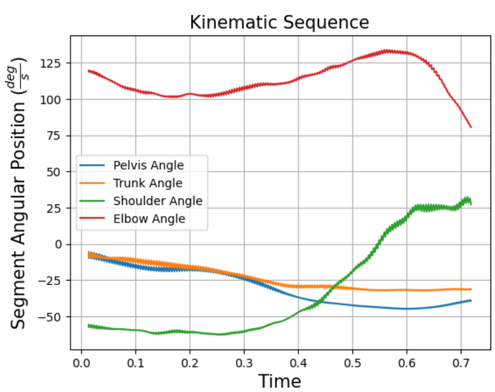
Texas Rangers Biomechanics Exercise

You have been provided with two CSV files. One contains full signal kinematic and kinetic data of a pitcher, whereas the other contains discrete data. The dataset is comprised of pitches from the 1st and 7th innings. Please provide all code and resources along with your answers to these questions to cwatkins@texasrangers.com prior to **Tuesday, October 1st**. LIMIT ANSWERS TO 200 WORDS

1. Calculate and provide the averages and standard deviations for each inning and pitch type, returned in a table format (preferably generated using a coding method) for:

- Pitch velocity
- Maximum shoulder external rotation Maximum elbow varus torque
- Peak pelvis rotational velocity
- Peak trunk rotational velocity
- Peak elbow extension velocity
- Peak shoulder internal rotation velocity

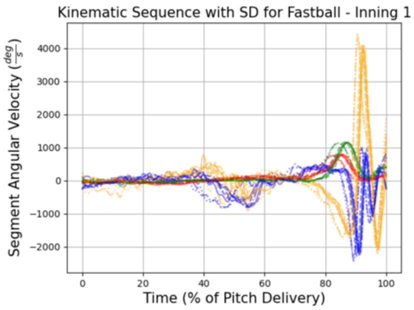


INNING	PITCH_TYPE	Mean_Pitch_Velocity	Mean_Spin_Rate	Peak_Shoulder_Internal_Rotation_Velocity	Peak_Elbow_Extension_Velocity	Peak_Pelvis_Rotational_Velocity	Peak_Trunk_Rotational_Velocity	Max_External_Rotation	Max_Elbow_Varus_Torque
1	Curveball	82.3 ± 0.6	2955.6 ± 88.8	4917.43 ± 429.11	2473.28 ± 182.3	770.07 ± 24.77	1118.79 ± 12.12	177.01 ± 3.8	118.88 ± 10.06
1	Fastball	95.5 ± 0.9	2234.0 ± 68.55	4740.54 ± 226.96	2359.37 ± 104.27	782.23 ± 15.73	1144.13 ± 17.76	178.67 ± 1.82	126.21 ± 9.16
7	Changeup	86.5 ± 0.0	2000.0 ± 0.0	nan ± nan	nan ± nan	nan ± nan	nan ± nan	nan ± nan	nan ± nan
7	Curveball	81.0 ± 0.6	2999.8 ± 62.29	4792.03 ± 351.5	2411.74 ± 103.4	800.65 ± 14.42	1111.42 ± 16.11	173.99 ± 2.59	113.94 ± 15.8
7	Fastball	93.6 ± 0.5	2278.2 ± 40.49	4298.6 ± 45.77	2489.53 ± 83.83	797.16 ± 19.23	1120.39 ± 21.75	171.12 ± 2.39	135.18 ± 3.28
7	Sinker	93.3 ± 0.5	2112.6 ± 87.19	4654.83 ± 0.0	2520.61 ± 0.0	819.88 ± 0.0	1143.35 ± 0.0	178.96 ± 0.0	133.92 ± 0.0

From this question onward, note that the change up was excluded from the rest of this analysis. This is because the data signal data for the changeup was an outlier from the rest of the data, and did not look like the motion capture picked up the signal data properly. The signal change up data is shown above where none of the usual KPI's can be identified (such as MER) therefore because it is unrepresentative of Pitcher_A's movement patterns down the mound, it was excluded from further analysis moving forward.

2. Plot the kinematic sequencing velocities (listed above) for only fastballs using their averages and +/- 1 SD. Provide 2 plots, one for each inning. The data is normalized from peak leg lift to the follow thru.

	Pitch	Pelvis Peak (deg/s)	Pelvis Peak Time (%)	Trunk Peak (deg/s)	Trunk Peak Time (%)	Shoulder Peak (deg/s)	Shoulder Peak Time (%)	Elbow Trough (deg/s)	Elbow Trough Time (%)
0	1	772.512313	85.284281	1161.419187	86.956522	3986.659098	92.642140	-2117.700976	90.969900
1	5	783.838831	85.953177	1137.635651	87.290970	3739.657831	92.642140	-2190.130359	91.304348
2	11	750.363816	82.608696	1116.600692	83.946488	4422.526208	90.635452	-2434.374953	89.297659
3	13	778.520148	81.939799	1133.276346	84.280936	4296.714403	90.635452	-2307.204013	89.297659
4	6	779.860014	84.949833	1135.555341	86.956522	4067.177719	92.307692	-2229.161032	90.969900
5	4	792.627436	84.615385	1161.374375	86.287625	4083.081369	91.973244	-2282.430564	90.301003
6	7	795.067571	85.618729	1150.367885	87.290970	4118.870176	92.642140	-2289.146354	91.304348



Show Mean Plot

Segment	Peak Value (deg/s)	Time of Peak (%)
Pelvis	715.72	84.62
Trunk	1075.52	86.62
Shoulder	3367.75	92.31
Elbow	-1630.42	90.30

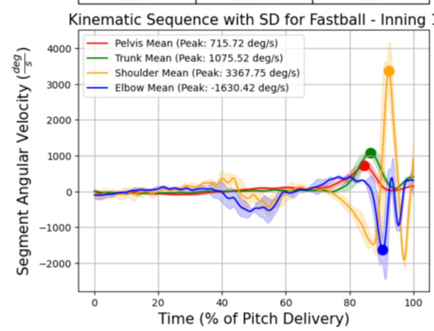
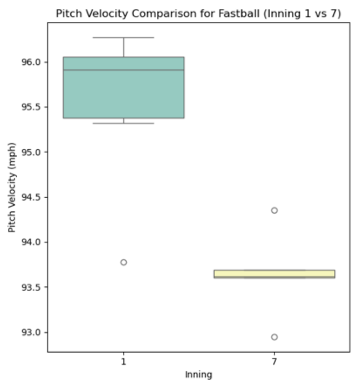
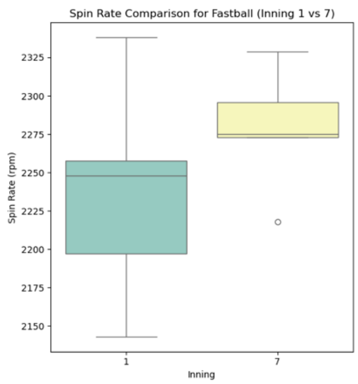


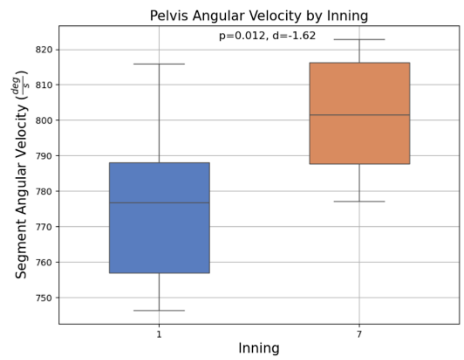
Figure 1 Kinematic Sequencing plot with toggle button. Individual plots are given and their respective peaks in the table on the left, while the image on the right shows how plot becomes interactive and changes into a mean plot with a transparent standard deviation wave.

For the Kinematic Sequencing plots, I chose to plot the individual segment angular velocities first, and then overlay a mean plot using a toggle button. First, I needed to ensure that the data was correctly synced. Even though the data was synced at Ball Release, I wanted to practice syncing the data just in case it wasn't, therefore I decided to sync the plots at Shoulder Max Internal Rotation Velocity because it was the closest point to ball release plus or minus a couple frames. Once the data was synced, I plotted the time series data by applying a Savitzky-Golay filter to smooth the signals out, and filtered out any unrealistic peaks by setting a filter range for peak velocity (400, 5000) deg/s. From there most of my time was spend debugging and make the toggle button feature more appeasing to the user. Other Pitch Types with their respective innings are in the Question 2 folder for further analysis.

3. Using your answers from Question #1, is there a statistical difference between the first and last inning of work that would raise any red flags for this pitcher for any signals / metrics or anything else? Explain why or why not.







'Pitch Comparison Statistics'

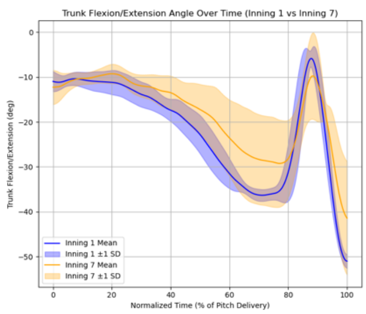
	Pitch Type	Metric	Inning 1 Mean	Inning 7 Mean	p-value	Effect Size
0	Curveball	RELEASE_SPEED	82.21968	80.97066	0.018522	2.076746
1	Curveball	SPIN_RATE	2935.18000	2999.78000	0.128762	-0.887521
2	Fastball	RELEASE_SPEED	95.44538	93.64210	0.025007	2.333500
3	Fastball	SPIN_RATE	2248.58000	2278.18000	0.325019	-0.519979

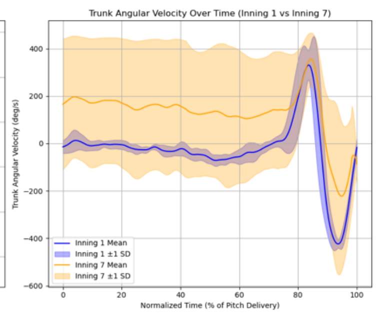
	Metric	First Inning Mean	Last Inning Mean	p-value	Cohen's d	Significance
0	Pelvis	773.507529	801.178872	0.011921	-1.624212	Significant
1	Trunk	1134.281926	1118.199016	0.153228	0.793263	Not Significant
2	Shoulder	4831.823603	4580.938632	0.220662	0.753880	Not Significant
3	Elbow	-2433.495907	-2453.744472	0.745966	0.149196	Not Significant

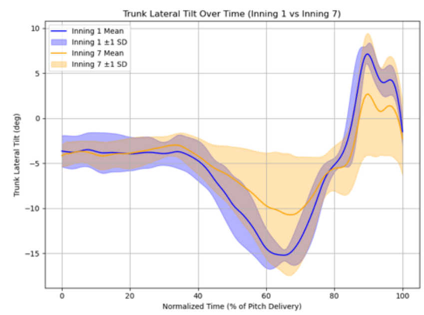
Using a paired t-test, I found a statistical significance between pitch velocity between both Curveballs and Fastballs and spin rate only between Curveballs. When looking at segment peaks significance, only the pelvis was shown to have statistical significance where Pitcher_A rotated faster in the 7th inning compared to the First Inning. While not significant, there was noticeable decrease in the other segmental angular velocities, and when combined with a decrease in pitch velocity by an average of 2mph, showcases that Pitcher_A is feeling fatigued due to the decrease in trunk and upper extremity angular velocities and pitch velocity. In the 7th Inning the pitch counts were also in the hundreds, which is another indicator that some fatigue has occurred throughout the game. Other box plots for segment data and pitch metrics are can be viewed in the Question 3 folder.

4. Are there any other metrics / signals from this data set that you would use / create that you feel would be valuable and why?

Trunk:

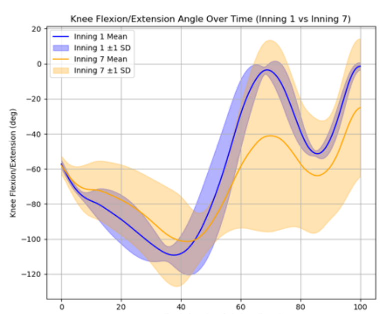


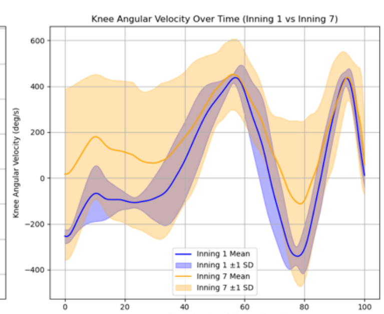




When looking at the trunk, we mainly focus on trunk lateral tilt and flexion and extension. We can see that compared to the 1st inning, Pitcher_A shows more trunk extension and holds their COM more compared to the 7th inning where both peak extension and flexion both decreased. This can tell us that Pitcher_A's does not use there trunk as efficiently when fatigued.

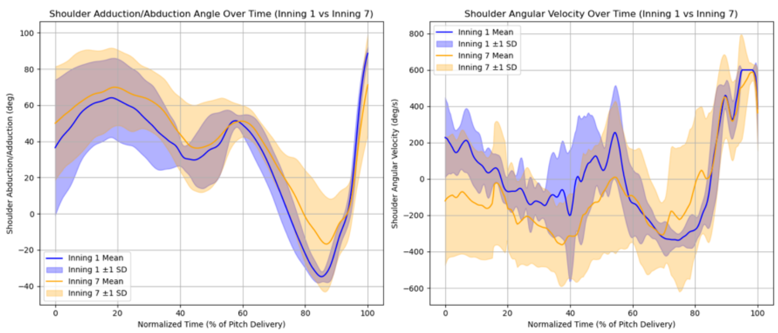
Knee Flexion/Extension:





The same effect can be seen looking at Mean Knee Flexion where the First inning exhibited more knee flexion and extension in the 1st inning comparing to the 7th inning. The same is also seen in the knee extension velocity. This can indicate that the Pitcher_A uses the ground more efficiently and transfers force more up the chain compared to the 7th inning. The first inning, Pitcher_A absorbs the GRF during Foot_Plant through knee flexion, and then transfers it up the chain by activating the knee extensors to extend the knee rapidly. The 7th inning achieves similar knee flexion, but does not reach complete knee extension, thus some of the GRF's could be leaking from the lack of knee extension driving force through the ground shooting back into the body. This lack of transfer of the GRF's can be a cause of why the trunk and upper_extremeties are rotating slower than the first inning.

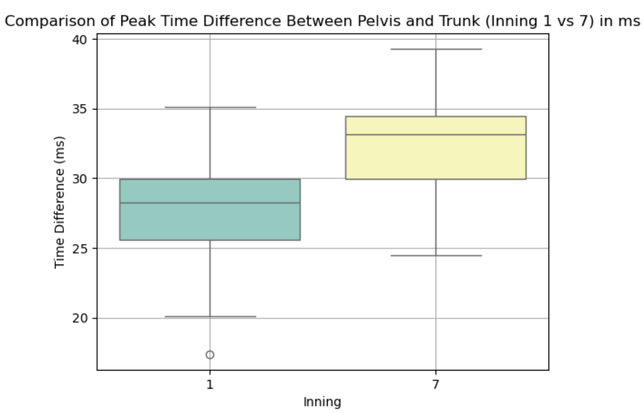
Shoulder Horizontal Abduction/Adduction:



When looking at Shoulder Horizontal ABD ADD, Pitcher_A loses scap retraction in the 7th Inning compared to the 1st inning, thus could explain why the upper arm isn't rotating as fast compared to the first inning. Also, no indication of a pushy elbow.

Peak Pelvis to Trunk Time:

INNING	PITCH_TYPE	Peak_Pelvis_Velocity (deg/s)	Peak_Trunk_Velocity (deg/s)	Time_Difference (ms)
1	Curveball	770.07 ± 24.77	1118.79 ± 12.12	29.15 ± 3.60
1	Fastball	782.23 ± 15.73	1144.13 ± 17.76	26.28 ± 6.02
7	Curveball	800.65 ± 14.42	1111.42 ± 16.11	30.42 ± 3.86
7	Fastball	797.16 ± 19.23	1120.39 ± 21.75	33.07 ± 6.16



When looking at peak pelvis to trunk timing differences, there are no statistical differences, nor a decrease in time when fatigued. This metric can be used to help explain why Pitcher_A is effective as he is due to his consistence segmentation of the segmental angular velocity peaks despite the trunk angular velocity being slower in the 7th inning.

5. Are there any metrics that you would target for development of this pitcher? Using published research; explain why the metrics selected may improve this pitcher's performance and / or injury risk.

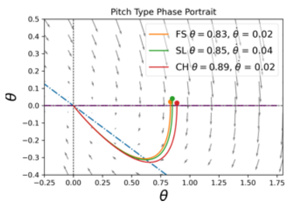
   Pitcher_A's Knee flexion and extension can explain a lot the fatigue and decrease in velocity/spin rate. When looking at inning 1 and 7, as explained in Q4, the front knee does not fully extend during release, thus indicating a weaker leg block compared to the 1st inning. This carries up the chain as the segmental angular velocities decreased (except the pelvis), the trunk does not slingshot forward as there is less trunk flexion and extension, and less lateral tilt during Ball Release. This data can be used to help the pitching coach, and the strength coach understand Pitcher_A's tendencies when he is fatigued. A study done by Dowling et. Al (2024) concluded that Proper lead knee extension allowed efficient energy transfer through the kinetic chain in professional pitchers. Pitcher_A's ability to produce proper knee extension directly impacts the ability produce higher ball velocities while minimizing elbow varus torque. Another study done by Matsuo et. Al (2001) showed that high velocity group showed knee extension during the approach to ball release, whereas the low velocity group showed a variety of knee movement patterns involving less knee extension and more knee flexion. This would easily apply to Pitcher_A's outing as the 1st inning exhibited more knee flexion while the 7th inning had the same knee flexion while demonstrating less knee extension during ball release.

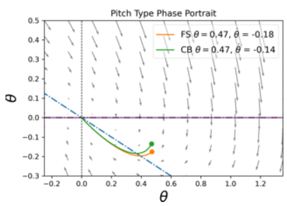
   https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11329978/

   https://journals.humankinetics.com/view/journals/jab/17/1/article-p1.xml

6. Is there anything in the data that stands out to you that you would like to investigate further? What else could be done using information like this given more time and resources / potential research avenues?

   One project I would like to work on or would be curious to see would be to analyzing trunk acceleration under different coordinates. The trunk's motion can be broken down into tangential and normal acceleration components. Tangential acceleration measures the change in speed of the trunk's rotational motion, while normal (centripetal) acceleration reflects how sharply the trunk changes direction. The curvature of the path taken by the trunk determines how quickly this direction shifts, impacting how efficiently energy transfers through the kinetic chain. A higher tangential acceleration can help generate more power and velocity, while excessive normal acceleration might indicate inefficient mechanics or increased injury risk. Understanding these components allows coaches to identify whether the pitcher's rotational speed and direction are optimized for performance or if mechanical adjustments are needed to improve force transfer and reduce stress on the elbow and shoulder. Tracking these accelerations helps refine pitching technique for both performance and safety.





Another Project that would be cool to look at would be plotting the rotation of the trunk and pelvis as a coupled system as a damped oscillator. This damped torsion oscillator would help understand how initial conditions at foot_plant can determine the effects of rotation during ball release. The further away your initial condition point is from the from the solution line, the more the trunk and pelvis will accelerate using the summations of speeds principal. The arrows represent the angular acceleration of the system, so the closer you are to the solution line, the slower you'll move based on how you during foot contact (the initial conditions).

7. Please choose one hitter or pitcher to break down mechanically. Include the videos used, and brief summary of strengths / opportunities and / or areas you would like more information.

   https://report.qualisys.com/r/e-hWrDuxy/details

The link above is a Qualisys report of my little brother AJ Arnold (15yr_5'10_185lbs). A first glance at AJ you can see that he has excellent external rotation of the throwing shoulder. Furthermore, when examining the Kinematic Sequence, we can see that his upper arm rotates at 4022 °/s while the pelvis (512 °/s) and trunk (786 °/s) rotate on the slower side. Ideally, we want to see these segments accelerate more and have both peaks be higher since most of the velocity produced is coming from the shoulder rather than the proximal segments. When looking at the pelvis, the video shows AJ opening his hips towards home plate, initiating pelvic rotation before front foot plant. From front foot plant, the pelvis does not decelerate as shown in the plot and continues to rotate when the trunk begins to rotate. The Trunk also doesn't experience proper deceleration after reaching its peak as it doesn't truly decelerate until after Max Internal Rotation Velocity. When examining the decent down the mound AJ jumps off the mound as seen from his early disconnect from the back rubber. This causes inefficient transfer of forces from absorbing the fall off the mound rather than efficiently transferring the force from the drive leg to the stride leg.

An Overview:

Good:

- good upper arm internal rotation velocity
- good segmentation timing of pelvis and trunk
- holds scap retraction throughout foot plant to MER
- does not have a pushy elbow during MER and BR
- Great Shoulder mobility of the throwing arm

Improvements:

- lack of pelvis and trunk decel;
- back foot disconnect causes jumping off the mound
- slow rotation of pelvis and trunk
- early pelvis rotation
- slow transfer of GRF from foot plant to release
- Most of velocity is produced from the upper arm and not proximal segments.