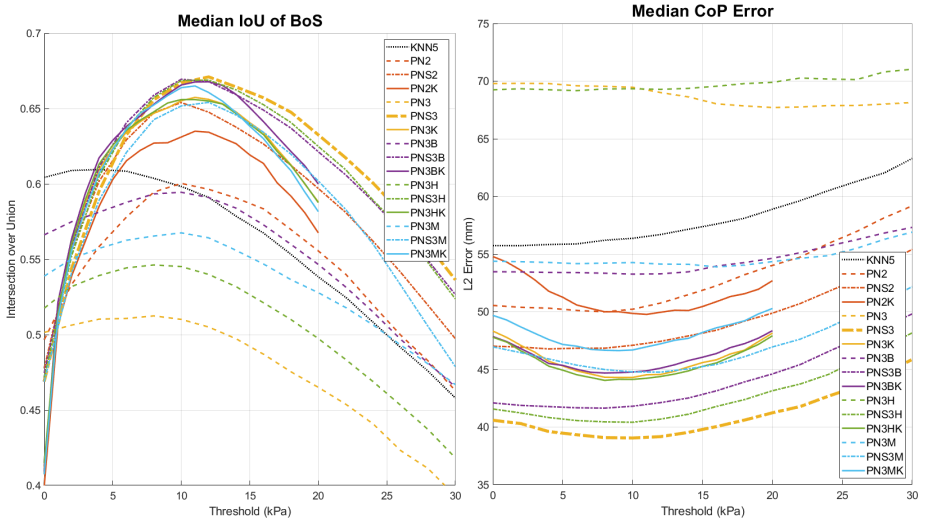


Fig. 8: A complete overview of all network architectures and dataset formats utilized and tested. Networks present in the main paper are a subset of these configurations. Left shows median IoU of base of support region (higher is better), and Right shows median center of pressure distance error (lower is better), evaluated at different pressure thresholds.

- KNN5 - KNN combining of 5 closest poses in 2D
- PN2 - PressNet network using 25 OpenPose 2D joints
- PNS2 - PressNet-Simple network using 25 OpenPose 2D joints
- PN2K - PressNet KL network using 25 OpenPose 2D joints
- PN3 - PressNet network using 25 OpenPose 3D joints
- PNS3 - PressNet-Simple network using 25 OpenPose 3D joints
- PN3K - PressNet KL network using 25 OpenPose 3D joints
- PN3B - PressNet network using 12 BioPose 3D joints
- PNS3B - PressNet-Simple network using 12 BioPose 3D joints
- PN3BK - PressNet KL network using 12 BioPose 3D joints
- PN3H - PressNet network using hybrid of 13 OpenPose + 12 BioPose 3D joints
- PNS3H - PressNet-Simple network using hybrid of 13 OpenPose + 12 BioPose 3D joints
- PN3HK - PressNet KL network using hybrid of 13 OpenPose + 12 BioPose 3D joints
- PN3M - PressNet network using 12 measured Mocap 3D joints
- PNS3M - PressNet-Simple network using 12 measured Mocap 3D joints
- PN3BM - PressNet KL network using 12 measured Mocap 3D joints

11 Relating Stability to Experience

Figure 9 shows correlation between years of Taiji experience and some standard stability metrics [1] in addition to the ones shown in main paper Figure 9 (Lines 558 - 569).

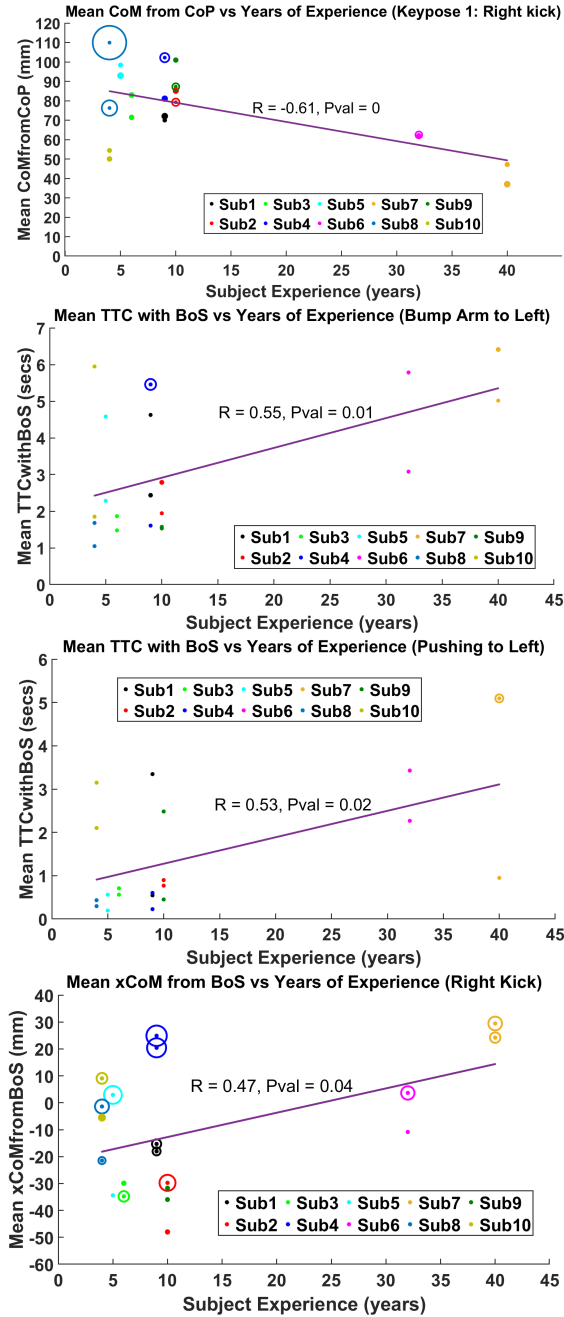


Fig. 9: Correlation of selected stability metrics relative to subject experience (years practicing Taiji). (TTC - Time To Collision [6], xCoM - Extended Center of Mass)

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