Analyzing Softball Pitch Speed Related to Arm Velocity, Stride Length and Drive Force

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Introduction

Success in softball is often determined by the athlete's ability to generate power, precision, and efficiency in their movements. For pitchers, the ability to throw a fastball at a high velocity is a crucial skill that can impede their performance if not done successfully, or even cause injury (Werner et al., 2005). To produce a high velocity for pitching, the athlete must use coordination of both the upper and lower extremities to transfer energy from the legs through to the core and into the throwing arm; this process is known as kinetic linking, or a kinetic chain (Karandikar & Vargas, 2011) which allows pitchers to maximize velocity by generating force from the ground up, progressively transferring it through each segment of the body creating a complex motor unit (Karandikar & Vargas, 2011). A fundamental portion of kinetic linking in softball is the lower limb placement (creating the wind-up) during the pitch, as it requires stability, balance, and ability to generate force effectively. The stability of foot placement acts as an anchor to allow for maximal rotational forces and energy transfer from the lower limbs, to the torso and arm for successful completion of the pitch (Elliott et al., 1988). These principles suggest that leg drive and arm velocity both play critical roles in a fastball pitch, and understanding how they each contribute to the throw is of most importance.

This study aims to understand the biomechanics of a fastball pitch and specifically how arm velocity and drive force of the leg(s) correlate to the pitch speed. We also aim to answer several questions about the biomechanics of pitching: does an increased arm angular velocity and greater leg drive force correlate with a higher fastball pitch speed? If so, which plays a more significant role, or are they interdependent? Additionally, does force distribution between the feet impact throw? Addressing these questions are important to understand as it can improve the efficiency of softball player's pitching form to maximize force/velocity production, prevent injury from occurring, and develop better weight training programs. Force, velocity and stride analysis could also be crucial in identifying mechanical differences between pitch types, i.e. fastball, change up, riseball etc., to improve the pitch delivery and movement of the pitch and avoid telegraphing pitch type to batters. Based on kinetic linking and biomechanical principles, we hypothesized that a higher angular arm velocity will be more important for producing a higher pitch speed than stride length or drive force.

Methods

A - Experiment Setup

We conducted our experiment to investigate the relationship of angular arm velocity and driving force, and how this correlates to pitch speed. Each participant, aged between eighteen and thirty-eight, was organized into 4 categories; no experience (n=4), novice level (recreational level youth pitching experience) (n=7), mid-level (competitive recreational level youth pitching experience) (n=2), and collegiate level (competitive club athletes) (n=3) for a total of n=16 participants. Data collection took place in the CARSA field house at the University of Victoria on March 3rd and 4th, 2025. Prior to data collection, each participant completed given consent forms, a PARQ+ form, and warmed up. Arm measurements were taken for each participant (from the superior ridge of the greater tubercle of the humerus to the IMU placed at the wrist, just superior of the ulnar head, and participant's height was recorded.

For device measurements, we placed two inertial measurement units (IMU) on each participant, one placed on the wrist of the throwing arm and one around the chest with the IMU sensor placed on the participants back as seen in Figure 1, and one strain bar force transducer was placed on the ground, shown in Figure 2 . Each IMU was connected to an iPhone via bluetooth to the Movesense app, and were set at a 208 Hz sampling frequency; the arm IMU had the 'gyroscope' setting to measure angular velocity, the chest IMU had 'linear acceleration' mode. Connected to the OpenCap software, the force plate measured parallel force (N) against time (s), with a sample rate of 500 Hz, for future use in data analysis. We allowed this force plate to rest while plugged in for 10 minutes prior to data collection in order to account for sensor drift.

Figure 1

Schematic representation of inertial measurement unit (IMU) placement illustrating the positioning of the IMU sensors on the back and arm shown in red(left). IMU sensor used with wrist placement and orientation(right).

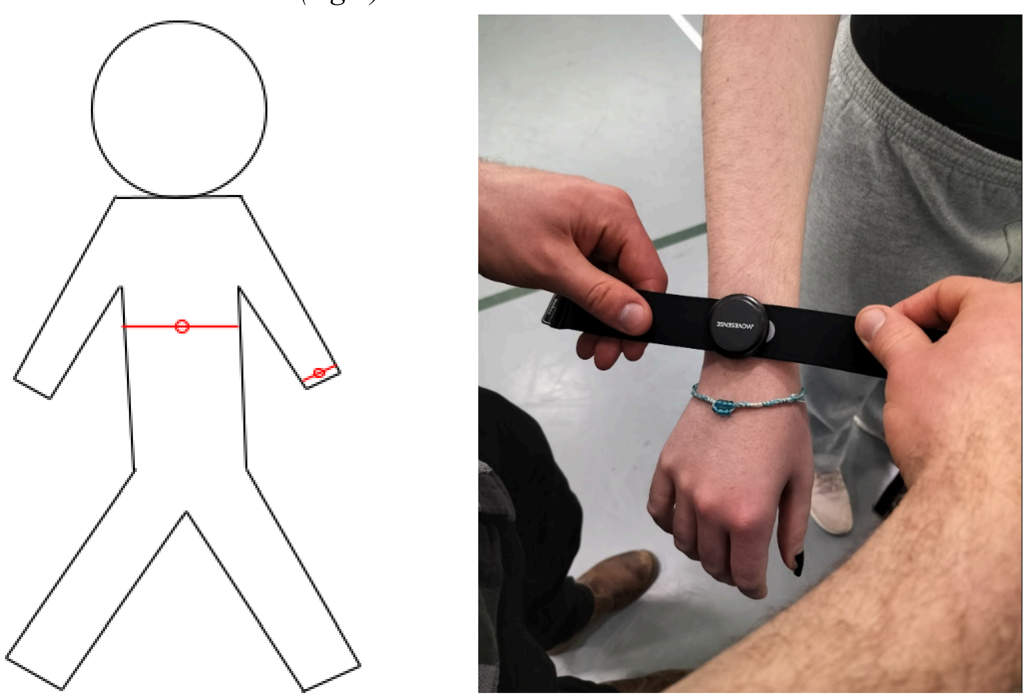
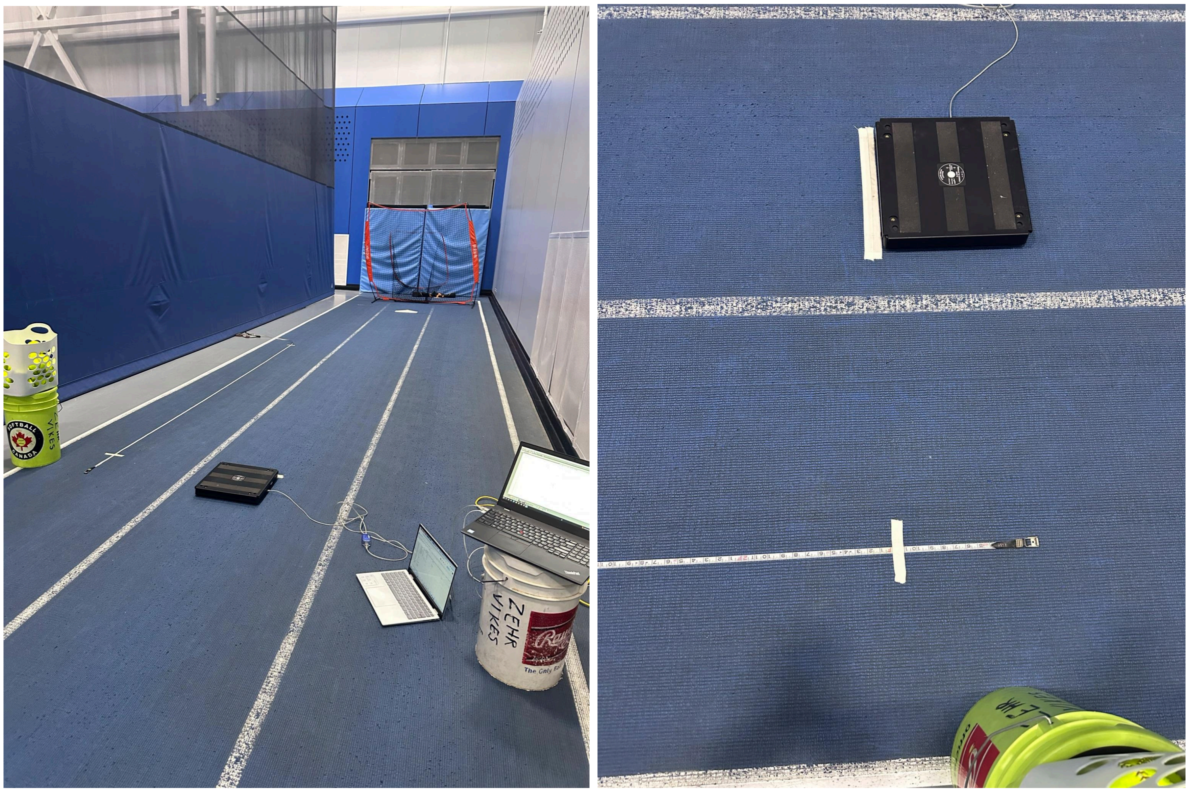


Figure 2

Data collection set up to measure angular velocity and driving leg forces in softball athletes to understand the relationships of pitch speed and force. Complete set up in the CARSA fieldhouse without athletes pictured (left) including force plate placement on the ground (right).



During the experiment, one of our group members positioned themselves behind and to the side of the participant, with a radar gun pointed towards the catching net target. This radar gun was set to measure the maximum velocity in miles per hour (MPH) recorded by the softball after release. A second group member positioned themselves to record a video of the data collection process for specific participants, as well as stopping and starting the IMU and force plate recordings. For each pitch thrown by the participant, a third group member in charge of recording physical data recorded the maximum speed achieved by each pitch, as well as recording the stride length achieved during each pitch; resulting in two data points for each pitch (stride length and pitch velocity) to complement the recorded IMU/force plate data. Between each recorded pitch, and prior to the first pitch, all participants were asked to stand still and record a flat reading on all sensors to later help discriminate peaks in data analysis.

In the first step of the data collection process, we asked participants to lock their legs in pitching stance, without stepping on the force plate, and throw a pitch using only a rotation of their arm. We recorded IMU data for the chest and wrist in this case, as well as recorded the maximum pitch speed achieved. No stride length was recorded in this case. In the second step of the data collection process, participants were asked to step onto the force plate, and throw a special pitch using only their push-off velocity. In this throw, participants restricted the movement of their shoulder joint; with their hand beginning at their hip complex and releasing the ball at the same point; propelling the ball using only on their push-off velocity from the wrist itself. Stride length, pitch velocity, force plate, chest IMU and wrist IMU data were recorded in this case. These first two recordings were used as a control. In the third step of the data collection process, participants were asked to throw five consecutive fastball pitches using their standard throwing technique. Stride length, pitch velocity, force plate, chest IMU and wrist IMU data were recorded in this case. For a visual representation of the 10 stages of a standard softball pitch, see Figure 3 a-j below. These stages will be later used to identify and analyze a pitch within the IMU and force plate signal data. Examples of recorded Wrist IMU and force data can be seen in Figures 5-12 in the Results section.

Figure 3

Fastball pitch phases.

Note: a) loading phase and beginning of unweighting, b) wind-up phase of pitching motion, continuance of unweighting, c) drive phase of pitch, increasing force until propulsion and start of arm acceleration, d) push off/propulsion phase, continuance of acceleration, e) flight phase where both feet are briefly off the ground, continuance of acceleration, f) push off foot drags to initiate plant phase, initiation of peak acceleration, g) front foot plants to decelerate the body just before release, h) release point where arm velocity is max, total velocity just below max, i) follow through phase, j) return to quiet stance.

A fourth step of data collection was also conducted only for the mid-level and collegiate level pitchers. In this step, they were asked to throw an additional five change up pitches, pitches thrown with an approximately 10 mph slower speed difference from their fastball, for additional data. Stride length, pitch velocity, force plate, chest IMU and wrist IMU data were recorded in this case. During statistical analysis, we used only data from the third step, five consecutive fastballs, for sake of consistency. The additional data collected in steps 1, 2 and 4 was used as supplementary to improve understanding of the key concepts studied in this report (see Results section) at the coaches request.

B - Data Analysis

For data analysis, each participant's recordings from the force plate, both IMU sensors (converted to a .csv file), pitch velocity, arm length, height, and stride length were added to a Google Sheets file. Data extraction and processing was conducted using Python. Each Python script that was developed utilizing the Pandas library for data manipulation, the Numpy library for numerical computing, and Scipy for advanced data analysis, including signal processing and interpolation. To analyze the pitch mechanics, key points in the data were identified to distinguish individual throws and to determine key phases of the pitch. The total linear velocity of the wrist at the point of release was defined as the moment of highest recorded acceleration throughout the throw. General kinematics formulas were then used to compute the final total acceleration values. For force analysis, force (N) was plotted against time (s) to identify maximum force produced for each throw. Using the manually collected data (stride length and velocity from the radar gun) combined with all IMU and force plate data, this allowed us to create graphs illustrating force, speed, and stride length relationships.

C - Statistical Approach

To answer the main question of whether there is a correlation between pitch speed and any of force, stride length, and arm speed, we performed a series of statistical calculations with the collected data. A set of three Pearson Correlation Coefficient calculations for each participant was completed to determine which pitch characteristic impacts their final pitch velocity the most. Based on this data, we used the highest magnitude r value to determine which characteristic has the strongest correlation with resultant pitch speed. We also created a graph for each Pearson Correlation Coefficient calculation, and identified whether the pitch characteristic has a positive or negative relationship with pitch speed. We then found the average values from the Pearson Correlation through the use of the Fisher’s z-transformation. We converted each r value into a z value, then averaged those values. We then converted the z value back into an r value to get our final numbers. We analyzed correlation trends for the whole study, as well as for each experience group, and for each person. A heat map was created for each of the above conditions, which also improved understanding of the correlation between each independent variable.

The Pearson Correlation formula is as follows:

$$r = \frac{\Sigma(x_i - \bar{x})(y_i - \bar{y})}{\Sigma\sqrt{(x_i - \bar{x})^2 (y_i - \bar{y})^2}}$$

Sample calculations for the Pearson Correlation Coefficient calculations are provided below, all using participant 5's data. The sample calculations were repeated for all participants, with the final Pearson Correlation data being found in Table 7.

The Fisher's z-transformation formula is as follows:

$$z = \frac{1}{2} ln(\frac{1+r}{1-r})$$

The Fisher z-transformation calculations were applied to all Pearson Correlation coefficients for all participants, to allow for hypothesis testing of the Pearson Coefficient. While in z form, the variables were averaged, then transformed back into r-values for use in our analysis using the equation below. The Fisher Z-transformed r-values can be found in Table 7*,* below the Pearson Correlation data.

$$r = \frac{e^{2z} - 1}{e^{2z} + 1}$$

i. Sample Calculations - Total Tangential Wrist Velocity versus Reference Pitch Speed

In this Pearson calculation, the x_i term represents the participant's throw velocity, or "fastball velocity" on the datasheet. The $\bar{x}$ term in this case is the mean of the ball velocity recorded over 5 fastball pitches. The y_i term in this case is the maximum tangential velocity associated with each pitch. The $\bar{y}$ term in this case is the mean of the maximum wrist velocities recorded over 5 fastball pitches. The data used in the sample calculations was extracted from Table 1, using both ball velocity and maximum recorded ball velocity values.

$$\bar{x} = \frac{x1 + x2 + x3 + x4 + x5}{5} = \frac{25 + 46 + 47 + 47 + 47}{5} = \textbf{42.4mph}$$

$$\bar{y} = \frac{y1 + y2 + y3 + y4 + y5}{5} = \frac{634.96 + 692.17 + 624.36 + 749.42 + 749.03}{5} = \textbf{689.99m/s}$$

$$\Sigma(x_i - \bar{x})(y_i - \bar{y}) = (x_1 - \bar{x})(y_1 - \bar{y}) + (x_2 - \bar{x})(y_2 - \bar{y}) + ... + (x_i - \bar{x})(y_i - \bar{y})$$

$$= (25 - 42.4)(634.96 - 689.99) + (46 - 42.4)(692.17 - 689.99) + (47 - 42.4)(624.36 - 689.99) + (47 - 42.4)(749.42 - 689.99) + (47 - 42.4)(749.03 - 689.99)$$

$$\Sigma(x_i - \bar{x})(y_i - \bar{y}) = \textbf{1208.43}\ (m/s)^2$$

$$\Sigma\sqrt{(x_i - \bar{x})^2 (y_i - \bar{y})^2} = \Sigma\sqrt{(x_1 - \bar{x})^2 (y_1 - \bar{y})^2} + \Sigma\sqrt{(x_2 - \bar{x})^2 (y_2 - \bar{y})^2} + ... + \; =$$

$$\Sigma\sqrt{(25 - 42.4)^2 (634.96 - 689.99)^2} + \sqrt{(46 - 42.4)^2 (692.17 - 689.99)^2} + \sqrt{(47 - 42.4)^2 (624.36 - 689.99)^2}$$

$$+\sqrt{(47 - 42.4)^2 (749.42 - 689.99)^2} + \sqrt{(47 - 42.4)^2 (749.03 - 689.99)^2}$$

$$\Sigma\sqrt{(x_i - \bar{x})^2 (y_i - \bar{y})^2} = 957.522+7.848+301.898+273.378+271.584 = \mathbf{1811.87}\ (m/s)^2$$

$$r = \frac{1208.43}{1811.87} = \mathbf{0.667}$$

The results in Table 2 were obtained after repeating the same calculations on all other participants using Pythons' built in function for Pearson correlation. Calculated value varies slightly from Python generated value due to slight variation of equation used despite theoretical mathematical equivalency.

ii. Sample Calculations - Stride Length versus Reference Pitch Speed

In this Pearson calculation, the x_i term represents the participant's throw velocity, or "fastball velocity" on the datasheet. The $\bar{x}$ term in this case is the mean of the ball velocity recorded over 5 fastball pitches. The y_i term in this case is the stride length associated with each pitch. The $\bar{y}$ term in this case is the mean of the stride lengths recorded over 5 fastball pitches. The data used in the sample calculations was extracted from *Table 3*, using both ball velocity and maximum recorded stride length values.

$$\bar{x} = \frac{x1 + x2 + x3 + x4 + x5}{5} = \frac{25 + 46 + 47 + 47 + 47}{5} = \mathbf{42.4mph}$$

$$\bar{y} = \frac{y1 + y2 + y3 + y4 + y5}{5} = \frac{63 + 62 + 61 + 60 + 63}{5} = \mathbf{61.8in}$$

$$\Sigma(x_i - \bar{x})(y_i - \bar{y}) = (x_1 - \bar{x})(y_1 - \bar{y}) + (x_2 - \bar{x})(y_2 - \bar{y}) + ... + (x_i - \bar{x})(y_i - \bar{y})$$

$$= (25 - 42.4)(63 - 61.8) + (46 - 42.4)(62 - 61.8) + (47 - 42.4)(61 - 61.8) + (47 - 42.4)(60 - 61.8) + (47 - 42.4)(63 - 61.8)$$

$$\Sigma(x_i - \bar{x})(y_i - \bar{y}) = \mathbf{-26.6}$$

$$\Sigma\sqrt{(x_i - \bar{x})^2 (y_i - \bar{y})^2} = \Sigma\sqrt{(x_1 - \bar{x})^2 (y_1 - \bar{y})^2} + \Sigma\sqrt{(x_2 - \bar{x})^2 (y_2 - \bar{y})^2} + ... +$$

$$= \Sigma\sqrt{(25 - 42.4)^2 (63 - 61.8)^2} + \sqrt{(46 - 42.4)^2 (62 - 61.8)^2} + \sqrt{(47 - 42.4)^2 (61 - 61.8)^2}$$

$$+ \sqrt{(47 - 42.4)^2 (60 - 61.8)^2} + \sqrt{(47 - 42.4)^2 (63 - 61.8)^2}$$

$$\Sigma\sqrt{(x_i - \bar{x})^2 (y_i - \bar{y})^2} = 20.88 + 0.72 + 3.68 + 8.28 + 5.52 = \mathbf{39.1}$$

$$r = \frac{-26.6}{39.08} = \mathbf{-0.68}$$

The results in Table 4 were obtained after repeating the same calculations on all other participants using Pythons' built in function for Pearson correlation. Calculated value varies slightly from Python generated value due to slight variation of equation used despite theoretical mathematical equivalency.

iii. Sample Calculations - Parallel Force Production versus reference Pitch Speed

In this Pearson calculation, the x_i term represents the participant's participant's throw velocity, or "fastball velocity" on the datasheet. The $\overline{x}$ term in this case is the mean of the ball velocity recorded over 5 fastball pitches. The y_i term in this case is the maximum Parallel force produced during each pitch. The $\overline{y}$ term in this case is the mean of the maximum parallel force recorded over 5 fastball pitches. The data used in the sample calculations was extracted from Table 5, using both ball velocity and maximum recorded force values.

$$\overline{x} = \frac{x1 + x2 + x3 + x4 + x5}{5} = \frac{25 + 46 + 47 + 47 + 47}{5} = \mathbf{42.4mph}$$

$$\overline{y} = \frac{y1 + y2 + y3 + y4 + y5}{5} = \frac{335.93 + 319.54 + 272.25 + 315.87 + 329.48}{5} = \mathbf{314.61}$$

$$\Sigma(x_i - \overline{x})(y_i - \overline{y}) = (x_1 - \overline{x})(y_1 - \overline{y}) + (x_2 - \overline{x})(y_2 - \overline{y}) + ... + (x_i - \overline{x})(y_i - \overline{y})$$

$$= (25 - 42.4)(335.93 - 314.61) + (46 - 42.4)(319.54 - 314.61) + (47 - 42.4)(272.25 - 314.61) + (47 - 42.4)(315.87 - 314.61) + (47 - 42.4)(329.48 - 314.61)$$

$$\Sigma(x_i - \overline{x})(y_i - \overline{y}) = \mathbf{-473.878}$$

$$\Sigma\sqrt{(x_i - \overline{x})^2(y_i - \overline{y})^2} = \Sigma\sqrt{(x_1 - \overline{x})^2(y_1 - \overline{y})^2} + \Sigma\sqrt{(x_2 - \overline{x})^2(y_2 - \overline{y})^2} + ... +$$

$$= \Sigma\sqrt{(25 - 42.4)^2(335.93 - 314.61)^2} + \sqrt{(46 - 42.4)^2(319.54 - 314.61)^2} + \sqrt{(47 - 42.4)^2(272.25 - 314.61)^2} + \sqrt{(47 - 42.4)^2(315.87 - 314.61)^2} + \sqrt{(47 - 42.4)^2(329.48 - 314.61)^2}$$

$$\Sigma\sqrt{(x_i - \overline{x})^2(y_i - \overline{y})^2} = 370.968 + 17.748 + 194.856 + 5.796 + 68.40 = \mathbf{657.77}$$

$$r = \frac{-473.878}{657.77} = \mathbf{-0.72}$$

The results in Table 6 were obtained after repeating the same calculations on all other participants using Pythons' built in function for Pearson correlation. Calculated value varies slightly from Python generated value due to slight variation of equation used despite theoretical mathematical equivalency.

Results

Tables 1, 3, and 5 show the data recorded for a single persons' peak tangential arm velocity, stride measured and peak force for each of the five pitches and the pitch speed associated with each. Tables 2, 4, and 6 show the Python produces r values for all participants for tangential arm velocity, stride length and force respectively.

Table 1

Participant 5's Maximum Recorded wrist velocity and associated recorded ball velocity

Pitch	Recorded Ball Velocity (x_i)	Max Recorded Wrist Velocity (y_i)
1	25mph	634.96m/s
2	46mph	692.17m/s
3	47mph	624.36m/s
4	47mph	749.42m/s
5	47mph	749.03m/s

Table 2

R values obtained for Max Arm Velocity vs Pitch Speed

Participant Number	r1 (for Max tangential arm velocity)
1	0.52
2	-0.51
3	-0.81
4	-0.59
5	0.52*
6	-0.19
7	0.15
8	-0.67
9	0.42
10	0.35
11	0.32
12	0.19
13	0.43
14	0.46
15	0.62
16	0.17
Fischer Averaged r	0.18

Note: Python value varies slightly from calculated.

Table 3

Participant 5's Stride Length and associated Recorded Ball Velocity

Pitch	Recorded Ball Velocity (x_i)	Recorded Stride Length (y_i)
1	25mph	63in
2	46mph	62in
3	47mph	61in
4	47mph	60in
5	47mph	63in

Table 4

R values obtained for Stride Length vs Pitch Speed

Participant Number	r2 (for Stride Length)
1	-0.70
2	-0.47
3	0.32
4	-0.64
5	-0.52*
6	-0.43
7	0.21
8	-0.15
9	0.74
10	0.89
11	0.27
12	0.78
13	0.81
14	-0.80
15	0.33
16	0.81
Fischer Averaged r	0.15

* Python value varies slightly from calculated.

Table 5

Participant 5's Maximum Force Production and associated Recorded Ball Velocity

Pitch	Recorded Ball Velocity (x_i)	Maximum Force Production (y_i)
1	25mph	335.93
2	46mph	319.54
3	47mph	272.25
4	47mph	315.87
5	47mph	329.48

Table 6

R values obtained for Max Parallel Force vs Pitch Speed

Participant Number	r3 (for Max Parallel Force)
1	-0.19
2	-0.82
3	0.55
4	-0.40
5	-0.49*
6	0.79
7	0.75

8	-0.44
9	-0.66
10	0.81
11	0.53
12	0.91
13	0.21
14	-0.63
15	0.51
16	0.31
Fischer Averaged r	0.05

Note: Python value varies slightly from calculated.

Table 7 summarizes the r-values calculated for each participant with the Fischer Average r-value calculated for each category (r1, r2, r3). These r-values were later categorized using *Figure 4*.

Table 7

Resulting r-values (correlation coefficient) for all study participant

Participant Number	Pitching Experience Level	r1 (Tangential Velocity)	r2 (Stride Length)	r3 (Parallel Force)
1	3 (Novice)	0.52	-0.70	-0.19
2	4 (No Experience)	-0.51	-0.47	-0.82
3	4 (No Experience)	-0.81	0.32	0.55
4	4 (No Experience)	-0.59	-0.64	-0.40
5	3 (Novice)	0.52	-0.52	0.49
6	3 (Novice)	-0.19	-0.43	0.79
7	2 (Mid-Level)	0.15	0.21	0.75
8	3 (Novice)	-0.67	-0.15	-0.44
9	2 (Mid-Level)	0.42	0.74	-0.66
10	3 (Novice)	0.35	0.89	0.81
11	4 (No Experience)	0.32	0.28	0.53
12	3 (Novice)	0.19	0.78	0.91
13	1 (Collegiate)	0.43	0.81	0.21
14	3 (Novice)	0.46	-0.80	-0.63
15	1 (Collegiate)	0.62	0.33	0.51
16	1 (Collegiate)	0.17	0.81	0.31
Fischer Averaged r - Total	-	0.07	0.15	0.23
Fischer Averaged r - Collegiate	-	0.42	0.7	0.35
Fischer Averaged r - Mid Level	-	0.12	0.23	0.04
Fischer Averaged r - Novice	-	0.17	-0.1	0.39
Fischer Averaged r - No Experience	-	-0.47	-0.16	-0.09

Note: Python value varies slightly from calculated.

The Pearson Correlation ranges in Figure 4 will be used to interpret the results from the r value calculations later.

Figure 4

Statistical scale of correlation coefficient significance (Pearson Correlations)

Scale of correlation coefficient	Value
$0 < r \leq 0.19$	Very Low Correlation
$0.2 \leq r \leq 0.39$	Low Correlation
$0.4 \leq r \leq 0.59$	Moderate Correlation
$0.6 \leq r \leq 0.79$	High Correlation
$0.8 \leq r \leq 1.0$	Very High Correlation

Figures 5-7 show the raw and filtered wrist IMU data for participant 15 who demonstrated the fastest pitch speed. Figure 8 shows a comparison of total arm velocity between the fastest fastball participant 15 threw, and the slowest change-up thrown.

Figure 5

Raw Wrist IMU data recorded over the entire experiment of Participant 15, Sophie

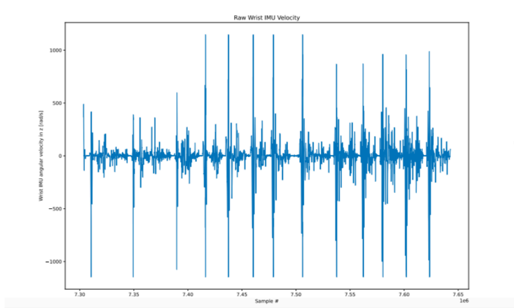


Figure 6.

Raw Wrist IMU data, highlighting one pitch from Participant 15, Sophie

Figure 7.

Filtered Wrist IMU data, highlighting one pitch from Participant 15, Sophie

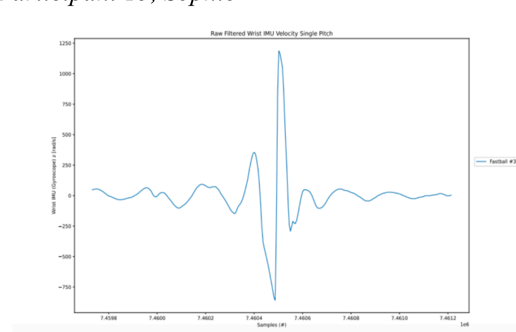


Figure 8.

Total velocity of the wrist, recorded over one normal pitch and one change-up from Participant 15, Sophie

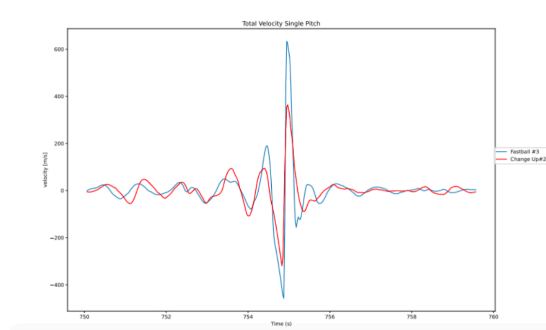


Figure 9 shows a breakdown of the biomechanical phases of the pitch within the signal which was used to designate where a pitch occurred in the signal. The pitch phase breakdown was shown in Figure 3 in the Methods section. Figures 10, 11 and 12 show the raw force data, filtered single pitch data for the fastest fastball and the biomechanical breakdown of the force signal respectively.

Figure 9

Velocity Profile of a Single Pitch, with stages colour coded

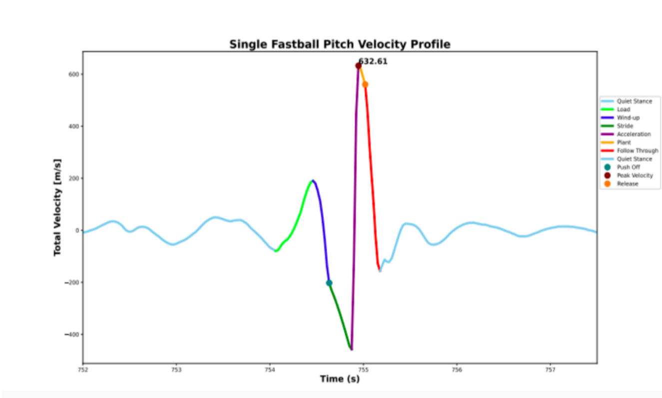


Figure 10

Raw Parallel Drive Force Data Recorded Over the Entire Experiment of Participant 15, Sophie

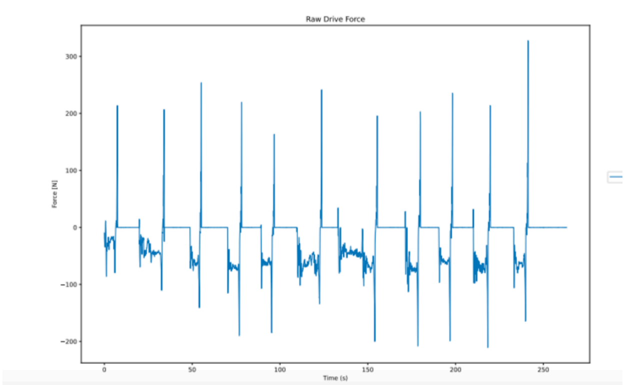


Figure 11

Filtered Parallel Drive Force Data for One Pitch From Participant 15, Sophie

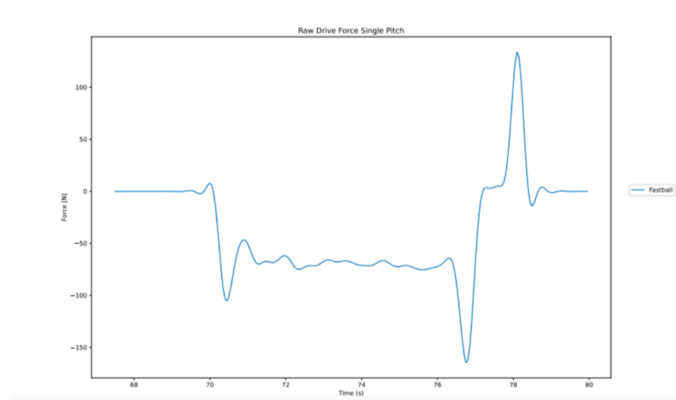
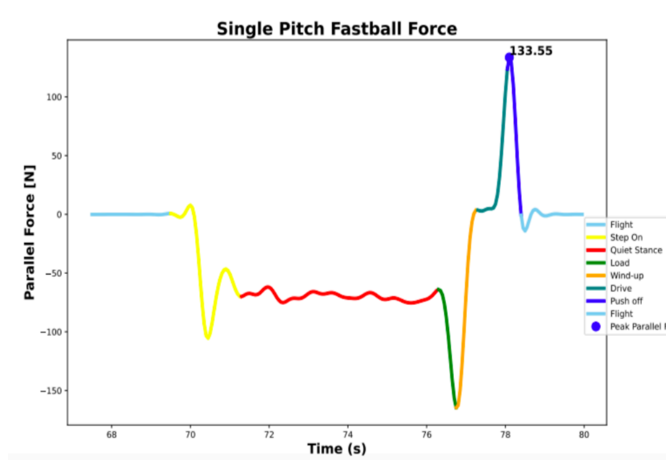


Figure 12

Parallel Force Profile of a Single Pitch, with Stages Colour-Coded



Figures 13-24 show the linear trends for each participant broken into experience levels.

Figure 13

Arm Velocity, Drive Force, and Stride Length vs Pitch Speed for Collegiate Level Pitchers

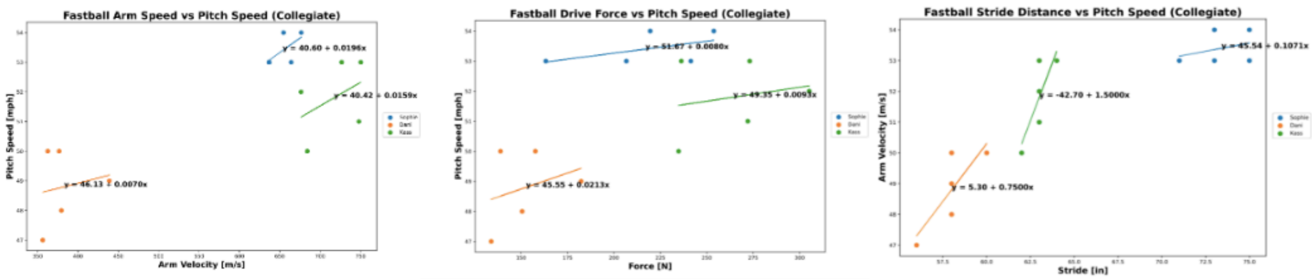


Figure 14

Arm Velocity, Drive Force, and Stride Length vs Pitch Speed for Mid-Level Pitchers

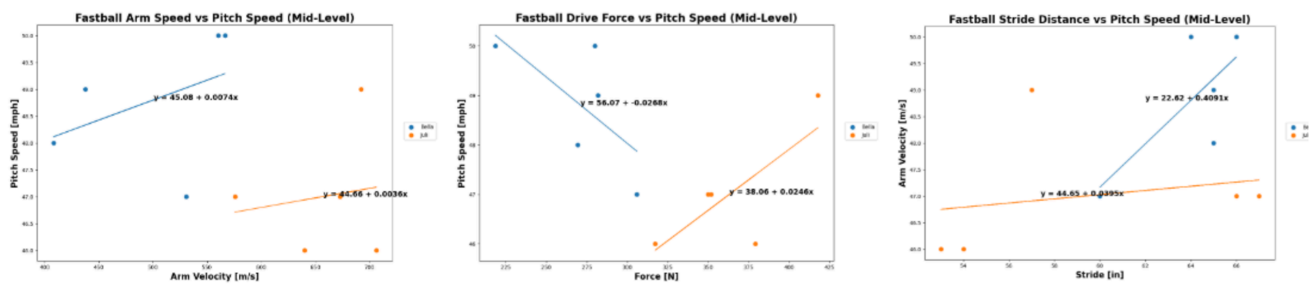


Figure 15

Arm Velocity, Drive Force, and Stride Length vs Pitch Speed for Novice Level Pitchers

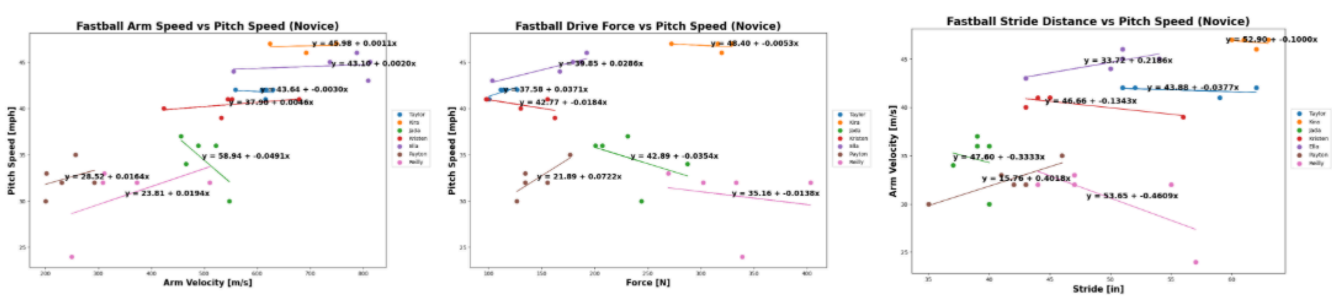
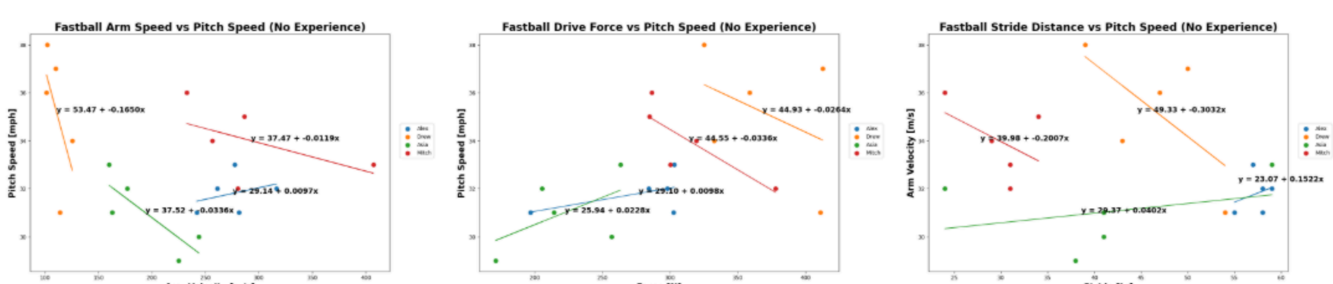


Figure 16

Arm Velocity, Drive Force, and Stride Length vs Pitch Speed for Pitchers with No Experience



Discussion

After analyzing all of the data produced, the overall r values showed the strongest correlation between drive force and pitch speed with drive force $r = 0.23$, which is still a low correlation value based on the standard, arm velocity $r = 0.07$ and stride $r = 0.15$. Since none of these showed a truly strong correlation to pitch speed, we decided to investigate the trends by experience category.

The no experience participants demonstrated a moderate negative, meaning pitch speed decreased with increased arm velocity, correlation between arm velocity and pitch speed with $r = -0.47$. This was the strongest correlation for this group with stride and force values being -0.16 and -0.09 respectively; again showing negative correlations. The no experience group having their strongest correlation with arm velocity makes sense as participants with no experience lack technique and would rely more heavily on arm velocity instead of mechanics to achieve speed, and also have less pitch control decreasing speed due to wild pitches. Despite this result confirming our initial hypothesis, further investigation is still needed before confirmation given that this group produced the lowest average pitch speed at 32.6 mph.

The novice level participants showed maximum positive low correlation value to force with $r = 0.39$, meaning pitch speed increased with force. The arm velocity and stride for this group have very low correlation values with $r = 0.17$ and $r = -0.1$ respectively, indicating a negative correlation with stride. The stronger correlation to force could indicate these participants have enough mechanical knowledge to know how to use their legs to generate power and momentum but lack the practice or mechanics to generate more pitch speed as the average pitch speed for this group was 38.1 mph. This result neither proves or disproves our hypothesis.

The mid-level participants showed the highest correlation to stride length with $r = 0.23$, which is a positive low correlation. The values for arm velocity and force were both very low positive correlations at $r = 0.12$ and $r = 0.04$ respectively. This group produced an average pitch speed of 47.9 mph. While this speed is quite a bit higher than the previous groups, having a better grasp on the mechanics of pitching but a sample size of only 2 participants makes it impossible to come to any statistically meaningful conclusions with such low correlation values.

The collegiate level pitchers had the highest average pitch speeds at 51.3mph, with a high of 54 mph, showed a high positive correlation to stride length with $r = 0.7$ and a moderate positive correlation to arm velocity at $r = 0.42$; force was the weakest correlation with low positive correlation of $r = 0.35$. These being the stronger r values could be due to the nature of the collegiate participants having more experience with pitching compared to the other participants; the collegiate-level participants have a greater ability for utilizing kinematic linking and force velocity principles during each pitch. This concept can be seen in Figures 13-16*,* which show the three variables compared to pitch speed for each group. The collegiate-level dataset is also more consistent and follows predictable patterns, all having a positive slope of similar magnitude, while the novice dataset, Figure 16, is more random having differing slopes and slope directions.

The results of the collegiate level pitchers combined with the results of the mid-level pitcher results, as these players had the higher pitch speeds and have overall better pitching mechanics compared to the other two groups, disproves, at least for the purposes of this report, our initial hypothesis that arm velocity would have the highest correlation to pitch speed. Though arm velocity did prove to have a stronger correlation to pitch speed than drive force for 3 of the 4 groups.

This is by no means an exhaustive evaluation of the correlations between arm velocity, drive force and stride length in relation to pitch speed. Further investigation including measurements from the hand to gauge velocity generated from the wrist snap, landing force, release angle and type of release of the ball should all be investigated, at a bare minimum, before coming to any decisive conclusions about which has the strongest correlation to pitch speed. It would also be beneficial to test the correlation between drive force and stride length as stride length is likely dependent, in part, on drive force to achieve the stride distance.

Examining and understanding biomechanical principles of pitching is essential for optimizing athletic performance, as a deeper understanding of the quantitative aspects of softball can enhance success on the field. Specifically, these results can optimize player development by understanding how stride length and arm velocity contribute to pitch speed will help coaches fine tune coaching programs for best results. This goes hand in hand with injury prevention and performance longevity; poor mechanics and improper form can increase strain and chance of injury on the arm and shoulder, so reinforcing the importance of proper force transitioning in coaching programs is crucial.

Conclusion

This study aimed to understand the biomechanics of softball fastball pitching, focusing on the relationships between arm velocity, leg drive force and pitch speed. We examined how kinetic linking - specifically, the coordination between the upper and lower extremities - affects pitch velocity. Sixteen participants, all varying in softball pitching experience ranging from no experience at all to collegiate level athletes, were used to collect data while throwing 5 fastball pitches each. Inertial measurement units (IMUs) on the chest and the wrist, along with a force plate to measure leg drive force and a radar gun for pitching speed were used to collect data. Statistical formula, the Pearson Correlation coefficients, analysis and linear regression modeling were used to determine which variable(s) had the strongest effect on pitch speed. Key findings include that stride length of the collegiate pitchers had the highest correlation with pitch speed with an average r value of 0.7, and r values of parallel force and tangential arm velocity each were 0.35 and 0.42, respectively. These results help us conclude that stride length has the highest correlation in maximizing pitching speed in softball, opposing our initial hypothesis that arm velocity would have the highest correlation. Collegiate level pitchers displayed more efficient kinetic linking through each pitch as seen through statistical analysis, suggesting that experience and practice both play crucial roles in throwing an efficient softball pitch. These results help us understand pitching mechanics in alignment with biomechanical principles such as kinetic linking and force velocity relationships, and furthermore help coaches implement proper training techniques for the athletes to maximize their performance in force velocity production. More testing is needed to rule out other contributing factors in pitch speed.

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