Movement Analysis of The Start in Track Cycling

Introduction

In sprint events across a range of sports, the smallest margins can significantly influence outcomes—often determining medal placement, team selection, or funding. In track cycling, the women's team sprint event at the 2024 Paris Olympics averaged a time difference between medal positions was just 0.325 ± 0.133 seconds. With total race times around 45–46 seconds, this margin underscores the importance of optimising every phase of performance.

Track cycling has long been a subject of scientific inquiry, with a strong focus on aerodynamics, pacing, and efficiency in longer events (>1000 m) or road endurance racing (Jongerius et al., 2022; Swart & Holliday, 2019; Underwood, 2012). In these cases, sustained exposure to air resistance justifies a biomechanical focus on reducing drag. However, in short-duration track events such as the team sprint—particularly during the start phase—riders are either shielded by teammates or are exposed for only a few seconds. Thus, maximizing propulsion and acceleration through biomechanically efficient start techniques becomes a critical performance determinant.

Despite its importance, the biomechanics of the track cycling start remain less thoroughly investigated. Key aspects such as joint kinematics, ground reaction forces, pedaling technique, and muscular coordination during the initial acceleration phase have not received the same level of scrutiny as aerodynamic factors. Understanding power-velocity characteristics has been shown to be key in sprint performance, but does not directly provide actionable change to coaches or athletes (Dorel et al., 2005).

This project aims to analyse the biomechanical characteristics of the track cycling start, using motion capture to identify effective movement strategies and quantify their impact on 0-10m performance. By focusing on the critical opening seconds of a sprint event, this study seeks to contribute to a growing body of evidence that supports data-driven optimization in elite track cycling.

Methods

7 participants from the Great Britain track cycling team (5 female, 2 male) will perform 3x10m starting bouts, with a team-member stationed at the rear stabilising the bike prior to the start. Each bout was recorded from the same location and calibrated before each session. Markers were placed on all major joints of the body facing the camera (shoulder, elbow, wrist, iliac crest, greater trochanter, knee, ankle, and metatarsal heads). All videos were then calibrated and digitised to the recommended specifications. Linear and angular joint data were calculated on the biomechanics program Quintic (v35). Joint data was then smoothed using the appropriate Butterworth pass filter before being exported as a excel document for further statistical analysis.

6 main phases of movement were considered, as they are commonly identified in the start of track cycling (Appendix section 1). Descriptive statistics were generated for each joint in each phase of the movement. Linear regression was performed on each joint angle in each phase with time as the dependent variable. In the 1st Rev phase, the distance between the greater trochanter and the wrist was recorded and linear regression was performed with time as the dependent variable. Additionally, the duration of time flexing and extending at the knee was recorded from “hips back” to “reset” and a flexion/extension ratio was calculated. Descriptive statistics were

calculated, and linear regression was then performed on the metrics with time as the dependent variable.

Results

Gender	Phase	Elbow Angle	Greater Trochanter Angle	Knee Angle	Ankle Angle
F	1ST REV	167.4 ± 6.88	142.8 ± 10.27	153.2 ± 6.05	132.8 ± 6.42
F	HIPS BACK	146.9 ± 15.09	59.4 ± 3.45	156.8 ± 7.75	133.1 ± 8.95
F	HIPS UP	159.8 ± 4.67	64.8 ± 2.56	156.2 ± 4.65	122.4 ± 12.15
F	PULL	154.4 ± 9.76	103.3 ± 7.98	125.9 ± 9.76	109.4 ± 8.5
F	RESET	182.1 ± 6.45	103.7 ± 10.49	128.0 ± 5.67	135.4 ± 5.3
M	1ST REV	136.3 ± 10.37	144.1 ± 2.87	147.8 ± 3.27	134.5 ± 3.92
M	HIPS BACK	160.7 ± 8.95	63.6 ± 2.66	153.6 ± 8.8	132.1 ± 7.39
M	HIPS UP	166.1 ± 4.2	74.6 ± 7.95	158.4 ± 12.46	131.3 ± 9.79
M	PULL	126.8 ± 15.98	104.5 ± 6.96	116.4 ± 5.75	106.8 ± 5.92
M	RESET	164.1 ± 3.35	92.3 ± 1.99	121.3 ± 6.68	130.4 ± 4.69

Descriptive statistics for phase of movement joint data:

Gender	Phase	Joint-Angle	p-value	r-value	Adj. R2	n
F	1ST REV	Knee	0.107	-0.405	0.1082	17
F	HIPS BACK	Knee	0.0107	-0.601	0.3186	17
F	HIPS BACK	Ankle	0.0006	-0.746	0.5276	17
F	HIPS UP	Greater Trochanter	0.0622	0.859	0.6504	5
F	RESET	Knee	0.0177	-0.567	0.2758	17
M	PULL	Greater Trochanter	0.1802	-0.709	0.3365	5
M	PULL	Ankle	0.1148	-0.786	0.4908	5

Only metrics with p-values<0.2 are shown

Gender	Mean ± Std (cm)
F	38.47 ± 9.8
M	31 ± 8.86

Mean distance from hip (greater trochanter) to wrist

Metric	Gender	p-value	r-value	Adj. R^2	n
HIP_TO_WRIST_CM	F	0.0002	0.787	0.594	17
HIP_TO_WRIST_CM	M	0.688	0.247	-0.252	5

Regression results for hip (greater trochanter) to wrist distance and time (0-10m)

Gender	Flex. Time (s)	Ext. Time (s)	Flex._%	Ext. %	Flex-Ext Ratio
F	0.907 ±0.114	0.873 ± 0.118	50.978 ± 5.785	49.022 ± 5.785	1.07 ± 0.261
M	0.950 ± 0.075	0.780 ± 0.059	54.902 ± 1.852	45.098 ± 1.852	1.22 ± 0.093

Descriptive statistics for flexion/extension time

Gender	Metric	p-value	r-value	Adj. R^2	n
Men	Extension Time (s)	0.0756	0.839	0.6053	6
Men	Flexion Time (s)	0.9153	0.0665	-0.3274	6
Men	Flexion %	0.1568	-0.7354	0.3877	6
Men	Extension %	0.1568	0.7354	0.3877	6
Men	Flex -Ext Ratio	0.1642	-0.7268	0.3709	6
Women	Extension Time (s)	0.2819	-0.2769	0.0151	17
Women	Flexion Time (s)	0.2834	0.2761	0.0146	17
Women	Flexion %	0.1781	0.3427	0.0586	17
Women	Extension %	0.1781	-0.3427	0.0586	17
Women	Flex-Ext Ratio	0.2011	0.3263	0.0469	17

Regression results for flexion/extension time and time (0-10m)

Gender	p-value	r-value	Adj R^2	n	Regression Equation
F	0.0557	-0.4722	0.17112	17	Ext time = 1.0920 + -0.0057 * HIP_TO_WRIST_CM
M	0.1972	0.6901	0.30163	5	Ext time = 0.6180 + 0.0051 * HIP_TO_WRIST_CM

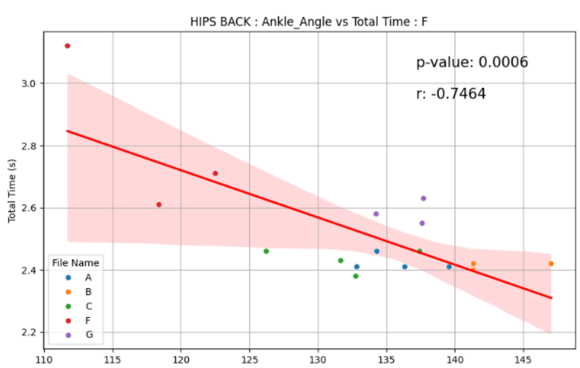
Additional linear regression analysing Hip-to-wrist distance and knee extension time (Ext time)

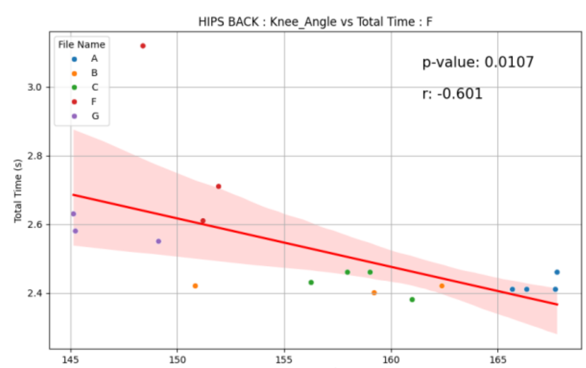
Discussion

Linear regression analyses were performed to examine how joint angles across different phases of the start influence 0–10m performance time in track cycling. The phases considered included “hips up,” “hips back,” “pull,” “1st rev,” and “reset,” though not all phases were relevant or recorded consistently for every athlete.

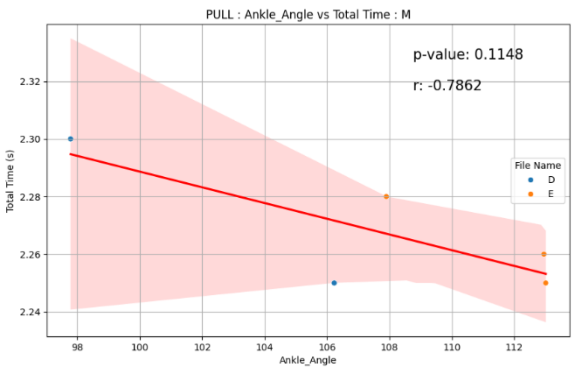
The “hips up” phase showed near statistical significance in the women’s group. However, due to inconsistent time gaps between “hips up” and “hips back,” its utility was limited. In many cases, this phase conveyed redundant information already captured in the “hips back” phase and was therefore not always recorded. This reduces its value as an independent predictor of performance.

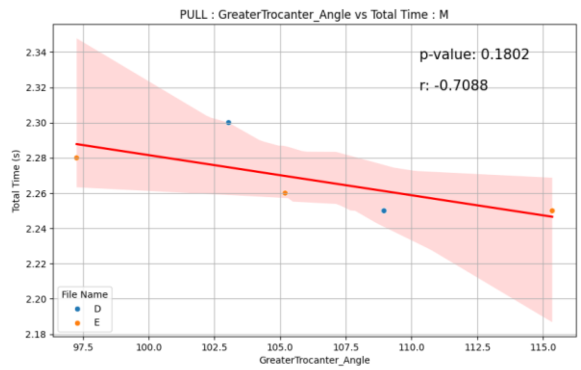
In the “hips back” phase, significant findings emerged in the women’s group. Both knee and ankle joint angles demonstrated moderately strong negative correlations with 0–10m performance time. Specifically, more extended knees and plantar-flexed ankles were associated with faster performances. These results suggest that certain biomechanical positions may be more favorable during the push-off. However, this may be influenced by individual differences within the sample—most notably, athlete F, whose slower performance paired with a more flexed knee and dorsiflexed ankle may have skewed the regression results. This raises an interpretive challenge: whether joint position directly impacts performance or whether slower athletes are unable to reach more optimal positions. The men’s group did not show significance in this phase, possibly due to the smaller sample size (n=5), which reduces statistical power and limits generalizability.





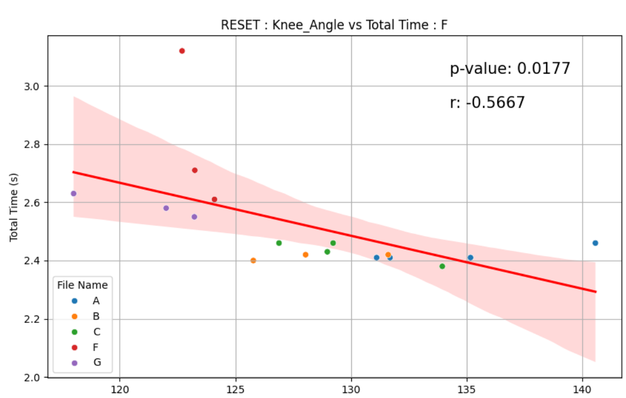
The “pull” phase yielded weak or non-significant results for both groups. The women’s group showed no significant correlation, and the men’s group only demonstrated poor significance. Despite some moderately strong negative correlations (e.g., ankle and hip angles), the inconsistency and limited sample make it difficult to draw firm conclusions. The apparent association of a more upright torso and extended leg with improved performance is promising but needs further exploration in larger cohorts.



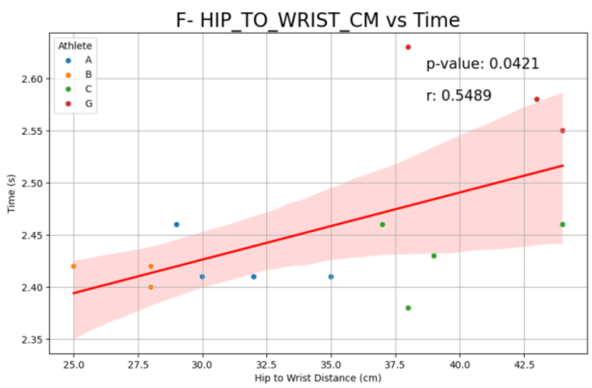


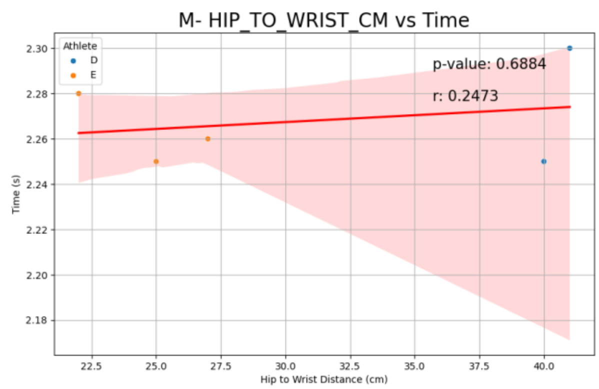
Within the “1st rev” (first revolution) phase, the women’s group showed weak-to-moderate negative correlation between knee angle and performance, though statistical significance was not reached (p=0.107). Despite this, a trend emerged suggesting that a more extended knee during this phase might be advantageous. Again, this could be influenced by the same sampling issues previously noted.

The “reset” phase was notable in the women’s group, where knee angle displayed a statistically significant moderate negative correlation with performance time. Greater knee extension was associated with faster starts, potentially reflecting superior strength or more efficient positioning. In contrast, the men’s group did not yield significant results in this phase, again likely due to limited participant numbers.



Beyond joint angles, the distance from the greater trochanter to the wrist (hip-to-wrist distance) during the "pull" phase showed significance in the women's group (p=0.042) with a moderate positive correlation. This suggests that athletes whose hips are positioned further from the bars may have better 0–10m times, although this may also reflect other biomechanical or strength factors not directly measured. Importantly, these results should be interpreted cautiously due to potential individual variation and unmeasured confounding factors.





"Extension time" was the only variable in the men's group approaching statistical significance (p=0.0756). Neither group showed significance for "extension %" or "flexion %," though the trends suggest that athletes with shorter extension times tend to be faster—perhaps reflecting superior strength or more efficient technique. This makes intuitive sense, as shorter flexion periods allow quicker repositioning for the subsequent extension.

A follow-up regression between hip-to-wrist distance and extension time in the women's group further supported this relationship (p=0.0557). A moderate negative correlation indicated that a shorter distance was associated with faster extension. This supports the hypothesis that hip positioning plays a key role in optimizing power transfer and performance during the start.

Limitations

The most substantial limitation was the small and uneven sample size between groups. The men's group included only five samples (2 athletes), compared to 17 samples (5 athletes) in the women's group. This disparity likely contributed to the weaker statistical power and reduced the generalizability of the men's results. Small sample sizes increase the risk of both Type I and Type II errors, making it difficult to draw robust conclusions.

Individual performance variation, most notably from a single outlier (athlete F), may have disproportionately influenced regression outcomes. In small samples, such outliers can skew coefficient estimates, exaggerating or masking relationships between variables. Although some attempts were made to interpret these influences contextually, the presence of even one atypical case undermines the reliability of linear models.

Due to imperfect positioning between bouts, there may be unnecessary variation in the accuracy of the estimated distance between joints, particularly that of the hip-to-wrist distance and athlete F. With athlete F removed from the hip-to-wrist distance dataset, regression results were shown to have less significant ($p=0.042$) and lower correlation ($r= -0.549$). While this doesn't change the conclusion, the strength of the relationship is one that needs to be questioned when outliers occur within the dataset, even if they are due to positioning errors.

In addition to the imperfect positioning of the athletes, it should also be noted that there is likely some degree of parallax error within the results. Typically, athletes would use the velodromes natural slope to increase their downward velocity, and in doing so, gradually get closer to the camera. This technique, while important to a quicker start, introduces parallax error that would otherwise not be present. Additionally, there is a variation of how close each athlete gets to the camera, thereby bringing the accuracy of the camera calibration into question.

The use of linear regression does not come without its flaws as it assumes linearity, homoscedasticity, and normally distributed residuals. Human movement often makes these assumptions difficult to meet. Linearity may not reflect the true nature of joint angle–performance relationships, which could be nonlinear or involve thresholds. Multicollinearity is likely, as joint angles at different phases may be interrelated. This can inflate standard errors and obscure the effects of individual predictors. Multicollinearity is likely, as joint angles at different phases may be interrelated. This can inflate standard errors and obscure the effects of individual predictors. Small sample sizes, particularly in the men's group, can further undermine regression stability, especially if there is outlying data. Performance in track cycling starts is influenced by other factors such as muscle strength, rate of force development, neuromuscular development, psychological arousal, and technical execution. The absence of these variables from the models limits explanatory power and may lead to omitted variable bias.

Conclusion

This study provides early evidence that specific biomechanical features during the start phase of track cycling—especially knee and ankle extension and hip positioning—may influence short-distance sprint performance, particularly in the 0–10m phase. In the women's group, joint angles during the "hips back" and "reset" phases consistently correlated with better performance outcomes, suggesting these may be key moments to target in coaching interventions. Reduced extension time and a shorter hip-to-wrist distance also showed potential as performance-relevant metrics, possibly reflecting greater technical efficiency or strength. These insights may help practitioners refine start technique, cue effective joint positions, and guide video-based movement feedback.

However, several limitations constrain how these findings should be applied. Most notably, the small and uneven sample sizes—particularly within the men's group—reduce statistical power and generalizability. The influence of outliers, such as athlete F, underscores the sensitivity of linear regression to individual variance, which can disproportionately shape results in small datasets. The methodology was also subject to potential parallax error, inconsistencies in athlete-camera distance, and measurement variability—each of which could compromise positional accuracy. Finally, while linear regression allowed for interpretable models, it oversimplifies what is likely a nonlinear and multivariate relationship between joint kinematics and performance. Movement data inherently violate assumptions of independence, linearity, and homoscedasticity. Thus, any apparent correlations should be treated as exploratory rather than confirmatory.

In sum, while the findings provide useful initial markers for technical feedback, future work should include larger, more controlled datasets and explore more robust analytical methods—such as nonlinear modeling or machine learning—to better capture the dynamic and multifactorial nature of sprint performance in track cycling.

References

Dorel, S., Hautier, C. A., Rambaud, O., Rouffet, D., Praagh, E. V., Lacour, J.-R., & Bourdin, M. (2005). Torque and Power-Velocity Relationships in Cycling: Relevance to Track Sprint Performance in World-Class Cyclists. *International Journal of Sports Medicine*, *26*(9), 739–746. https://doi.org/10.1055/s-2004-830493

Jongerius, N., Wainwright, B., Walker, J., & Bissas, A. (2022). The biomechanics of maintaining effective force application across cycling positions. *Journal of Biomechanics*, *138*, 111103. https://doi.org/10.1016/j.jbiomech.2022.111103

Swart, J., & Holliday, W. (2019). Cycling Biomechanics Optimization—The (R) Evolution of Bicycle Fitting. *Current Sports Medicine Reports*, *18*(12), 490. https://doi.org/10.1249/JSR.0000000000000665

Underwood, L. (2012). *Aerodynamics of Track Cycling*. University of Canterbury.

Appendix

1. Phases of Movement: