Analysis of Bike Seat Height on Performance and Ankling for Casual Bikers

ENGSCI-20: Final Paper

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December 13, 2023

Abstract:

Biking has grown as a sport over the last few years and consequently, many new, casual bikers have appeared. Much of the current literature on performance and injury prevention in cycling has focused on competitive bikers. In this paper, we explore ankling and cadence as measures of injury prevention and performance, respectively, of the casual biker. Using IMUs as a cheap alternative to more streamline sensors, we collected data from eight casual bikers. Due to our low sample size, few conclusions were able to be draw from our data.

Introduction:

In just over 10 years, Peloton has sold more than 2.33 million stationary bikes. [1] This trend has not been linear over time, though, as there was a recent boom in indoor cycling during the Covid-19 pandemic when people could not exercise in gyms. As the number of recreational cyclists increase, scholars and bloggers alike have researched the best biomechanical practices for cyclists.

In this paper, we examine whether a cyclist's seat height affects their performance, as measured by ankling, cadence, and output. More specifically, we want to know if seat-height is just important for competitive cyclists that need every possible advantage, or if there is still significant performance variability for the average cyclist.

Using a sample of eight recreational cyclists, we measured their performance and ankling at three saddle heights: inseam length and +/- 5% inseam length. Our results did not point to any strong differences across saddle heights, although the higher saddle height was associated with a slightly significant increased ankling. Moving forward, we believe that a larger-scale study with our approach would help uncover these relationships in better detail. There were, however, interesting findings that were not related to our initial research questions. We found that the IMU sensors performed extremely well when compared to the more advanced technology at Harvard's Motion Capture Lab and that our participants exhibited strong asymmetry across legs.

Literature Review:

The canon of cycling biomechanics is evolving rapidly, especially in the area of optimizing saddle, or seat, heights. However, there is a lack of consensus on how to optimize saddle height. In "Effects of Saddle Height on Economy in Cycling," Peveler explores the two main methods for measurement: inseam length and knee angle. When this was written in 2008, the convention was that cyclists should reach a 25-35 degree knee angle, which is best achieved through a 109% inseam height. After adjusting the seat height by inseam length or knee angle, the authors did not find a significant difference across methods in the heart rate or perceived exertion. However, O_2 levels were lower when the knee angle was at 25 degrees, rather than 35 degrees, suggesting that the 109% inseam length and 35 degree knee angle was too high. [2]

On the whole, lower than optimal saddle heights are correlated with significantly worse health and performance metrics. Sanderson and Amoroso use an observational study of female cyclists to conclude that the lower seat height decreased Electormygraphic (EMG) activity. They posit that the lower seat height decreased contraction velocities in the ankle and knee joints, which caused an increased gastrocnemius length. [3]

Moreover, in "Patellofemoral Joint Forces During Ergometric Cycling," the authors find that patelloformal joint forces were increased when the saddle height decreased or workload increased. [4] Hence, in order to prevent anterior knee point, cyclists should be careful to set an appropriately high seat length and not overdo their workload. Interestingly, the authors do not find a significant relationship between the joint forces and pedaling rate or foot position. [4]

It is important to note that cyclists often underestimate the height of the saddle. In "Effects of Saddle Height on Pedal Force Effectiveness," the authors collect data at four saddle heights for each participant. Subjects first choose their "preferred" saddle height and from there, the lab coordinators adjusted the height by 3% in either direction to create a 10 degree difference in knee flexion. They also measured each subject's optimal height as the position where the knee flexion was 25 degrees. The average participant's knee flexion was close to 25 degrees at their high saddle height, as opposed to their preferred saddle height. Furthermore, the researchers found that the average pedal effectiveness was significantly higher at the optimal saddle height than the subject's preferred height. [5]

The relationship between saddle height and performance is not entirely linear, though, and a saddle that is too high for the participant can overwhelm their VO_2, or maximal oxygen intake. Using a study of five subjects across saddle heights from 100% to 112% of their inseam height, researchers Shennum and DeVries calculated efficiency as the lowest possible $\mathrm{VO_2}$ per unit of work. They concluded that the most effective work was being done at an inseam length of 100% to 104%. [6] Hence, a saddle height that roughly approximates inseam length, while maintaining an appropriate knee angle, is believed to be the best setup for all types of cyclists.

Hypotheses:

For this study, our performance metric is cadence. We hypothesize that the optimum seat height for performance will be the median height, while both the lower and higher seat heights will be associated with lower performance scores. While many studies focus on knee-joint angles, we will use a measurement of ankling as our primary joint of interest. Thus, we hypothesize that as a person's seat height increases, the angle between their ankle and the pedal will necessarily have to grow as well. Therefore, the highest seat height will be associated with the greatest ankling value.

Experimental Methods:

Experimental Design

To test the effects of seat height on performance and potential injury, we designed an experiment using IMUs and a Peloton bike. By placing IMUs under the bike pedals it is possible to get cadence and ankling during a bike ride. In an attempt to standardize body positioning among different participants, we set the bike dimensions of the Peloton before each trial. The adjustments included adjusting the height of the handlebars to '*g*' and the handlebar to the middle of the seat distance to 62 cm. The crank length of the Peloton was 17 cm and resistance was set to 50%.

After setting the dimensions of the bike, we attached an IMU with tape to the bottom of each pedal. In the frame of the bike we oriented the IMU such that the positive y-axis faced backward, the positive z-axis faced down, and the positive x-axis pointed to the left of the bike. The orientation was selected to simplify certain data output features of our IMUs and could be changed if desired. This concluded the preparation phase for each trial.

During the measuring phase of the trial, we followed a three-step procedure, including taking baseline measurements, setting the seat height, and biking. They are as follows:

Step 1: Baseline Measurements:

1. Measure participant's inseam length.
2. Measure participant's shoe size
3. Survey participants on past biking experience and current workout regime.

Step 2: Setting Seat height: For each participant, the order of the seat heights (low, mid, high) was randomized.

1. Define a mid, low, and high seat height as inseam length, inseam length - 5%, and inseam length + 5%, respectively.

2. Set seat height to initial height.

Step 3: Bike: This step was repeated three times, once for each seat height.

1. Strap shoes into the pedals and start with left foot down, right foot up. Standardizing this allows for easy alignment of data.
2. Turn both sensors on.
3. Start ride on the Peloton by navigating to “More Rides” $\rightarrow$ “Just Ride - Start Riding” $\rightarrow$ “No Goal” $\rightarrow$ "START".
4. Have the participant accelerate to their maximum effort as quickly as possible and hold for 30 seconds.
5. At 30 seconds have the participant fully stop, turn sensors off, and allow them to take a short rest while adjusting seat height.

Calculating Cadence

Our IMUs do not have a cadence calculation built-in, however, from the IMUs’ collected data it is possible to derive cadence. By looking at the raw data, we noted linear acceleration in the z-direction (L_z) was cyclic. By finding the peak of L_z for a trial, we got the points where the foot was in the approximately same position during its cycle. By taking the difference between neighboring points you can get the cycle period in seconds. This can be converted to rotations per minute, which is cadence.

One reason why a Peloton was chosen for the experiment was to check the IMUs’ derived cadence value to the Peloton’s measured cadence value. However, due to the limitations of the Peloton, this idea had to be scrapped. Nevertheless, the IMUs accuracy was measured during a separate trial, where everything in the *Experimental Design* section was held constant except for the bike itself. The bike used was from the Motion Capture Lab (MCL) at Harvard and provided accurate measurements of cadence. From Figure 1, which compares derived average sensor cadence against MCL measured average cadence we see that the sensors perform well while measuring cadence.

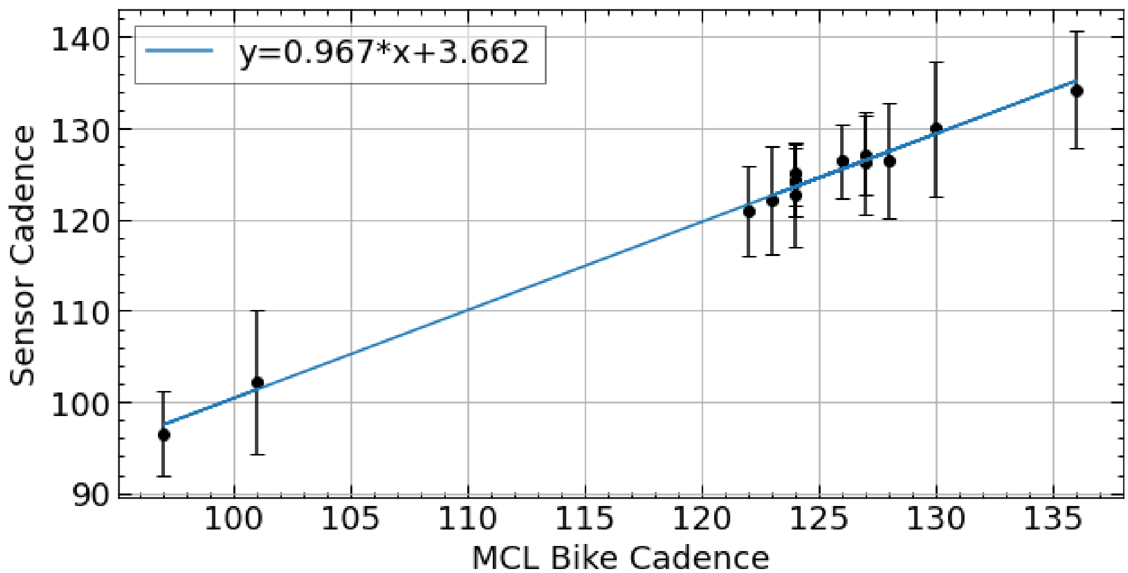

Figure 1: Derived average cadence from the sensors vs measured average cadence from the bike from the Motion Capture Lab at Harvard.

Calculating Ankling

The IMUs collected rotational data that we could use to determine ankling. Due to the way we attached our IMUs to the pedals, we only needed to evaluate the roll data to get the angle of the pedal with respect to the ground. This in turn implies the ankling parameter (Figure 2) for the foot at any time throughout the testing as ankling is defined as the ankle between the plane of the foot and the ground (horizontal reference point).

Collecting this data over the course of a trial gave us oscillatory data for both the left and right ankling data. From this data, as shown in Figure 3, we exclude the initial 5 seconds and the final 5 seconds of each person's run in order to remove any non-standard data emerging from the ramp-up and cool-down phases of the trials.

Figure 2: This diagram displays the angle evaluated for an ankling measurement.

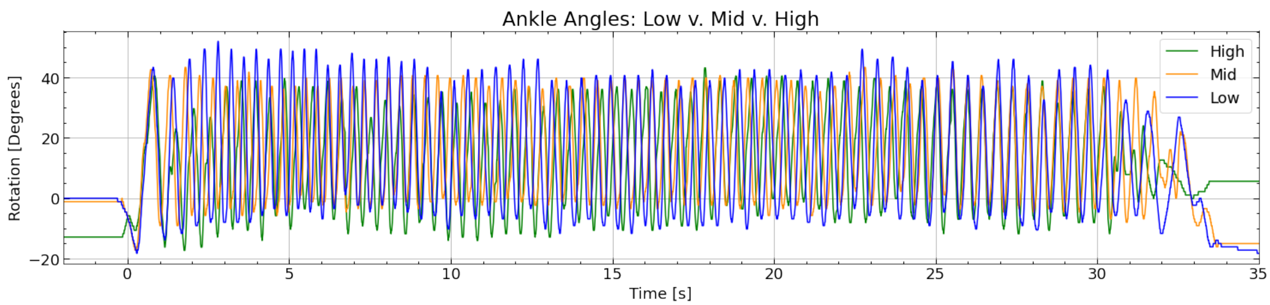

Figure 3: An example of the data retrieved from one side for low, mid, and high seat heights.

Now, we need to determine the ankle angles at certain positions throughout the pedal. These are defined explicitly in Figure 4, where PP is the forward pedal position.

Figure 4: Diagram showing the four major phases of pedaling.

Based on the data we recieved from the MCL, we can assume that the maximum angle is associated with the RP and the minimum angle is associated with the PP. This is not an exact correlation, but as Figure 5 shows, this is a good assumption to make and allows us to associate all the peaks with the RP and all the troughs with the PP.

Finally, to get the points associated with the BDC, we take the value of the curve whose index is is exactly between each trough and the immediately following peak. To get the points associated with the TDC, we take the values of the curve whose index is exactly between each peak and the immediately

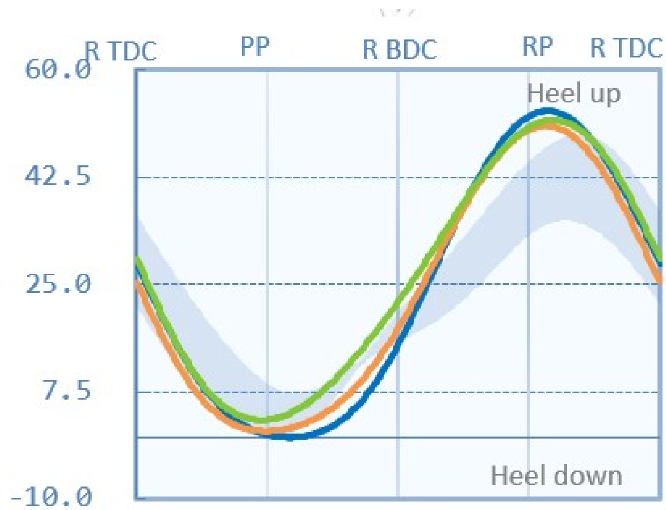

Figure 5: Ankling data from the MCL to show how the oscillations align with pedal positioning.

following trough.

Once we have identified all these values, we can simply average them across each dataset. This gives us an average value for TDC, BDC, PP and RP across each dataset. This is the ankling data we will use for analysis in this paper.

Results:

Performance:

To quantify performance, we planned to compare cadence between each trial. However, due to our small number of participants, and for each a small number of trials, cadence resulted in being a poor measure of performance. As seen in Figure 6, there is no trend in seat configuration and cadence as we hypothesized. However, this might be because of the stronger correlation we see in Figure 7, which plots normalized cadence versus the order of the trial. The figure shows the first trial is more likely to yield the highest cadence throughout all trials. This is likely a feature of our experimental methods and having the participants push themselves to the max each trial with no proper warm-up.

We can also refer to the regression table (Figure 12) to check the conclusions we drew from the graphs. Here the only statistically significant thing to predict cadence is the inseam. We suspect this may stem from our small sample where taller people were generally fitter. It doesn't make sense that this would have to be true. Furthermore, a potential reason we don't see more statistical significance in the cadence column may be because of the large standard deviations stemming from the low number of participants.

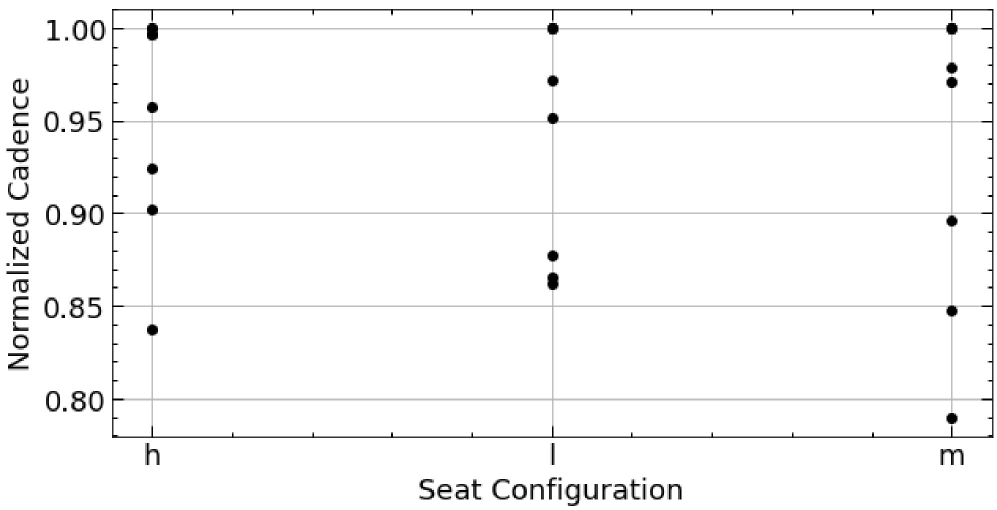

Figure 6: Cadence normalized per person plotted versus the seat configuration.

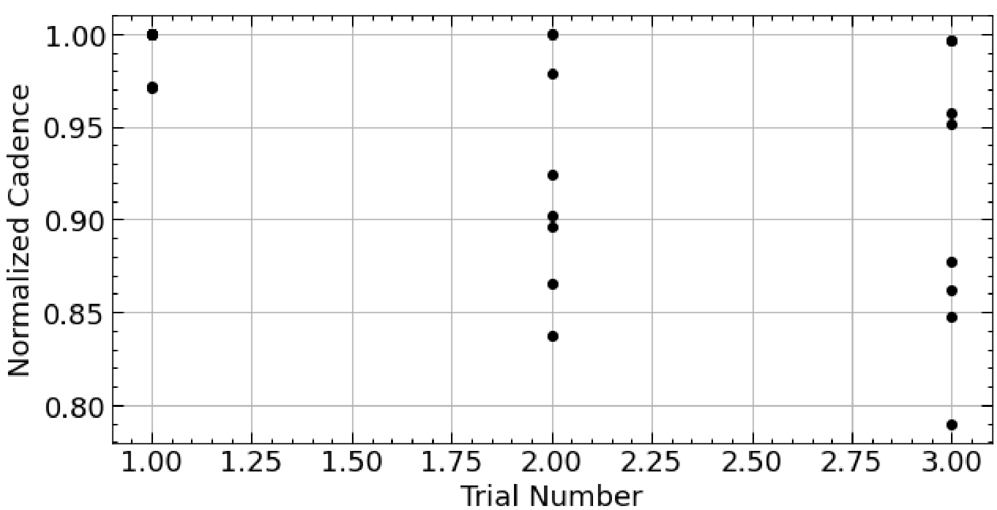

Figure 7: Cadence normalized per person plotted versus the trial number.

Injury Prevention

In this experiment, we used ankle angles as a proxy for evaluating injury risk. Repeated forces at high ankling angles can be accosiated with increased stress over time. Therefore, we wanted to evaluate whether seat height had a significant impact on ankling.

The first parameter we looked into was the range of ankling angles between the maximum (RP) and minimum (PP) values. This data is displayed in Figure 8. Ankling range does not appear to be a good predictor of whether an individual was at a low, mid or high seat height. In other words, the ratios of low:mid:high ankling ranges per individual were not consistent across different participants.

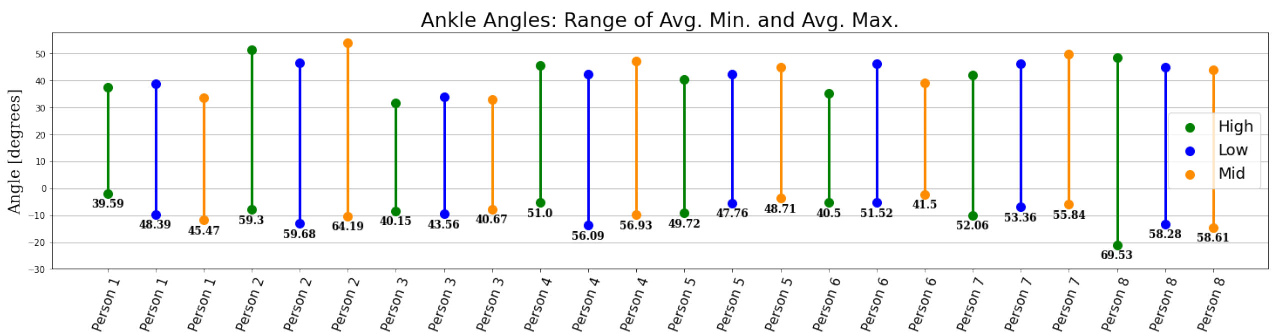

Figure 8: The ankling angle ranges, from the minimum (PP) to the maximum (RP), for each participant's three trials.

Next we tried to evaluate the variation in the PP and the RP values for each participant. To do so, we plotted the minimum and maximum angle values for each participant as shown in Figure 9. To explicitly describe this plot, each participant has two bars connecting there three maximum values and their three minimum values for the low, mid and high trials. We had expected to see the high trials at categorically greater angles. Unfortunately, this is not what we see in this plot.

However, with closer analysis of the pedaling cycle, we realized that we would expect to find this discrepancy between trials mainly in the BDC data. Therefore, we compiled the same data for the BDC as shown in Figure 10. Here it is readily apparent that a high seat height correlates positively with a higher ankling angle at the BDC for all but one participant. Referencing the statistical analysis from the regression table in Figure 12, we see that the high seat height does have a positive correlation with ankle

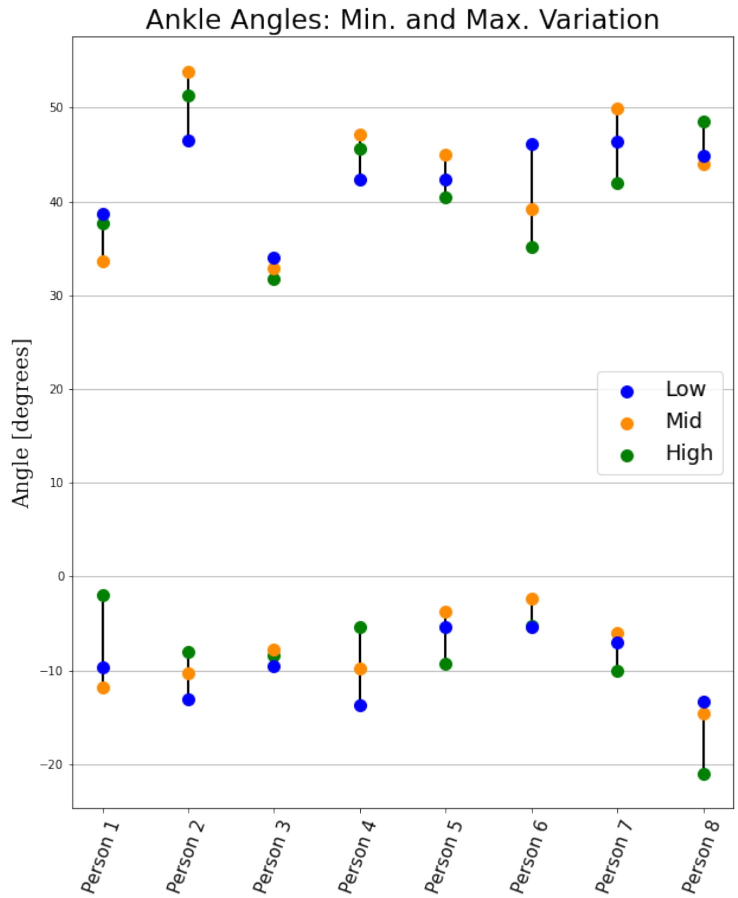

Figure 9: The ankling angle variations, between the minimum (PP) and the maximum (RP), for each participant's three trials.

BDC. However, the p-value here is only significant to a factor of $p < 0.1$. This means that we cannot claim this fact with statistical significance.

Therefore, we can make no concrete claims as to whether differing seat heights are correlated with certain ankling angles. This is largely due to a small sample size that makes it hard to achieve the threshold of statistical significance.

Ankling Asymmetry

As a final piece of analysis, we tried to evaluate ankling variation between participant's left and right sides for each trial. To do so, we simply take the absolute value of the difference between the average ankling

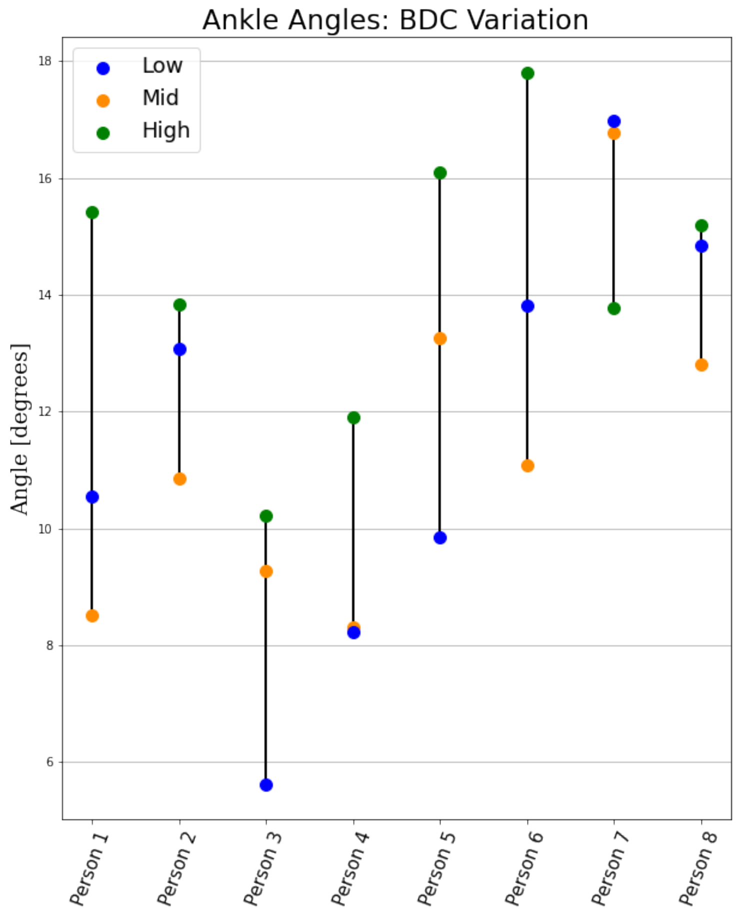

Figure 10: Ankling variation at the BDC.

angle of the left and right datasets per trial.

While it is clear that all participants have a significant measure of variation between their left and right sides during all trials, this asymmetry also does not appear to be a significant predictor of seat height.

At most, from figures 10 and 11, we can conclude that the average cyclist likely has significant pedaling asymmetries. This means that the pedaling mechanics are different in each leg of the cyclist. This implies that one leg is the dominant driver in the pedal and performance may be able to be increased if this asymmetry is decreased.

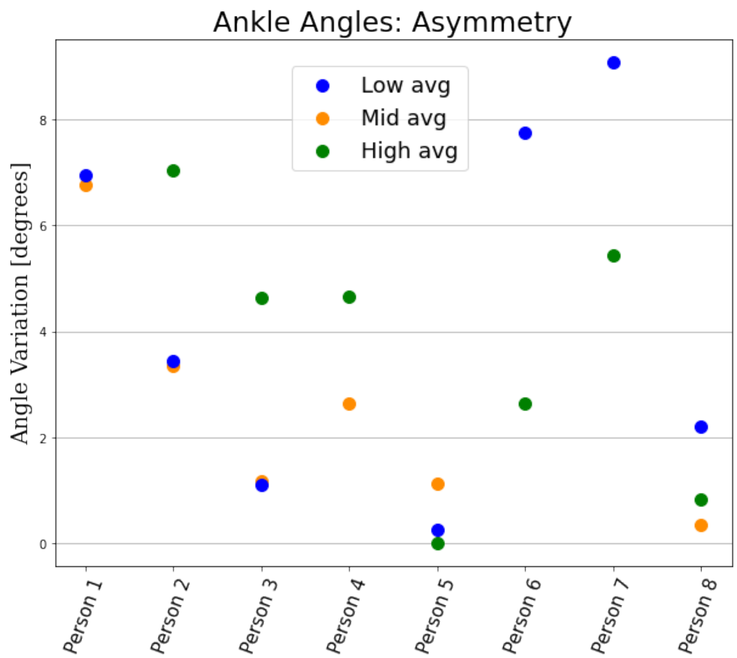

Figure 11: Asymmetry between left and right sides.

Regressions

A: Methodology

In each of the six regressions, we use a linear regression to model the three outcome variables - avg angle BDC, avg angle TDC, and cadence. In the first regression for each outcome variable,we only use indicator variables for the seat height, where the intercept represents the mid height. In the second regressions for each outcome variable, we add linear terms for the standardized inseam height and trial order. The relevant variables are defined as:

1. Avg angle BDC: mid way between valley and next peak, bottom dead center (measured in degrees)

2. Avg angle TDC: mid way between peak and next valley, top dead center (measured in degrees)

3. Cadence: Number of revolutions per minute

4. HighSeat= Binary for high seat: 1 if saddle height is 5% above inseam length, 0 otherwise

5. LowSeat= Binary for high low seat: 1 if saddle height is 5% below inseam length, 0 otherwise

6. Inseamsc= Standardized inseam height

7. Trial order= linear scale representing trial number, can take on values 1-3.

Each regression equation is outlined below, where the βs represents the coefficient and the ϵ represents the error term. β_0 is the intercept in each equation and measures the value of the outcome variable at the middle, or optimal seat height.

$$AvgAngleBDC_i = 1 * HighSeat_i + 2 * LowSeat_i + \beta_0 + \epsilon_i \tag{1}$$

$$AvgAngleBDC_i = \beta_1 * HighSeat_i + 2 * \beta_2 LowSeat_i + \beta_3 * inseamsc + \beta_4 * trialorder + \beta_0 + \epsilon_i \tag{2}$$

$$AvgAngleTDC_i = \beta_1 * HighSeat_i + \beta_2 * LowSeat_i + \beta_0 + \epsilon_i \tag{3}$$

$$AvgAngleTDC_i = \beta_1 * HighSeat_i + 2 * LowSeat_i + \beta_3 * inseamsc + \beta_4 * trialorder + \beta_0 + i \tag{4}$$

$$Cadence_i = \beta_1 * HighSeat_i + \beta_2 * LowSeat_i + \beta_0 + \epsilon_i \tag{5}$$

$$Cadence_i = \beta_1 * HighSeat_i + \beta_2 * LowSeat_i + \beta_3 * inseamsc + \beta_4 * trialorder + \beta_0 + \epsilon_i \tag{6}$$

B: Output

The regression results are displayed below in figure 12 with each equation following sequentially. It is important to note that the adjusted R^2 values were very low, especially when only using the factored variable for seat height. Hence, very little of the variation is explained by the independent variables in columns 1, 3, and 5. After including inseam height and trial order, the R^2 improves, especially for predicting cadence.

Regression Table for Avg Ankle BDC, Avg Ankle TDC, and Cadence:

	Avg Angle BDC		Avg Angle TDC		Cadence	
	(1)	(2)	(3)	(4)	(5)	(6)
High_Seat	2.922*	2.850*	-0.277	-0.475	0.518	1.638
	(1.526)	(1.586)	(2.055)	(2.091)	(9.499)	(5.591)
Low_Seat	0.259	0.223	-0.429	-0.529	0.485	1.045
	(1.526)	(1.576)	(2.055)	(2.079)	(9.499)	(5.558)
Intercept	11.362***	10.825***	20.463***	18.974***	117.528***	125.922***
	(1.079)	(1.857)	(1.453)	(2.449)	(6.717)	(6.546)
inseam_sc		-0.507		-0.858		14.327***
		(0.642)		(0.847)		(2.265)
trial_order		0.287		0.794		-4.477
		(0.793)		(1.046)		(2.795)
Observations	24	24	24	24	24	24
R^2	0.176	0.208	0.002	0.080	0.000	0.692
Adjusted R^2	0.098	0.041	-0.093	-0.114	-0.095	0.627
Residual Std. Error	3.052 (df=21)	3.147 (df=19)	4.110 (df=21)	4.150 (df=19)	18.999 (df=21)	11.094 (df=19)
F Statistic	2.247 (df=2; 21)	1.245 (df=4; 19)	0.022 (df=2; 21)	0.411 (df=4; 19)	0.002 (df=2; 21)	10.650*** (df=4; 19)
Note:						*p<0.1; **p<0.05; ***p<0.01

Figure 12: Regression table

C: Interpretation

1. Avg Angle BDC: In predicting the average angle BDC, none of the variables reported significance at the 5% significance level. At the 10% significance level, a higher seat was associated with about a 2.9 greater BDC, even after holding constant for the standardized inseam height and trial order.

2. Avg Angle TDC: In predicting the average angle BDC, again none of the variables reported significance at the 5% or 10% significance level. This does not necessarily mean that there is no relationship, but rather that our sample size is too small to get precise estimates.

3. Cadence: In my first regression for cadence, neither of the seat height coefficients reported significance, meaning that the seat height was not associated with a significant difference in cadence. After adding terms for trial order and inseam height, inseam height is correlated with higher cadence. Specifically, for each one standard deviation increase in inseam height, the average cadence

increases by 14.3 rev/min. However, this could be confounded by variables like gender and average physical activity.

Discussion:

We looked at cadence and ankling in eight casual bikers to examine the effect of adjusting seat height on performance and injury prevention. Our findings were predominately inconclusive. While a higher seat height may be associated with more extreme ankling angles, we found these trends to have no statistical significance when performing a regression. We suspect that the lack of statistical significance stems from the low number of participants causing a high standard deviation in our data. We did find a rather surprising amount of asymmetry in most riders which could be an area of further research.

To improve the study, it could be repeated but with many more participants to more accurately represent the casual biker. Additionally, we may consider determining the “optimal" seat height through a knee flexion measure rather than inseam height. We also believe that our study was limited by not being able to control for personal characteristics, and would recommend integrating gender and physical activity data into further analysis.

References

[1] Jason Wise. How many peloton users in 2022 are there? - earthweb, 7 2022. URL https://earthweb.com/how-many-peloton-users/.

[2] Will W. Peveler. Effects of saddle height on economy in cycling. *Journal of Strength and Conditioning Research*, 22:1355–1359, 2008. ISSN 10648011. doi:10.1519/JSC.0B013E318173DAC6. URL https://journals.lww.com/nsca-jscr/Fulltext/2008/07000/Effects_of_Saddle_Height_on_Economy_in_Cycling.45.aspx.

[3] David J. Sanderson and Annita T. Amoroso. The influence of seat height on the mechanical function of the triceps surae muscles during steady-rate cycling. *Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology*, 19, 12 2009. ISSN 1873-5711. doi:10.1016/J.JELEKIN.2008.09.011. URL https://pubmed.ncbi.nlm.nih.gov/19042140/.

[4] M. O. Ericson and R. Nisell. Patellofemoral joint forces during ergometric cycling. *Physical Therapy*, 67:1365–1369, 9 1987. ISSN 0031-9023. doi:10.1093/PTJ/67.9.1365. URL https://academic.oup.com/ptj/article/67/9/1365/2728250.

[5] Rodrigo R. Bini, Patria A. Hume, and James L. Crofta. Effects of saddle height on pedal force effectiveness. *Procedia Engineering*, 13:51–55, 1 2011. ISSN 1877-7058. doi:10.1016/J.PROENG.2011.05.050.

[6] Paul L. Shennum and Herbert A. DeVries. The effect of saddle height on oxygen consumption during bicycle ergometer work. *Medicine and Science in Sports*, 8:119–121, 1976. URL https://journals.lww.com/acsm-msse/Abstract/1976/00820/The_effect_of_saddle_height_on_oxygen_consumption.20.aspx.