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3 **Bicycling and tricycling road race performance in international UCI events between**
4 **2011 and 2019**

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ABSTRACT

Purpose: This study described bicycling (C-classes, 1–5) and tricycling (T-classes, 1–2) performance in International Cycling Federation (Union Cycliste Internationale; UCI) road race events between 2011 and 2019. **Methods:** A total of 3,243 race results (bicycling = 2,571; tricycling = 672) from 33 UCI events held between May 2011 and August 2019 were included in the analysis. Mean race velocity was calculated for each race result. Bicycling and tricycling data were separately modelled using hierarchical regression. Cohen’s d was calculated for the standardised difference between adjacent classes. **Results:** Road race performance was statistically different between men’s classes C1/C2 ($p < .001$; $d = 0.42$), C2/C3 ($p < .001$; $d = 0.47$) and C3/C4 ($p < .001$; $d = 0.73$). In contrast, performance was not statistically different between men’s C4/C5 ($p = .506$; $d = 0.14$), or between all adjacent women’s bicycling classes ($p = .050$ to $.121$; $d = 0.46$ to 1.15). The absence of statistical differences between adjacent women’s bicycling classes may be due to the relatively small number of observations in these classifications. As expected, race performance was statistically different between T1 and T2 for men ($p < .001$; $d = 1.64$) and women ($p < .001$; $d = 1.38$). **Conclusion:** Road race performance was hierarchical within the disciplines of bicycling and tricycling, with higher classes characterised by faster mean velocities. However, not all adjacent classes were statistically different. Future research should examine the influence of prosthetic technologies and the impact of different impairments on bicycling and tricycling performance.

Key words: Classification, cycling, disability, impairment, parasport

INTRODUCTION

Para-cycling athletes compete on bicycles, handcycles and tricycles in classes based on their functional disability.¹ Riders with impaired muscle power or passive range of motion, athetosis, hypertonia, ataxia, limb deficiency, or leg length differences are considered eligible for classification.¹ Notably, only athletes with athetosis, hypertonia or ataxia can compete in tricycling.¹ The disciplines of bicycling, handcycling and tricycling comprise five (C1–5), five (H1–5) and two (T1–2) classes, respectively.¹ Higher class numbers reflect less impairment. For example, in theory, a T1 athlete has greater co-ordination impairments when compared to a T2 athlete. The sport of para-cycling, including classification, is governed by the International Cycling Federation (Union Cycliste Internationale; UCI). The purpose of the classification system is to promote participation in the sport of cycling by persons with disability, by reducing the effect of impairment on the outcome of competition.^{2,3}

Research on para-cycling has grown in recent times.^{4–6} Such interest is essential for increasing the profile of the sport and participation rates.³ The promotion of para-cycling—and as such, physical activity—is important for persons with disability, to help prevent the development of secondary health problems which often occur.^{7–9} Multiple UCI para-cycling events are held each year, generally at European locations.¹ Unfortunately, there are limited descriptions of athlete performances in these events. Recent studies have reported on handcycling¹⁰ and bicycling¹¹ performance in 1 km road race and velodrome time trial events, respectively. To date, road race performance across the classes of bicycling and tricycling has not been described.

This study aimed to describe bicycling and tricycling road race performance in UCI events between 2011 and 2019. It was hypothesised that within each discipline adjacent classes (e.g., C1/C2) would be statistically different.

METHODS

Participants and data extraction

Road race results from 523 unique athletes were obtained from the UCI open source platform.¹² Data from bicycling and tricycling athletes across all respective classes were extracted from 33 events held between May 2011 and August 2019. This consisted of six UCI World Championships and 27 UCI World Cups. Because race distance varied within each class between events, mean race velocity ($\text{km}\cdot\text{h}^{-1}$) was calculated for each result. Athletes' age and sex were also taken from published results. Ethical approval was not required because data were publicly available, and all athletes were de-identified before analysis.

Data analysis

All analyses were performed in R (Version 3.5.3; R Core Team¹³). A total of 4,037 race results were initially extracted. Entries were excluded if they were not ranked by the UCI, i.e., if the athlete did not start ($n = 103$) or finish ($n = 219$) the race, or if the athlete was disqualified ($n = 10$). Results for lapped athletes were also excluded ($n = 459$), as finish times were not available for these entries.

Possible erroneous race results within each class were considered outliers if >1.5 times outside of the interquartile range¹⁴. Outliers may be indicative of mechanical problems during the race (e.g., a flat tyre) and inclusion of these results could falsely lower the class velocity. Identified outliers (bicycling = 28; tricycling = 8) were removed from analysis if the case met the following criteria¹⁰: (1) results for the athlete were available from ≥ 2 events to allow intra-individual comparison; (2) results from the athlete were not considered an outlier in any other event; (3) the race had >10 athletes in the respective class, so to avoid the identification of outliers in very small samples; and (4) the athlete was ranked above 25% of the competitive group in ≥ 1 race comprising >10 athletes in the respective class, to avoid removing athletes who often ranked among the final class places. Applying these criteria, three results were excluded (all from bicycling classes). The analysis was performed on 3,243 road race results (bicycling = 2,571; tricycling = 672).

Mean race velocity was modelled using hierarchical regression. Separate models were fit for bicycling and tricycling, using the 'lmerTest' package.¹⁵ Both models considered adjustment for *age* and included *event*, *sex*, *class* and *sex x class* as fixed factors. Before analysis, age was standardised using the equation: $y' = y - \bar{x} / s$, where ' $\bar{x}$ ' is the sample mean, ' s ' the sample standard deviation, and ' y ' the observed value. The age term was removed from the model when there was no evidence that it was statistically important. Both models included a random intercept for each unique athlete to account for the correlation between repeated observations on an individual.

Contrasts between adjacent classes were made using the 'emmeans' package, with p -values corrected using Tukey's method.¹⁶ A Bayes Factor (BF) was also calculated for each comparison using 'BayesFactor'.¹⁷ BF's were interpreted as: weak 0.33–1, substantial 0.10–0.33, strong 0.03–0.10 and decisive <0.01 evidence for the null hypothesis; or weak 1–3, substantial 3–10, strong 10–30 or decisive >100 evidence for the alternate hypothesis.¹⁸ Data are reported as the estimated marginal mean, or marginal mean difference (MD) between adjacent classes ' k ' and ' l ', and 95% confidence interval (CI). Cohen's d (and 90% CI) was

calculated for the standardized difference between classes k and l ¹⁹ using the ‘psych’ package.²⁰ The pooled SD was used as the denominator and a t -distribution for the CI. Values of d were interpreted as small 0.20, medium 0.50 and large ≥ 0.80 .¹⁹ Figures were generated using the ‘ggplot2’ package.²¹ The dataset and R code are available at <https://github.com/SciBorgo/para-cycling-road-race-performance.git>.

RESULTS

Of the 523 unique athletes in the dataset, 420 competed in bicycling events and 106 in tricycling events. Three athletes competed in both bicycling and tricycling; however, this was never at the same event. One female competed in C2 and T2 once each, respectively. A male athlete competed in C1 once and T2 twice. Another male competed in C1 at two events, and in T2 at 14 events.

Bicycling

In the dataset, the number of unique male athletes competing in the bicycling classes of C1 to C5 was 32, 76, 63, 76, and 87, respectively. The number of unique female athletes competing in C1 to C5 was 4, 18, 16, 20 and 28, respectively. There was no evidence of an effect of age on race performance ($\beta \pm SE = -0.01 \pm 0.07$; $p = .94$). There was, however, evidence of effects for sex and class on performance (Table 1). Except for the C4/C5 comparison, men’s performance was statistically different between all adjacent bicycling classes (Figure 1; Table 3). Race performance was not statistically different between men’s C4/C5, with Cohen’s d indicating a negligible effect, and BF_{10} showing no support for the alternate hypothesis (i.e., that performance was different between C4 and C5). There was insufficient evidence that bicycling performance was statistically different between adjacent women’s classes (Figure 1; Table 3). Although Cohen’s d indicated medium-to-large effects, the small number of observations in some classes (e.g., C1 = 17, C3 = 79) could mean that these effect size estimates are inflated, and therefore, misleading.²²

Tricycling

In the dataset, the number of unique male tricycling athletes competing in T1 and T2 was 19 and 58, respectively. The number of unique female tricycling athletes competing in T1 and T2 was 11 and 15, respectively. There was no evidence of an age effect on race performance ($\beta \pm SE = 0.27 \pm 0.27$; $p = .32$). There was, however, evidence of effects for event, sex and class on performance (Table 2). Men’s and women’s performance was statistically

165 different between T1 and T2 (Figure 2; Table 3), and Cohen's d indicated large differences
166 (Table 3).

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Figure 1. Mean (95% confidence interval) road race performance of para-cycling athletes competing in the men's (A) and women's (B) bicycling (i.e., C) classes at UCI events between 2011 and 2019. Grey circles indicate individual race results. * indicates statistically different to the adjacent class in the same sex.

Figure 2. Mean (95% confidence interval) road race performance of para-cycling athletes competing in the men's (A) and women's (B) tricycling (i.e., T) classes at UCI events between 2011 and 2019. Grey circles indicate individual race results. * indicates statistically different to the adjacent class in the same sex.

181 **Table 1.** Parameter estimates of the fixed effects from the bicycling model.

Parameter	β	Standard error	95% CI [lower, upper]	<i>t</i> -value	<i>p</i> -value
Intercept	34.40	0.28	[33.90, 34.99]	122.40	<.001*
Event	0.02	0.01	[0.01, 0.03]	3.70	<.001*
Sex (Women)	-6.55	0.81	[-8.14, -5.00]	-8.10	<.001*
Class 2	1.28	0.31	[0.68, 1.88]	4.11	<.001*
Class 3	2.60	0.32	[1.97, 3.22]	8.02	<.001*
Class 4	4.06	0.33	[3.43, 4.70]	12.36	<.001*
Class 5	4.50	0.32	[3.88, 5.12]	13.94	<.001*
Sex (Women) x Class 2	0.72	0.89	[-1.00, 2.47]	0.81	.419
Sex (Women) x Class 3	0.76	0.93	[-1.01, 2.57]	0.83	.410
Sex (Women) x Class 4	0.85	0.91	[-0.90, 2.61]	0.93	.353
Sex (Women) x Class 5	1.42	0.89	[-0.28, 3.15]	1.60	.111

182 Note. CI = Confidence interval.

183 * indicates a statistically important effect

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Table 2. Parameter estimates of the fixed effects from the tricycling model.

Parameter	β	Standard error	95% CI [lower, upper]	<i>t</i> -value	<i>p</i> -value
Intercept	24.17	0.53	[23.12, 25.22]	45.29	< .001*
Event	0.04	0.01	[0.02, 0.07]	3.32	.001*
Sex (Women)	-4.07	0.83	[-5.68, -2.46]	-4.93	< .001*
Class 2	3.50	0.48	[2.52, 4.50]	7.27	< .001*
Sex (Women) x Class 2	0.01	0.89	[-1.72, 1.74]	0.01	.989

Note. CI = Confidence interval.

* indicates a statistically important effect

189 **Table 3.** Differences in road race performance (i.e., velocity) between adjacent cycling (C1–5) and tricycling (T1–2) classes for men and women.

Sex	Comparison	Mean difference	SE	MD 95% CI [lower, upper]	<i>t</i> -value	<i>p</i> -value	BF ₁₀	Cohen's <i>d</i>	Cohen's <i>d</i> 90% CI [lower, upper]
<i>Bicycling</i>									
Men	C1 vs. C2	1.28 km·h⁻¹	0.31	[0.43, 2.13]	4.13	<.001*	236,972	0.42	[0.30, 0.55]
	C2 vs. C3	1.32 km·h⁻¹	0.26	[0.61, 2.03]	5.07	<.001*	>999,999	0.47	[0.36, 0.58]
	C3 vs. C4	1.47 km·h⁻¹	0.28	[0.71, 2.23]	5.34	<.001*	>999,999	0.73	[0.61, 0.85]
	C4 vs. C5	0.44 km·h ⁻¹	0.27	[-0.32, 1.19]	1.59	.506	0.382	0.14	[0.02, 0.25]
Women	C1 vs. C2	2.00 km·h ⁻¹	0.84	[-0.29, 4.30]	2.39	.121	956	1.15	[0.71, 1.60]
	C2 vs. C3	1.36 km·h ⁻¹	0.55	[-0.14, 2.85]	2.48	.096	4,987	0.71	[0.46, 0.96]
	C3 vs. C4	1.55 km·h ⁻¹	0.57	[0.00, 3.10]	2.74	.050	21	0.48	[0.24, 0.72]
	C4 vs. C5	1.01 km·h ⁻¹	0.48	[-0.30, 2.31]	2.12	.215	165	0.46	[0.27, 0.66]
<i>Tricycling</i>									
Men	T1 vs. T2	3.50 km·h⁻¹	0.49	[2.55, 4.46]	7.22	<.001*	>999,999	1.64	[1.45, 1.82]
Women	T1 vs. T2	3.51 km·h⁻¹	0.75	[2.03, 4.99]	4.67	<.001*	>999,999	1.38	[1.08, 1.67]

190 Note. BF = Bayes factor; CI = confidence interval; MD = mean difference; SE = standard error. Statistically different comparisons are shown in
191 bold.

192 * indicates evidence of a statistical difference between classes

DISCUSSION

This study reported on bicycling and tricycling road race performance in UCI events between 2011 and 2019. As hypothesised, performance was statistically different between the adjacent men's classes C1/C2, C2/C3 and C3/C4 (Figure 1; Table 3). In contrast to the hypothesis, race performance was not statistically different between the men's C4/C5, or between all adjacent women's bicycling classes (Figure 1; Table 3). The absence of statistical differences between the women's adjacent classes may be explained by the small number of observations in these classifications. As expected, race performance was statistically different between T1 and T2 for both men and women (Figure 2; Table 2). Findings from the study show that road race performance is hierarchical within the disciplines of bicycling and tricycling; however, not all adjacent classes were statistically different.

A hierarchical performance structure does not necessarily validate the classification system. There are two plausible mechanisms that could create a classification system in which performance is hierarchical. First, and ideally, athletes in each class may have impairments that cause approximately the same amount of activity limitation in the sport, and the amount of limitation is different to the class above and/or below.² However, and equally, a hierarchical performance structure could be created by placing athletes in classes based on how fast they cycle. In the absence of scientific evidence on which to base decision-making in classification, current best practice requires classifiers to incorporate their subjective clinical judgement, particularly in cases where athletes have unusual or atypical impairment profiles, or multiple impairment types (e.g., cerebral palsy, acquired brain injury).² As such, factors other than impairment severity—like training history, and natural physiological or psychological athletic advantages—may affect decision-making. This is particularly the case at the cut points between classes, where differences in impairment severity between athletes at the top of one class, and those at the bottom of the class above, are relatively small. Unfortunately, depending on the class, classifying an athlete 'higher' (e.g., C3 rather than C2) could be detrimental to their medalling chances. For example, the top five fastest C2 performances fall outside the top 20 fastest performances of the C3-class (Supplemental 1).

The current study provides a broad indication of the levels of performance attained in UCI road race events, by athletes competing in the bicycling and tricycling classes (Figure 1; Figure 2; Supplemental 2). In agreement with previous work¹¹, there was no evidence that race performance was statistically different between men's C4/C5 (Table 3). In our study, this result was also observed for women's C4/C5 (Table 3). This is interesting, as Liljedahl et al.¹¹ examined men's track performances over 1 km and included only the top-five results of each

race. In contrast, the shortest race distance for C4/C5 men or women in our study was ~58 and ~43 km, respectively; and all eligible race results were included in the analysis. Findings from the current study provide further evidence that the smallest (absolute) performance difference exists between C4 and C5 (Table 3), irrespective of distance, event (i.e., track or road) or sex. Arguably, for the fastest athletes, the decision to classify an individual in C5 rather than C4 may have less impact on their medalling chances compared to other situations (e.g., classifying an athlete in C4 rather than C3; Supplemental 1). Performance in tricycling races has not previously been reported on, meaning comparison with other studies is not possible.

Future research should consider several areas for investigation. Although para-cyclists with different impairment types compete in the same classes, it is largely unknown how this affects the validity of the classification system. The influence of upper body impairments on performance requires examination, particularly because a number of athletes in C5 have only upper body impairments. A common impairment in the C4 class is a below knee amputation, which requires the athlete to race with a lower-limb prosthesis.²³ It is unclear whether these individuals have an advantage over other athletes in the same class with impairments that do not require lower-limb prosthesis.²³ More broadly, the effect of new technologies—particularly in relation to prosthesis—on performance requires ongoing investigation.⁴ Such information has important implications for sport-technical rules and possibly classification. Athletes with hypertonia, ataxia and athetosis are eligible for tricycling. Individuals with these impairments are among the most difficult to classify in Paralympic sport.²⁴ The effect of these impairment types on performance in the other cycling disciplines (i.e., not tricycling) is warranted.

The sample sizes for bicycling and tricycling classes were considerably smaller for women compared to men. As such, there is insufficient evidence to conclude that adjacent women's bicycling classes are different at present. Future work should continue to investigate the separation in race performance between adjacent women's classes by compiling the data used in the current study with results from future UCI races.

CONCLUSION

This study reported on bicycling and tricycling performance in UCI road races between 2011 and 2019. With the exception of C4/C5, men's bicycling performance was statistically faster in each higher adjacent class. Bicycling race performance was not statistically different between adjacent women's classes. However, this result may be explained by the small number of observations in the women's bicycling classes. As expected, race performance was statistically faster in T2 compared to T1 for men and women. This study shows that while the

classification system creates a performance hierarchy within the disciplines of bicycling and tricycling, not all adjacent classes are statistically different.

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Supplemental 1. The top five road race performances in bicycling and tricycling classes and their ranking in the higher adjacent class.

Class	Men Top 5 fastest class performances (km·h ⁻¹)	Athlete ID	Rank in higher adjacent class	Women Top 5 fastest class performances (km·h ⁻¹)	Athlete ID	Rank in higher adjacent class
C1	[1] 40.386	521	=1	[1] 32.288	312	=25
	[2] 40.379	452	=3	[2] 30.168	577	72
	[3] 40.328	570	=6	[3] 29.994	577	77
	[4] 40.214	571	=12	[4] 29.418	80	92
	[5] 40.138	285	16	[5] 29.293	577	=94
C2	[1] 40.386	447	22	[1] 37.203	411	=1
	[=2] 40.379	56	=23	[2] 36.333	263	5
	[=2] 40.379	426	=23	[3] 34.847	412	12
	[=3] 40.328	187	=24	[4] 34.829	263	13
	[=3] 40.328	198	=24	[5] 33.990	387	17
C3	[1] 42.005	112	47	[1] 37.203	507	8
	[2] 41.942	505	48	[2] 36.410	628	10
	[3] 41.649	63	52	[3] 36.404	42	11
	[=4] 41.629	23	=53	[4] 36.051	628	18
	[=4] 41.629	53	=53	[5] 35.957	628	20
C4	[1] 45.718	366	1	[1] 39.635	445	6
	[2] 45.690	450	2	[=2] 39.541	381	=7
	[3] 44.921	300	4	[=2] 39.541	445	=7
	[=4] 44.777	89	=7	[=3] 38.673	166	=11
	[=4] 44.777	159	=7	[=3] 38.673	209	=11
C5	[1] 45.079	4	—	[1] 39.826	558	—
	[2] 44.901	153	—	[=2] 39.819	135	—
	[3] 44.829	48	—	[=2] 39.819	226	—
	[=4] 44.777	7	—	[=2] 39.819	227	—
	[=4] 44.777	34	—	[3] 39.655	226	—
T1	[1] 33.120	519	18	[1] 28.925	190	21
	[2] 32.989	410	24	[2] 28.816	533	=23
	[3] 32.550	467	31	[3] 27.440	637	53
	[4] 30.760	106	134	[4] 27.019	190	57
	[5] 30.718	655	135	[5] 26.604	190	63
T2	[1] 35.874	150	—	[=1] 32.834	118	—
	[2] 35.798	161	—	[=1] 32.834	621	—
	[3] 34.799	465	—	[3] 31.937	118	—
	[4] 34.234	72	—	[4] 31.910	621	—
	[5] 34.144	150	—	[5] 31.752	332	—

Note. C1–5 = bicycling classes; T1–2 = tricycling classes

Supplemental 2. Bicycling and tricycling road race performance (i.e., velocity) in UCI events between 2011 and 2019.

Sex	Class	Estimated marginal mean	Standard error	95% CI [lower, upper]	Interquartile range
<i>Bicycling</i>					
Men	C1	34.79 km·h ⁻¹	0.26	[34.28, 35.30]	(33.76–37.73)
	C2	36.07 km·h ⁻¹	0.18	[35.71, 36.43]	(35.25–38.51)
	C3	37.39 km·h ⁻¹	0.19	[37.01, 37.77]	(37.13–38.71)
	C4	38.86 km·h ⁻¹	0.20	[38.46, 39.25]	(38.13–40.74)
	C5	39.29 km·h ⁻¹	0.19	[38.92, 39.66]	(38.72–40.94)
Women	C1	28.24 km·h ⁻¹	0.77	[26.74, 29.74]	(26.96–29.29)
	C2	30.24 km·h ⁻¹	0.36	[29.54, 30.95]	(29.52–32.14)
	C3	31.60 km·h ⁻¹	0.43	[30.75, 32.45]	(31.04–33.31)
	C4	33.15 km·h ⁻¹	0.36	[32.44, 33.86]	(31.93–35.04)
	C5	34.16 km·h ⁻¹	0.31	[33.55, 34.76]	(33.37–35.90)
<i>Tricycling</i>					
Men	T1	24.95 km·h ⁻¹	0.44	[24.07, 25.82]	(23.02–26.55)
	T2	28.45 km·h ⁻¹	0.30	[27.85, 29.04]	(27.83–31.44)
Women	T1	20.87 km·h ⁻¹	0.70	[19.51, 22.24]	(18.74–24.05)
	T2	24.39 km·h ⁻¹	0.54	[23.33, 25.44]	(24.14–28.21)

Note. C = Bicycling; CI = Confidence interval; T = Tricycling.