

Follow Up Report for Elsa Bates

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Research Questions

1. Is there a significant difference between IMU and MoCap machines ?
 - a. Dynamic Time Warping [\[Resource\]](#)
2. What is the difference between IMU and MoCap?
 - a. Visual inspection with difference time series plots with LOESS smoothers [\[Resource\]](#)
 - b. Proportion of aligned timesteps in harmful
 - i. Linear Mixed Model for characteristics (e.g., proportion of time in harmful posture, time spent in harmful posture, range of motion) [\[Resource\]](#)

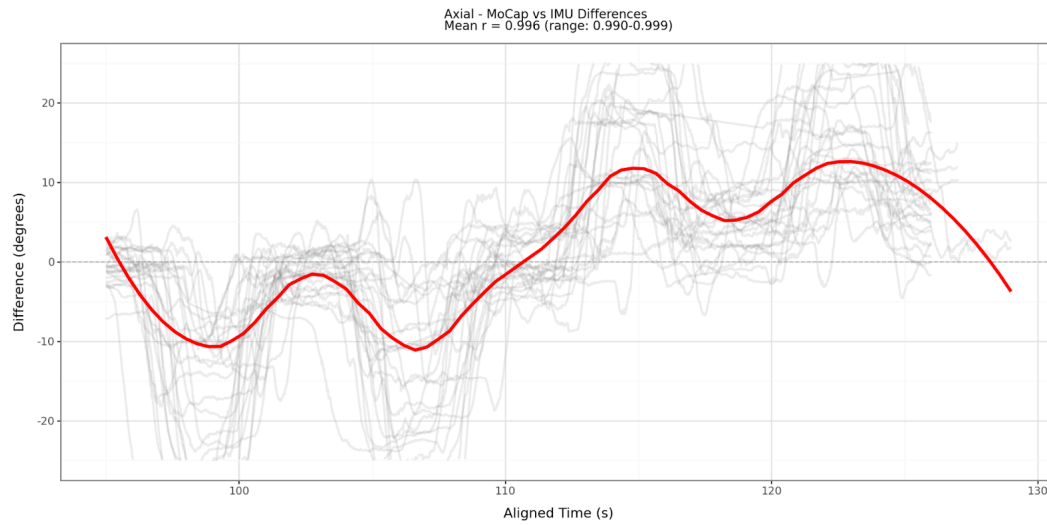
Methodology

1. **Data cleaning (data_cleaning.ipynb):**
 - a. To align the datasets by time, observed times were rounded to 3 decimal places, grouped by this rounded value and averaged. Basically, this averaged times across the 100th of a second.
 - b. Missing data: We were missing datasets for participants 6 & 8 (all movements), 5 & 18 (axial), and 29 (lateral). Based on your email, these were dropped due to inconsistencies in the participants' movements during the study.

Some MoCap sets contain missing data for a certain period of time, usually during a movement. As discussed, this is likely due to the MoCap system losing sight of the sensor. We dropped the times of the MoCap missing data in the IMU data for our comparisons, per your suggestion.

2. Plots (observing differences) (visualizations.ipynb)

- a. These plots display the differences in angle captured between MoCap and IMU overtime (MoCap - IMU) for each participant. Each gray line represents a

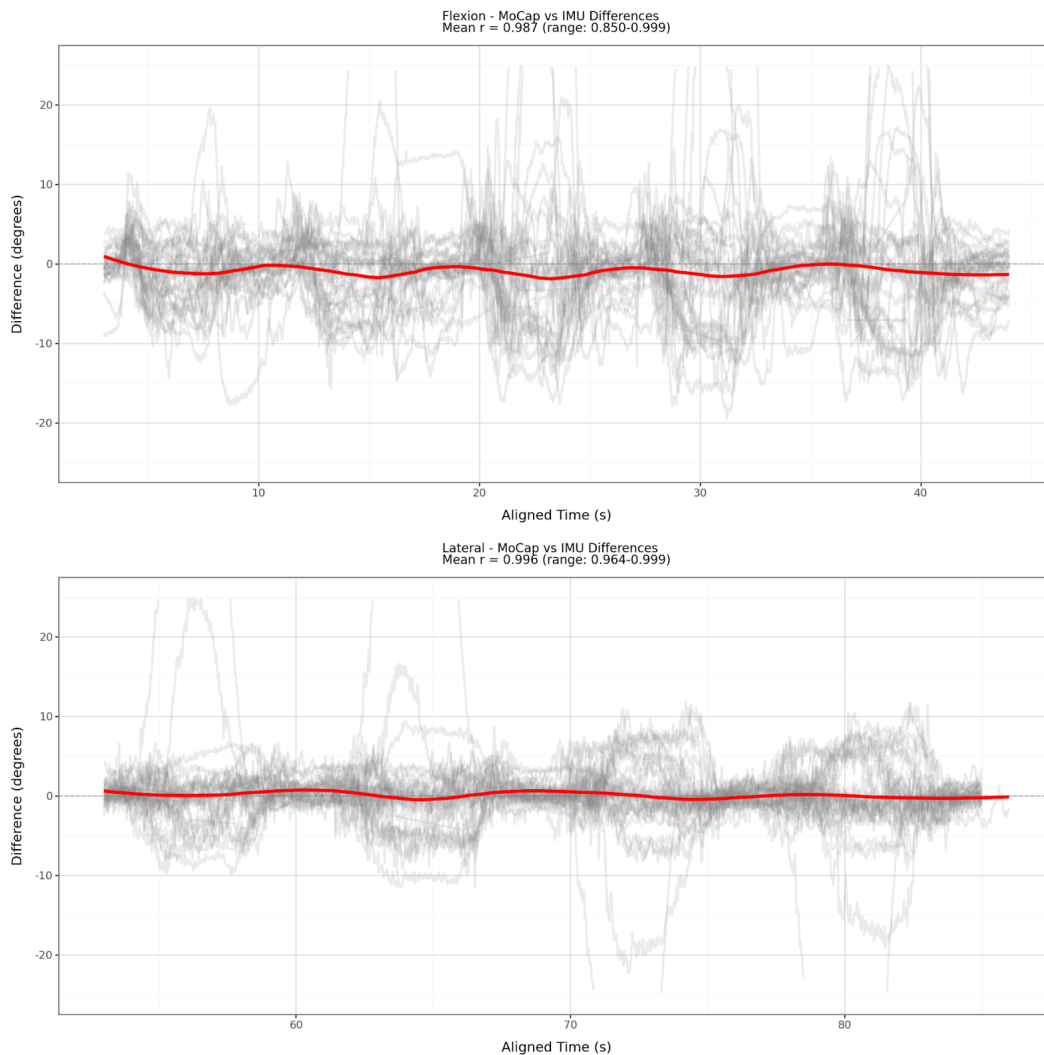


participant.

- b. If there is no systematic difference in what these sensors were capturing, we would expect to see random lines with no clear pattern centered around 0, and a flat smoother (red line).
- c. The first graph displays the axial rotation data. There is a clear and consistent pattern following the pattern of movements, seen with the red line. This suggests that the IMU is systematically failing to capture this type of movement. The two graphs (lateral and flexion movements) show differences that occur between IMU and MoCap are mostly random. There are a couple instances where it seems the IMU was not capturing angle data very well in these graphs, but the overall pattern is random and close to 0.

3. Testing differences (dtw.ipynb)

- a. Dynamic time warping was chosen because the IMU and MoCap data were collected at different hertz. Dynamic time warping is a way to compare two time series models that don't line up or have different sampling rates (which IMU and MoCap are both measured at). This technique minimizes the Euclidean distance

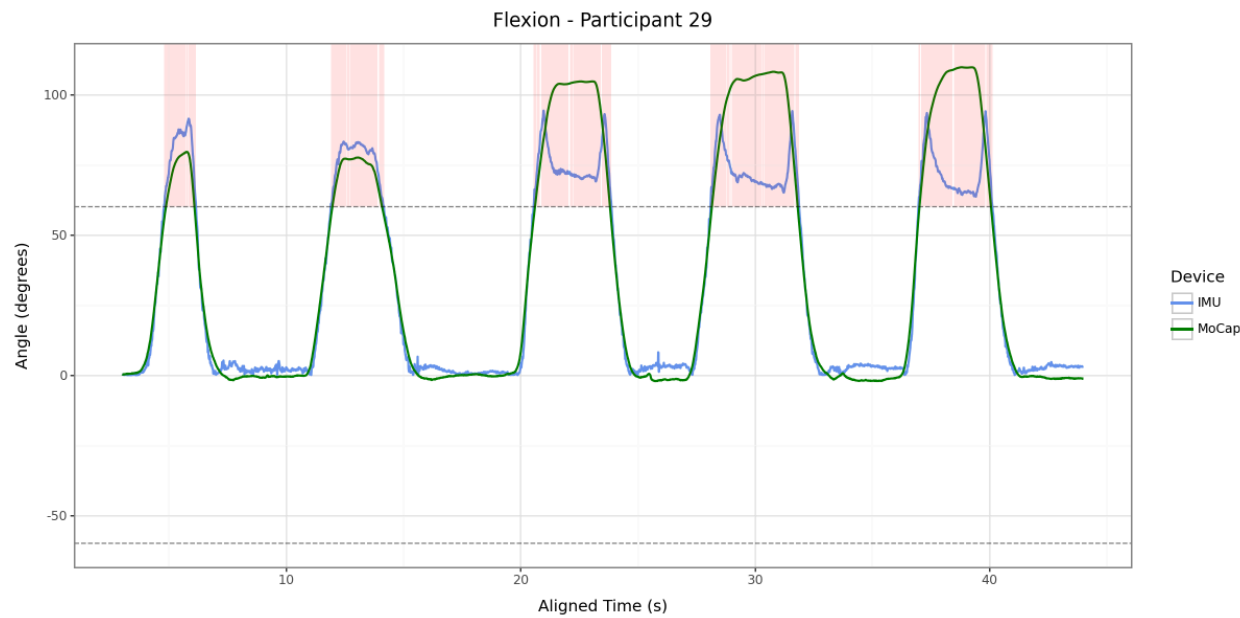
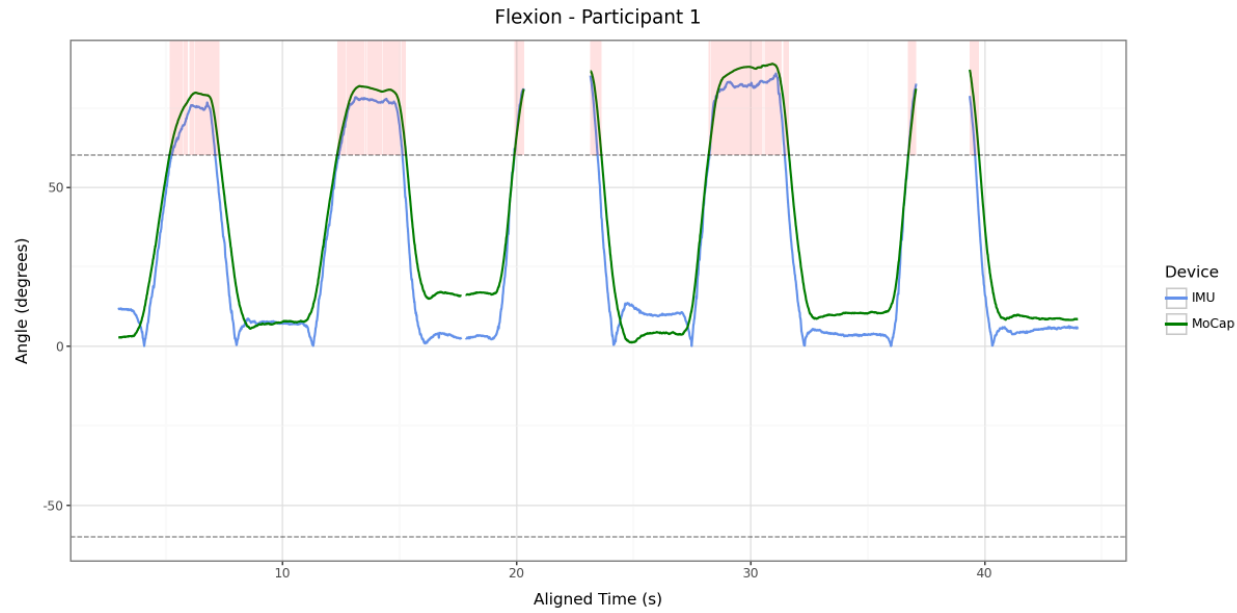


between the two curves to detect differences between them. Once time warping is run, a permutation test is done to determine if the distance is statistically different versus distances that don't have a major difference. Afterwards, there will be one p-value per pair of measurements for each one of the movements. The null alternate hypothesis as follows:

- i. H0: The observed DTW similarity between IMU and MoCap is no better than what would be expected under random phase shifts of IMU (Any observed alignment could be due to chance phase alignment between two signals with similar internal structure.)
- ii. Ha: The observed DTW similarity between IMU and MoCap is significantly better than what would be expected under random phase shifts of IMU (a meaningful, temporally-aligned relationship exists!)

This means we are looking for significant results, as they signify a meaningful, temporal relationship. However, rather than interpreting p-values in a binary fashion (reject null vs. not reject null), we should understand what the p-value represents in context. For instance, a p-value of 0.038 means that 3.8% of permuted, phase aligned time series resulted in a lower distance than what was observed for this particular participant

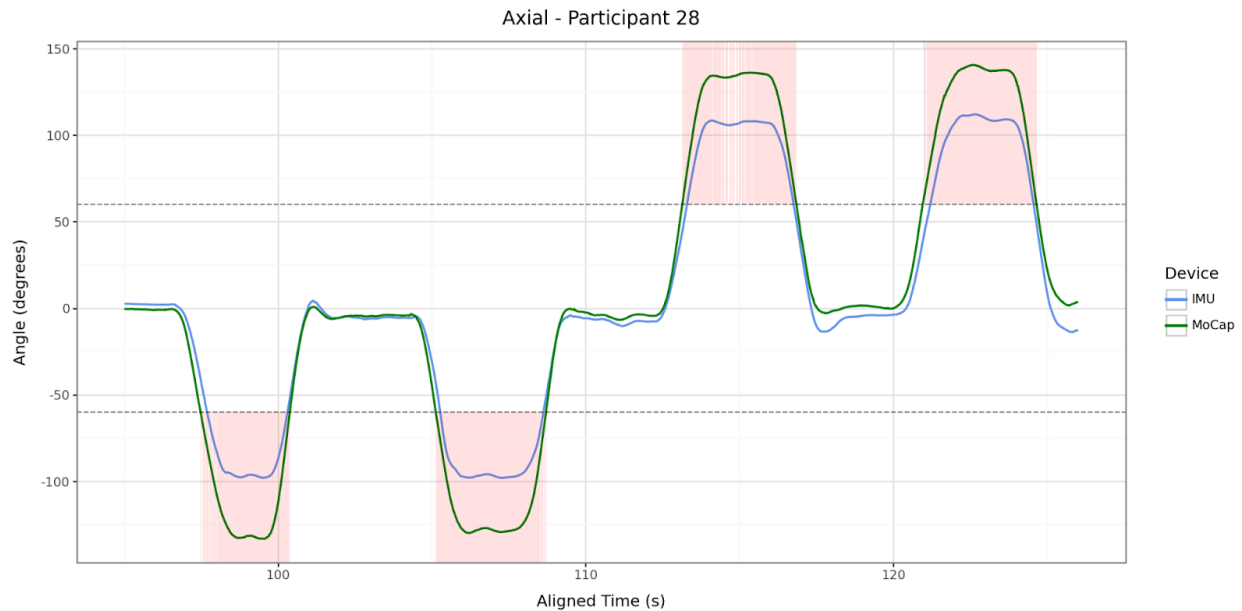
- b. Pre processing: We started off by syncing major gaps that existed between either IMU or MoCap measurements across each participant in any of the 3 pairs of measurements. This will help “normalize” our dynamic time warping metrics to ensure that differences measured will not come from any major measurement errors.
- c. Results from DTW:
 - i. Axial Rotations: Out of 26 participants for axial rotations, none of them resulted in insignificant results at an alpha level = 0.1.
 - ii. Lateral Bending: Out of 27 participants for lateral bending, none of them resulted in insignificant results at an alpha level = 0.1.
 - iii. Flexion: Out of the 28 participants for flexion, two of them resulted in insignificant results at an alpha level = 0.1. These two being participant 1 and participant 29:



Again, it is important to realize that in this context p-values should be interpreted more granularly, but these are the pair of measurements that were deemed insignificant from a holistic, reject vs. not reject perspective.

4. Summary Measures (visualizations_and_bad_posture.ipynb)

- a. Time spent in a harmful position may not be an accurate way to compare sensors when missing data is dropped. Most of the missing data in the MoCap sensor occurred during the movements. This means it is likely that the IMU and MoCap sensors will have different values for this metric, even if the devices would be capturing the same amount of time spent in harmful positions if there were no instances of missing data.
- b. Proportion of time spent in harmful position:



The p-value for axial, flexion, and lateral all are extremely small and significant indicating that IMU and MoCap have inconsistent measurements for classifying whether study participants are in harmful positions.

5. Appendix

DTW Axial Rotation Results:

Key: 1, Observed DTW: 2287.5116059455454, p-value: 0.048, Mean Sim Distance: 6957.521388990037, SD Sim Distance: 2842.9371384476212
Key: 2, Observed DTW: 774.0564917161372, p-value: 0.012, Mean Sim Distance: 4672.788100978274, SD Sim Distance: 2535.5740940889145
Key: 3, Observed DTW: 478.25501718143704, p-value: 2e-16, Mean Sim Distance: 5482.6265196691265, SD Sim Distance: 2958.082309377639
Key: 4, Observed DTW: 1973.4635210828185, p-value: 0.07, Mean Sim Distance: 5811.490408828528, SD Sim Distance: 2253.3597174184124
Key: 7, Observed DTW: 1500.8782826207446, p-value: 0.056, Mean Sim Distance: 5697.995664011592, SD Sim Distance: 2782.87423486587
Key: 9, Observed DTW: 1915.5376223435806, p-value: 0.038, Mean Sim Distance: 7672.258831787424, SD Sim Distance: 3620.3839393423314
Key: 10, Observed DTW: 1333.8765863648457, p-value: 0.06, Mean Sim Distance: 6308.980746299572, SD Sim Distance: 3272.60190807031
Key: 11, Observed DTW: 3623.481753471097, p-value: 0.04, Mean Sim Distance: 6397.630890043292, SD Sim Distance: 1782.372663462418
Key: 12, Observed DTW: 3114.1705079046233, p-value: 2e-16, Mean Sim Distance: 8002.171202973197, SD Sim Distance: 3069.5727439903976
Key: 13, Observed DTW: 1209.4345369902599, p-value: 0.016, Mean Sim Distance: 6257.382831882344, SD Sim Distance: 3049.3879725873276
Key: 14, Observed DTW: 1599.4992424448187, p-value: 2e-16, Mean Sim Distance: 9689.4489192524, SD Sim Distance: 4419.2202468458045
Key: 15, Observed DTW: 1910.5026676907673, p-value: 0.032, Mean Sim Distance: 7203.129240089566, SD Sim Distance: 3036.295929870765
Key: 16, Observed DTW: 2950.815220369879, p-value: 0.032, Mean Sim Distance: 6470.058701032654, SD Sim Distance: 2236.7584834038194
Key: 17, Observed DTW: 1634.1167080080156, p-value: 2e-16, Mean Sim Distance: 6858.8116741690565, SD Sim Distance: 3006.728370691938
Key: 19, Observed DTW: 2562.6011944989036, p-value: 0.016, Mean Sim Distance: 8365.51814086296, SD Sim Distance: 3767.2615489572445
Key: 20, Observed DTW: 811.0368086567888, p-value: 0.024, Mean Sim Distance: 5032.098857635399, SD Sim Distance: 2309.889855256853
Key: 21, Observed DTW: 2283.4041323004863, p-value: 2e-16, Mean Sim Distance: 7508.419281630417, SD Sim Distance: 2993.992432082419
Key: 22, Observed DTW: 812.0562328830654, p-value: 0.008, Mean Sim Distance: 5624.307128783989, SD Sim Distance: 3132.377349689486
Key: 23, Observed DTW: 888.7008668567438, p-value: 2e-16, Mean Sim Distance: 7650.0667044959255, SD Sim Distance: 3916.6353512908345
Key: 24, Observed DTW: 4086.6578597312723, p-value: 0.026, Mean Sim Distance: 8889.185470542017, SD Sim Distance: 2813.503038111397
Key: 25, Observed DTW: 2151.732886179997, p-value: 2e-16, Mean Sim Distance: 6552.004817841318, SD Sim Distance: 2854.191723649804
Key: 26, Observed DTW: 1774.825892902923, p-value: 0.048, Mean Sim Distance: 7266.120116496959, SD Sim Distance: 3545.931990447334
Key: 27, Observed DTW: 974.9690529546139, p-value: 0.02, Mean Sim Distance: 5651.980672755871, SD Sim Distance: 2758.153054682707
Key: 28, Observed DTW: 3428.6638249342714, p-value: 0.098, Mean Sim Distance: 10117.702507020167, SD Sim Distance: 4094.3078256359836
Key: 29, Observed DTW: 2177.7326738219426, p-value: 0.004, Mean Sim Distance: 6599.457714982446, SD Sim Distance: 2569.8567627992093
Key: 30, Observed DTW: 3027.582594315905, p-value: 0.004, Mean Sim Distance: 7769.550564579526, SD Sim Distance: 2924.400220070682

DTW Lateral Bending Results:

Key: 1, Observed DTW: 304.5404381527296, p-value: 0.02, Mean Sim Distance: 3821.9859322788147, SD Sim Distance: 2300.768473476973
Key: 2, Observed DTW: 249.3379876307666, p-value: 0.016, Mean Sim Distance: 2110.69095162572, SD Sim Distance: 1105.6638659315681
Key: 3, Observed DTW: 449.3437140148661, p-value: 0.004, Mean Sim Distance: 2654.823256710609, SD Sim Distance: 1330.9906062329335
Key: 4, Observed DTW: 224.99359051317927, p-value: 2e-16, Mean Sim Distance: 3161.538196220086, SD Sim Distance: 1783.252761133557
Key: 5, Observed DTW: 1275.303428700717, p-value: 0.016, Mean Sim Distance: 4399.880095330044, SD Sim Distance: 1914.9782765870875
Key: 7, Observed DTW: 877.8681429127348, p-value: 0.022, Mean Sim Distance: 3230.468900851127, SD Sim Distance: 1418.7152815147226
Key: 9, Observed DTW: 806.5520451717422, p-value: 0.022, Mean Sim Distance: 3000.546109529315, SD Sim Distance: 1465.3289432489041
Key: 10, Observed DTW: 258.9673494317371, p-value: 0.012, Mean Sim Distance: 3017.960071703616, SD Sim Distance: 1670.3613668634994
Key: 11, Observed DTW: 246.4389140700025, p-value: 2e-16, Mean Sim Distance: 2880.1444660537763, SD Sim Distance: 1641.8458823031278
Key: 12, Observed DTW: 375.95474462755885, p-value: 0.07, Mean Sim Distance: 2800.867131014375, SD Sim Distance: 1518.747051472759
Key: 13, Observed DTW: 293.26616573210583, p-value: 2e-16, Mean Sim Distance: 3537.9629696487095, SD Sim Distance: 1936.58777881563013
Key: 14, Observed DTW: 435.9650334840429, p-value: 0.05, Mean Sim Distance: 3749.3934481176802, SD Sim Distance: 1936.1292082631426
Key: 15, Observed DTW: 4869.574698567414, p-value: 2e-16, Mean Sim Distance: 6558.655256118288, SD Sim Distance: 1098.5499905812453
Key: 16, Observed DTW: 187.2071095364143, p-value: 2e-16, Mean Sim Distance: 2129.7344263121736, SD Sim Distance: 1270.299162237659
Key: 17, Observed DTW: 749.5625994255439, p-value: 0.002, Mean Sim Distance: 3636.862844485201, SD Sim Distance: 1834.826524040365
Key: 18, Observed DTW: 705.8168999605311, p-value: 0.018, Mean Sim Distance: 2873.686954654635, SD Sim Distance: 1274.7699932608448
Key: 19, Observed DTW: 531.794250762897, p-value: 0.004, Mean Sim Distance: 3585.0232285601373, SD Sim Distance: 1865.7770666864035
Key: 20, Observed DTW: 240.66114419833266, p-value: 2e-16, Mean Sim Distance: 2397.088092625942, SD Sim Distance: 1350.1234142456394
Key: 21, Observed DTW: 231.80379459888843, p-value: 0.006, Mean Sim Distance: 1907.0038976941476, SD Sim Distance: 998.5748986356195
Key: 22, Observed DTW: 248.496052619812, p-value: 0.006, Mean Sim Distance: 2909.3262583813794, SD Sim Distance: 1652.0188405765398
Key: 23, Observed DTW: 596.14812389103, p-value: 0.02, Mean Sim Distance: 3463.2379023110148, SD Sim Distance: 1724.7899240679444
Key: 24, Observed DTW: 686.7339989600875, p-value: 0.018, Mean Sim Distance: 3121.503765535281, SD Sim Distance: 1602.6293911569157
Key: 25, Observed DTW: 729.362849171571, p-value: 0.04, Mean Sim Distance: 3077.2986785805124, SD Sim Distance: 1486.1237018932586
Key: 26, Observed DTW: 352.22115612149355, p-value: 0.068, Mean Sim Distance: 2743.048683387749, SD Sim Distance: 1421.0433771114524
Key: 27, Observed DTW: 252.9869046415888, p-value: 2e-16, Mean Sim Distance: 2764.5776051745706, SD Sim Distance: 1468.4432266427998
Key: 28, Observed DTW: 221.4919894054836, p-value: 2e-16, Mean Sim Distance: 2363.401684159804, SD Sim Distance: 1215.7346138782923
Key: 30, Observed DTW: 916.0941664182837, p-value: 2e-16, Mean Sim Distance: 3056.7515928732687, SD Sim Distance: 1346.206357357331

DTW Flexion Results:

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Key: 1, Observed DTW: 1529.0343052695846, p-value: 0.376, Mean Sim Distance: 2495.9643791757608, SD Sim Distance: 1223.2665795490593
Key: 2, Observed DTW: 438.3791026474238, p-value: 0.002, Mean Sim Distance: 2622.3632217915215, SD Sim Distance: 1113.2918302629103
Key: 3, Observed DTW: 725.80813382195, p-value: 0.028, Mean Sim Distance: 2633.23886740087, SD Sim Distance: 1186.2200571297087
Key: 4, Observed DTW: 959.6747984914522, p-value: 0.03, Mean Sim Distance: 2653.6871875325564, SD Sim Distance: 1179.4680905206078
Key: 5, Observed DTW: 1457.844198154674, p-value: 0.018, Mean Sim Distance: 5359.530684717366, SD Sim Distance: 2171.8621476870535
Key: 7, Observed DTW: 1053.4649075897994, p-value: 0.076, Mean Sim Distance: 4323.827995499059, SD Sim Distance: 1996.0960957106918
Key: 9, Observed DTW: 519.0417277651823, p-value: 2e-16, Mean Sim Distance: 3789.65347024388, SD Sim Distance: 1803.7615589148581
Key: 10, Observed DTW: 451.37512401693857, p-value: 0.028, Mean Sim Distance: 2967.9832441206327, SD Sim Distance: 1439.469152231679
Key: 11, Observed DTW: 1407.5472581561964, p-value: 2e-16, Mean Sim Distance: 2902.3984970555634, SD Sim Distance: 1140.7330543018506
Key: 12, Observed DTW: 765.7977421938042, p-value: 0.084, Mean Sim Distance: 3429.6311596497394, SD Sim Distance: 1366.9124221069417
Key: 13, Observed DTW: 648.0462793297712, p-value: 0.122, Mean Sim Distance: 2737.297738548655, SD Sim Distance: 1338.3212768324306
Key: 14, Observed DTW: 1487.6522667230574, p-value: 0.026, Mean Sim Distance: 3717.4750770922697, SD Sim Distance: 1345.002194094468
Key: 15, Observed DTW: 1024.3393781119773, p-value: 0.028, Mean Sim Distance: 2702.8292793637943, SD Sim Distance: 1128.3535942861567
Key: 16, Observed DTW: 1462.3518467201145, p-value: 0.018, Mean Sim Distance: 4460.09395056564, SD Sim Distance: 1701.107694212067
Key: 17, Observed DTW: 737.1523625520355, p-value: 2e-16, Mean Sim Distance: 3904.528256878356, SD Sim Distance: 1772.0636076948815
Key: 18, Observed DTW: 972.5649101782258, p-value: 2e-16, Mean Sim Distance: 3305.093097099308, SD Sim Distance: 1309.4782245837553
Key: 19, Observed DTW: 535.0795109132723, p-value: 2e-16, Mean Sim Distance: 1982.6046324518047, SD Sim Distance: 947.3137198890615
Key: 20, Observed DTW: 1137.3069850341953, p-value: 0.032, Mean Sim Distance: 4176.010853717388, SD Sim Distance: 1566.1608856321504
Key: 21, Observed DTW: 842.3428498202887, p-value: 2e-16, Mean Sim Distance: 3802.19551461317, SD Sim Distance: 1677.5908182725957
Key: 22, Observed DTW: 1146.9953609474353, p-value: 0.006, Mean Sim Distance: 3197.6717276210106, SD Sim Distance: 1300.1728097749594
Key: 23, Observed DTW: 386.54810668023975, p-value: 0.068, Mean Sim Distance: 2279.915378689299, SD Sim Distance: 1060.8153626757626
Key: 24, Observed DTW: 1299.9246361161995, p-value: 0.072, Mean Sim Distance: 3550.7568354311156, SD Sim Distance: 1503.699865802116
Key: 25, Observed DTW: 872.041746244018, p-value: 0.022, Mean Sim Distance: 4158.372400824028, SD Sim Distance: 1885.2458659040472
Key: 26, Observed DTW: 673.1280221138514, p-value: 0.028, Mean Sim Distance: 2875.2419586184246, SD Sim Distance: 1359.5851394990825
Key: 27, Observed DTW: 873.6130736566133, p-value: 0.126, Mean Sim Distance: 2987.412763292201, SD Sim Distance: 1490.9156084047859
Key: 28, Observed DTW: 4743.274754857403, p-value: 0.022, Mean Sim Distance: 5666.013340195832, SD Sim Distance: 770.4052441512974
Key: 29, Observed DTW: 1958.589324039087, p-value: 0.19, Mean Sim Distance: 2998.9350416161296, SD Sim Distance: 1116.4902351436883
Key: 30, Observed DTW: 730.0791507033166, p-value: 0.03, Mean Sim Distance: 2221.6615923443464, SD Sim Distance: 1170.7714605225863

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Mixed Effect Model Results:

