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Muchaxo, Rafael E.A. ; Groot, de, Sonja; van der Woude, L. H. V.; Janssen, Thomas W.J. ; Nooijen, Carla F J

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Do Handcycling Time-Trial Velocities Achieved by Para-Cycling Athletes Vary Across Handcycling Classes?

Rafael E.A. Muchaxo
Vrije Universiteit Amsterdam and Amsterdam Rehabilitation Research Center

Sonja de Groot
Amsterdam Rehabilitation Research Center, University of Groningen, and Amsterdam Institute of Sport Science

Lucas H.V. van der Woude
University of Groningen

Thomas W.J. Janssen
Vrije Universiteit Amsterdam, Amsterdam Rehabilitation Research Center, and Amsterdam Institute of Sport Science

Carla Nooijen
Swedish School of Sport and Health Sciences and Karolinska Institutet

The classification system for handcycling groups athletes into five hierarchical classes, based on how much their impairment affects performance. Athletes in class H5, with the least impairments, compete in a kneeling position, while athletes in classes H1 to H4 compete in a recumbent position. This study investigated the average time-trial velocity of athletes in different classes. A total of 1,807 results from 353 athletes who competed at 20 international competitions (2014–2018) were analyzed. Multilevel regression was performed

Muchaxo and Janssen are with the Faculty of Behavioral and Human Movement Sciences, Vrije Universiteit Amsterdam, Amsterdam, the Netherlands. Muchaxo, de Groot, and Janssen are with the Amsterdam Rehabilitation Research Center, Amsterdam, the Netherlands. de Groot and van der Woude are with the University Medical Center Groningen, Center for Human Movement Sciences, University of Groningen, Groningen, the Netherlands. van der Woude is also with the University Medical Center Groningen, Center of Rehabilitation, University of Groningen, Groningen, the Netherlands. de Groot and Janssen are also with the Center for Adapted Sports Amsterdam, Amsterdam Institute of Sport Science, Amsterdam, the Netherlands. Nooijen is with the Swedish School of Sport and Health Sciences (GIH), Stockholm, Sweden, and the Karolinska Institutet, Stockholm, Sweden. Muchaxo (r.e.de.andrademuchaxo@vu.nl) is corresponding author.

to analyze differences in average velocities between adjacent pairs of classes, while correcting for gender, age, and event distance. The average velocity of adjacent classes was significantly different ($p < .01$), with higher classes being faster, except for H4 and H5. However, the effect size of the differences between H3 and H4 was smaller ($d = 0.12$). Hence, results indicated a need for research in evaluating and developing evidence-based classification in handcycling, yielding a class structure with meaningful performance differences between adjacent classes.

Keywords: average velocity, classification, handbike, multilevel analysis, Paralympics

Handcycling is a popular sport among people with physical impairments (Hettinga et al., 2010). It started as an alternative human-powered vehicle to bicycling, but its higher mechanical efficiency, peak power output, and the lower shoulder load compared with wheelchair propulsion soon made it popular in both recreational use and elite sports performance (Hettinga et al., 2010; van der Woude, Dallmeijer, Janssen, & Veeger, 2001). Over the past decades, handcycling performance has increased significantly with the many technical and training improvements (Abel, Vanlandewijck, & Verellen, 2010), and the sport has been part of the Paralympic Games since 2004 (IPC Sport Data Management System, 2018).

Handcycling competition revolves around two main types of events: road races and time trials. According to the Union Cycliste Internationale (UCI) manual (Union Cycliste Internationale, 2019), road races are longer events ranging from 37 to 70 km in the women's categories and from 45 to 80 km in the men's categories. Time-trial distances range from 10 to 30 km in the women's categories and from 12 to 35 km for the men's categories. Both are outdoor events, with circuits' climbing length no more than 25% of the total length and a maximum inclination of 15% in the steepest section. In the case of time trials, drafting is not allowed, and athletes start individually with a time interval in between (Union Cycliste Internationale, 2019).

As a Paralympic sport, handcycling must comply with the International Paralympic Committee Code, stating that all Paralympic sports competitions must be based on an evidence-based classification system (Tweedy & Vanlandewijck, 2011). According to Tweedy and Vanlandewijck (2011), parasport classification systems should aim to promote sport participation, by people with disabilities, by minimizing the impact of impairment on competition outcome. (Tweedy & Vanlandewijck, 2011). Systems that achieve this aim will ensure that competitive success will depend on their training commitment, biological predisposition, and natural talent and will not be simply determined by the severity of their impairment level (Tweedy, Beckman, & Connick, 2014). In addition, systems that achieve this aim will prevent highly talented and trained athletes from being moved toward a less impaired class.

The present handcycling classification system has been applied since 2014 when the sport changed from four to five sport classes (Union Cycliste Internationale, 2019). Currently, athletes in the four first classes (H1–H4) compete in a recumbent position (arm-powered handbikes), whereas those in class H5 compete in a kneeling position (arm–trunk-powered handbike; Union Cycliste Internationale, 2019).

The UCI classification aims to categorize athletes into five sport classes according to the extent of activity limitation. These classes are based on a classification manual mainly centered on people with spinal cord injury as a reference of the functional limitation for comparison with other impairments, aiming to include the athletes with the greatest impairment in class H1 and athletes with the least impairments in class H5 (Union Cycliste Internationale, 2019). In summary, the most significant difference between H1 and H2 is based on arm strength, between H2 and H3 on hand strength, and between H3 and H4 on trunk strength. Finally, between H4 and H5 the main differences are based on hip–leg function, full trunk function, and on the ability to sit on the knees. For athletes with hypertonia, ataxia, or athetosis, referred to as people with coordination impairments for the remainder of this study, classification profiles are less clearly defined (mild, moderate, or severe) (Union Cycliste Internationale, 2019).

The International Paralympic Committee recommends that sports classification systems should not be susceptible to classifier subjectivity or experience and should be based on scientific evidence and objective ratio-scaled measures with high reliability and validity (Tweedy, Mann, & Vanlandewijck, 2016). However, similar to other Paralympic sports, today's handcycling classification is based on ordinal scales, for example, the manual muscle test, and primarily based on expert opinion (Union Cycliste Internationale, 2019). The limited scientific evidence supports neither the assumptions made regarding the influence of impairment on handcycling performance, nor the testing protocols conducted during the actual athlete's classification (Tweedy et al., 2016).

To the best of our knowledge, only two studies to date have been conducted on handcycling classification (Kouwijzer, Nooijen, Van Breukelen, Janssen, & De Groot, 2018; Weissland & Leprêtre, 2013). One study focused on the classification system before 2014 and the equal opportunities to participate in a team competition and concluded that the athletes with higher spinal cord injury levels were in disadvantage due to their functional and physiological limitations (Weissland & Leprêtre, 2013). The second study found that handcyclists in a recumbent handbike who have the ability to push off with their legs on the footrest, inducing a closed chain, might have the advantage of achieving higher power outputs than handcyclists who do not have such ability (Kouwijzer et al., 2018). This push-off ability with the legs is not part of the current description of handcycling sport classes, and consequently, athletes with and without this ability may have been competing in the same classes.

The lack of scientific evidence behind the current classification system imposes questions on whether the five sport classes present five different levels of performance. Therefore, the aim of this retrospective descriptive study was to investigate whether there is a significant difference in handcycling performance at major international competitions between the five consecutive sport classes. We hypothesized that the current classification system would show differences in handcycling race performance, expressed by average time-trial velocity, and when corrected for possible differences in classes regarding event distance, gender, and age, it would show an increase in average velocity from the lower to the higher classes.

Methods

Data Collection

Publicly available official handcycling time-trial results were obtained retrospectively from the UCI's website (Union Cycliste Internationale, 2018; https://www.uci.org/para-cycling/results) from 2014 until 2019, that is, the beginning of the current classification system up to the start of the current research study. Data from four UCI World Championships, 15 UCI World Cups, and one Paralympic Game were analyzed. All international races involved both female and male elite handcycling athletes. In total, 1,816 time-trial results were collected corresponding to 354 athletes. As a measure of handcycling performance, average time-trial velocity (in meter per second) was calculated by dividing race time results of each athlete's time trial by the race distance. Demographic information regarding age and gender and event characteristics was also available from the UCI's website. In accordance with the Code of Ethics for Research in the Social and Behavioral Sciences Involving Human Participants, from the Faculty of Behavioral and Movement Sciences, Vrije Universiteit Amsterdam, ethical approval was not required as all data were publicly available and deidentified in the current analysis.

Statistical Analysis

Data were first analyzed using descriptive univariate statistics and examined for the presence of outliers using SPSS (version 25.0; IBM Corp, Armonk, NY). These possible outliers may be an indicator of technical "on-race" problems (falsely lowering the average speed of a class) or of individual performance characteristics (representing the range of intraclass variability). Following Tukey's method (Komorowski, Marshall, Salciccioli, & Crutain, 2016), outliers were first identified based on the interquartile range, with outliers defined as 1.5 times the interquartile range below or above the first or the third quartile, respectively. Afterward, the identified outliers were individually analyzed, and each case was removed from the analysis only if it was confirmed to be a unique outlying race result based on the following criteria:

- Time-trial results of the athlete were available from more than one event, allowing for a prescanning and comparison of the individual results;
- Race results of the athlete were not considered an outlier in any other event;
- The race result was an outlier in a race with more than 10 athletes in the respective class, avoiding identification of outliers in very small samples; and
- The athlete was ranked above 25% of the group in at least one race with more than 10 participants in the respective class, avoiding removal of athletes who were frequently ranked among the last places.

In addition, time-trial results were removed from the analysis if the athlete was not ranked by the UCI; that is, athletes who were disqualified, did not finish the race or had to be reclassified after racing. Based on the previously mentioned criteria, a total of five time-trial outliers (one female athlete) and four not ranked time trials (one female athlete) were removed. While most of the removed results were from athletes who were still included in the analysis with race results at other events, one case of a not ranked time-trial belonged to a single participation of an athlete. As a result, this athlete was removed from the analysis. Consequently, we obtained an analytical sample of 1,807 time-trial results from 353 athletes (20% women; Table 1).

During the initial analysis and after outlier inspection, data were visually examined for differences within and between classes. This visual examination was focused on the amount of overlapping values between consecutive classes. Multilevel analyses (fixed effect) were used to assess differences in average time-trial velocity among race classes using the statistical software MLwiN (version 2.02, Centre for Multilevel Modelling, University of Bristol, Bristol, United Kingdom). Potential differences among events and repeated measures within athletes were taken into account by these multilevel analyses. A two-level model was built with events as the first level and athletes as the second level. In addition, sport classes were dummy coded (0–1), and four different models were built with classes H1–H4 as reference (1). All models were adjusted for gender, age, and event distance by adding these to the models. In addition, country socioeconomic development (developed or developing countries) and athlete's participation (independent or national representation) were also analyzed. Significance level was set at $\alpha = .05$, and effect sizes were calculated as Cohen's *d* with the following cutoffs: $d < 0.01$ for a very small effect, $0.01 \le d < 0.2$ for small, $0.2 \le d < 0.5$ for medium, $0.5 \le d < 0.8$ for large, and $d \ge 1.2$ for a very large effect (Cohen, 1988; Sawilowsky, 2009).

Results

Mean average time-trial velocities are presented for each class and event and for men and women separately in Table 1. Figures 1 and 2 display practical examples of the initial visual analysis by a scatter plot of observations of the average velocity per event and per class, for both men and women separately. Figure 3 shows the average velocity of all athletes at the 20 events as well as the means and *SD* per class for men and women separately. Visual inspection of these figures indicates that there is a considerable overlap among the consecutive classes H3, H4, and H5.

Table 2 displays the multilevel regression results showing differences in average time-trial velocity between handcycling classes. Variables socioeconomic development and athlete's participation were not significantly related to average velocity and therefore not included in our models. Comparisons between consecutive recumbent handcycling classes H1 and H2 and H2 and H3 showed significant positive differences with medium effect sizes ($p < .01$; $d = 0.34$). These comparisons exhibited the largest differences between consecutive classes and in both combinations athletes with the least impairments raced on average 1.6 m/s (5.8 km/h) faster than the consecutive class with athletes with the greatest impairments. The smallest significant difference between adjacent recumbent classes was found between H3 and H4 and showed a small effect size ($\beta = 0.458$; $SE = 0.124$; 95% confidence interval [0.215, 0.701]; $p = .0002$; $d = 0.12$), with H4 being 0.46 m/s (1.66 km/h) faster. Average velocities between H4 and H5 classes (recumbent vs. kneeling position) were not significantly different, with an average race velocity difference of 0.13 m/s (0.47 km/h). Moreover, the smallest significant difference among all comparisons was found on the difference between H3 and H5 ($\beta = 0.33$; $SE = 0.16$; 95% confidence interval [0.01, 0.64]; $p = .045$; $d = 0.07$).

Table 1 Descriptive Statistics of All International Handcycling Events, per Gender and per Class, Without Outliers and Not Ranked Performances

	Sport class (men)						Sport class (women)					
Event	**H1**	**H2**	**H3**	**H4**	**H5**	**Total**	**H1**	**H2**	**H3**	**H4**	**H5**	**Total**
World Cups												
Castiglione 2014												
Sample (*n*)	3	11	27	30	10	81	0	1	10	7	3	21
Distance (m)	15,000	15,000	15,000	15,000	15,000		—	15,000	15,000	15,000	15,000	
Mean velocity (m/s)	6.49	8.77	10.32	10.58	10.11		—	—	8.76	8.79	9.97	
SD (m/s)	1.22	1.06	0.74	0.61	0.89		—	—	0.91	0.75	0.21	
Segovia 2014												
Sample (*n*)	5	15	29	27	12	88	0	2	9	8	2	21
Distance (m)	11,000	11,000	11,000	22,000	22,000		—	11,000	11,000	11,000	11,000	
Mean velocity (m/s)	6	8.51	10.55	10.7	10.14		—	6.44	8.79	8.88	9.09	
SD (m/s)	0.51	1.11	0.88	0.63	0.97		0.79	1.2	1.47	1.1		
Maniago 2015												
Sample (*n*)	8	12	26	30	12	88	0	3	13	7	4	27
Distance (m)	12,500	12,500	12,500	12,500	26,400		—	12,500	12,500	12,500	12,500	
Mean velocity (m/s)	4.57	6.23	8.78	9.33	9.63		4.25	6.98	7.68	8.86		
SD (m/s)	0.41	1.24	1.05	0.66	0.87		—	1.71	1.33	1.09	0.19	

(continued)

Table 1 (continued)

Event	Sport class (men)						Sport class (women)					
	H1	H2	H3	H4	H5	Total	H1	H2	H3	H4	H5	Total
Yverdon-les-Bains 2015												
Sample (*n*)	8	12	30	30	9	89	0	2	10	6	6	24
Distance (m)	14,150	14,150	14,150	14,150	14,150		—	14,150	14,150	14,150	14,150	
Mean velocity (m/s)	7.09	9.18	10.73	11.02	10.99		—	5.43	9.5	9.04	10.42	
SD (m/s)	0.35	0.85	0.78	0.59	0.66		—	0.57	0.37	0.8	0.47	
Elzach 2015												
Sample (*n*)	9	9	23	22	6	69	0	1	7	4	5	17
Distance (m)	9,000	9,000	9,000	9,000	9,000		—	9,000	9,000	9,000	9,000	
Mean velocity (m/s)	3.6	5.23	7.31	7.89	8.23		—	6.07	6.48	7.48		
SD (m/s)	0.51	1.24	0.63	0.57	0.75		—	—	0.59	0.76	0.56	
Pietermaritzburgh 2015												
Sample (*n*)	5	7	10	11	7	40	0	2	5	4	2	13
Distance (m)	8,000	16,000	16,000	16,000	16,000		—	8,000	16,000	16,000	16,000	
Mean velocity (m/s)	5.33	7.36	8.51	9.26	9.23		—	5.04	6.76	7.62	9.07	
SD (m/s)	0.63	0.51	1.47	1.39	0.77		—	0.58	1.36	0.52	0.21	
Pietermaritzburgh 2016												
Sample (*n*)	3	3	8	6	4	24	0	2	2	0	0	4
Distance (m)	12,300	18,450	18,450	18,450	18,450		12,300	18,450	—	—		
Mean velocity (m/s)	5.41	6.82	8.5	9.12	9.33		—	5.24	6.64	—	—	
SD (m/s)	0.66	1.37	1.62	1.27	1.09		1.44	2.13	—	—		

(continued)

Table 1 (continued)

Event	Sport class (men)						Sport class (women)					
	H1	H2	H3	H4	H5	Total	H1	H2	H3	H4	H5	Total
Ostend 2016												
Sample (*n*)	7	11	29	28	11	86	0	2	10	7	6	25
Distance (m)	16,700	16,700	16,700	16,700	16,700		—	16,700	16,700	16,700	16,700	
Mean velocity (m/s)	5.74	7.82	9.13	9.66	9.55		5.52	7.74	7.14	8.8		
SD (m/s)	0.43	0.87	0.61	0.56	0.83		—	0.84	1.25	1.29	0.54	
Basque 2016												
Sample (*n*)	8	10	23	23	4	68	0	3	6	4	1	14
Distance (m)	14,080	14,080	21,120	21,120	21,120		—	14,080	14,080	14,080	14,080	
Mean velocity (m/s)	6.66	8.57	10.1	10.75	10.46		—	7.49	8.75	8.65	—	
SD (m/s)	1.28	0.57	0.82	0.64	0.82		—	0.77	1.02	1.18	—	
Maniago 2017												
Sample (*n*)	10	12	22	30	11	85	1	1	6	7	3	18
Distance (m)	11,400	11,400	11,400	11,400	24,000		1,140	11,400	11,400	11,400	11,400	
Mean velocity (m/s)	6.34	8.38	9.82	10.26	10.24		—	—	8.92	7.84	9.83	
SD (m/s)	0.82	1.16	0.67	0.77	0.95		—	0.21	1.34	0.1		
Ostend 2017												
Sample (*n*)	9	11	25	27	10	82	0	2	5	5	4	16
Distance (m)	15,000	15,000	15,000	15,000	15,000		15,000	15,000	15,000	15,000		
Mean velocity (m/s)	5.93	7.41	8.94	9.37	9.35		5.73	8.25	7.47	8.95		
SD (m/s)	0.36	0.96	0.84	0.71	0.64		—	0.25	0.47	1.35	0.25	

(continued)

Table 1 (continued)

	Sport class (men)						Sport class (women)					
Event	H1	H2	H3	H4	H5	Total	H1	H2	H3	H4	H5	Total
Emmen 2017												
Sample (*n*)	8	12	36	19	9	84	0	1	7	6	4	18
Distance (m)	17,200	17,200 8.84	17,200	17,200	17,200		—	17,200	17,200	17,200	17,200	
Mean velocity (m/s)	7.26	0.89	10.09	10.77	10.74		—	—	9.18	9.38	10.17	
SD (m/s)	0.31		0.78	0.69	0.49		—	—	0.68	0.34	0.31	
Ostend 2018												
Sample (*n*)	9	14	35	24	13	95	0	1	8	9	4	22
Distance (m)	18,000	18,000	18,000	18,000	18,000		—	1,800	18,000	18,000	18,000	
Mean velocity (m/s)	6.53	7.81	9.41	9.84	10.05		—	8.03	8.01	8.13		
SD (m/s)	0.38	1.03	0.62	0.94	0.66		—		1.11	1.03	1.62	
Emmen 2018												
Sample (*n*)	8	8	29	21	15	81	0	1	9	9	3	22
Distance (m)	16,000	16,000	16,000	16,000	16,000		16,000	16,000	16,000	16,000		
Mean velocity (m/s)	6.99	8.8	10.3	10.54	10.57		—	—	8.92	8.53	8.12	
SD (m/s)	0.48	0.81	0.45	0.55	0.66		—	—	0.91	1.12	1.94	
Baie-Comeau 2018												
Sample (*n*)	6	9	16	7	6	44	0	1	7	5	1	14
Distance (m)	9,450	18,900	18,900	18,900	18,900		—	9,450	9,450	9,450	9,450	
Mean velocity (m/s)	5.58	7.3	9.32	9.78	10.17		—	—	7.78	8.37	—	
SD (m/s)	0.36	1.14	0.53	0.56	0.53		—	—	1.01	0.51	—	

(continued)

Table 1 (continued)

Event	Sport class (men) H1	H2	H3	H4	H5	Total	Sport class (women) H1	H2	H3	H4	H5	Total
World Championships												
Greenville 2014												
Sample (*n*)	4	10	14	16	10	54	0	1	13	5	4	23
Distance (m)	8,300	16,600	16,600	16,600	16,600		—	16,600	16,600	16,600	16,600	
Mean velocity (m/s)	5.93	8.3	10	10.23	10.15		—	—	7.54	8.32	9.05	
SD (m/s)	0.18	0.73	0.5	0.46	0.58		—	—	1.06	1.14	0.54	
Nottwil 2015												
Sample (*n*)	10	11	22	19	9	71	1	3	12	7	5	28
Distance (m)	14,000	14,000	15,500	15,500	15,500		1,400	14,000	14,000	14,000	14,000	
Mean velocity (m/s)	4.86	7.13	7.29	7.91	8.41		—	4.84	7.08	7.86	9.1	
SD (m/s)	0.44	1.09	0.99	0.74	0.71		—	1.19	1.01	0.49	0.23	
Pietermaritzburgh 2017												
Sample (*n*)	8	8	20	15	9	60	1	2	5	3	3	14
Distance (m)	15,500	15,500	23,300	23,300	23,300		1,550	15,500	15,500	15,500	15,500	
Mean velocity (m/s)	4.99	7.63	8.96	9.06	9.58		—	4.34	7.59	7.84	8.91	
SD (m/s)	0.51	0.87	0.56	1.23	0.66		—	0.95	0.51	0.17	0.37	
Maniago 2018												
Sample (*n*)	10	10	33	20	14	87	1	3	13	7	3	27
Distance (m)	13,600	13,600	13,600	13,600	27,200		1,360	13,600	13,600	13,600	13,600	
Mean velocity (m/s)	6.42	8.03	9.64	10.02	10.59		—	5.3	8.32	8.77 0.75	9.28	
SD (m/s)	0.49	1.17	1.02	0.83	1.14		—	0.79	1.13		0.85	

(continued)

Table 1 *(continued)*

	Sport class (men)						Sport class (women)					
Event	H1	H2	H3	H4	H5	Total	H1	H2	H3	H4	H5	Total
Paralympic Games												
Rio 2016												
Sample (*n*)	0	7	13	12	10	42	0	3	8	4	6	21
Distance (m)	—	20,000	20,000	20,000	20,000		—	20,000	20,000	20,000	20,000	
Mean velocity (m/s)	—	9.55	10.74	11.21	11.08		—	7.2	9.41	9.57	9.94	
SD (m/s)	—	0.65	0.65	0.55	0.58		—	0.98	0.43	0.56	0.52	
Total of time-trial results ($N = 1{,}807$)	138	202	470	417	191	1,418	4	37	165	114	69	389
Total of participants						283						70

Note. Total of time-trial results included in the analyses, and additional information on the number of male and female athletes represented.

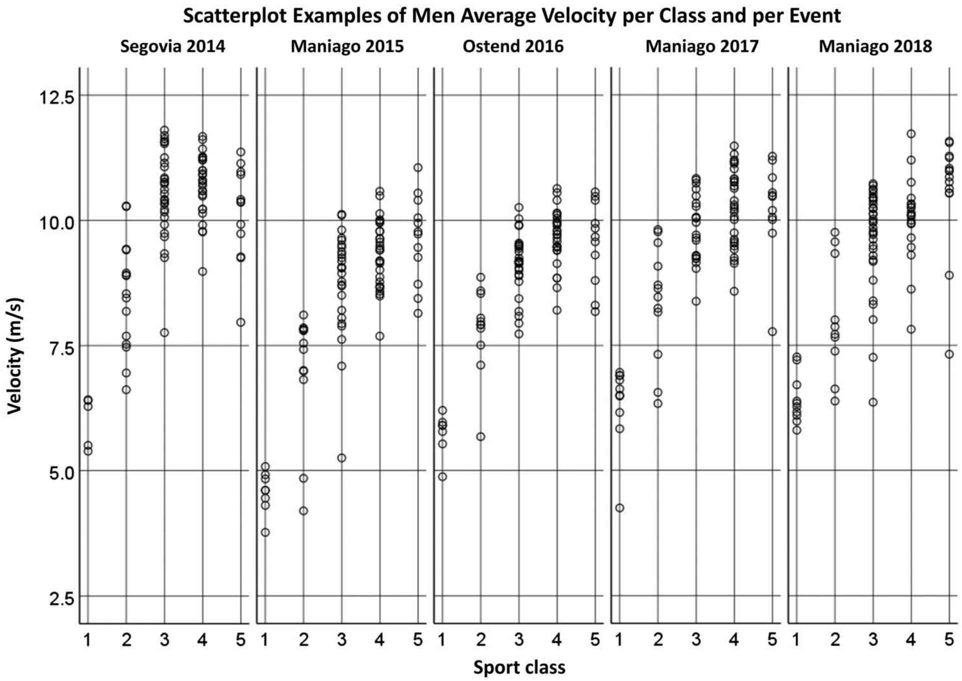

Figure 1 — Scatterplot of the men's average velocity per class from five example events. The *y* axis represents average velocity. The *x* axis represents the five sport classes, namely, Segovia 2014 ($n = 88$), Maniago 2015 ($n = 88$), Ostend 2016 ($n = 86$), Maniago 2017 ($n = 85$), and Maniago 2018 ($n = 87$).

Discussion

This study was the first to evaluate today's handcycling classification system by retrospectively studying the differences in average time-trial velocity among the five sport classes at major international competitions, controlling for event location, athlete's repeated test results, age, gender, and race distance. The findings of the current study indicated that the handcycling classification system successfully hierarchizes performances of athletes with the greatest impairments (H1 and H2); however, it clearly showed little differences in average velocity among those classes with athletes who had the least impairments (H3–H5).

The smallest significant difference between consecutive recumbent classes was found between H3 and H4 ($p = .0002$, $d = 0.12$). This limited difference in time-trial average velocity between H3 and H4 may indicate that athletes from these classes may not be disadvantaged when competing together. According to the UCI manual, H3 class profile includes athletes with moderate to almost no trunk function, whereas in the H4 class profile, athletes present a range from mildly impaired to complete trunk function (Union Cycliste Internationale, 2019). In an attempt to understand the reasons behind the small difference in performance

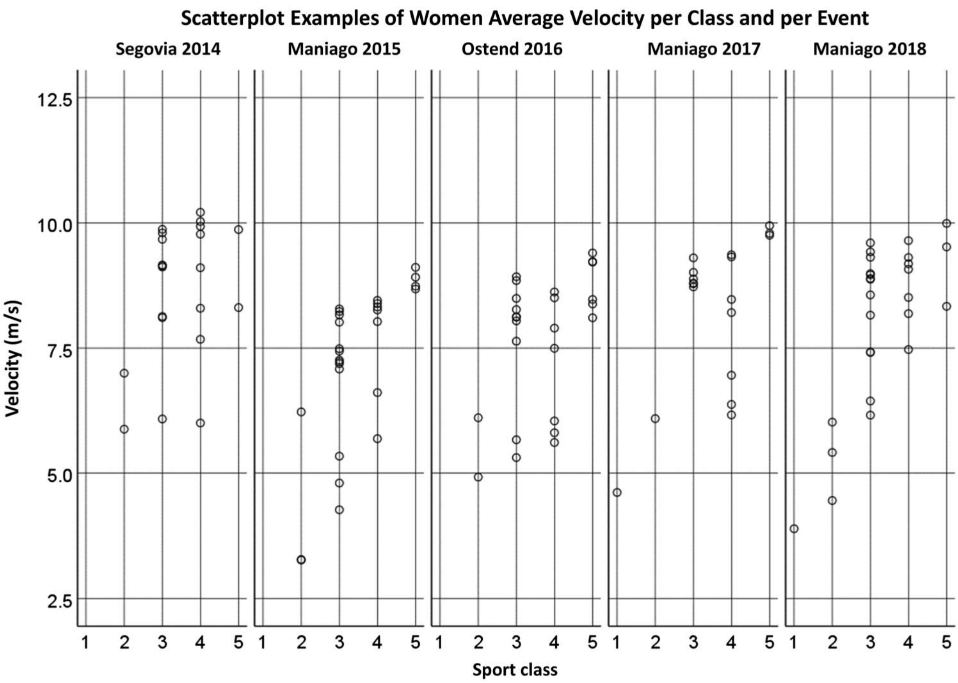

Figure 2 — Scatterplot of the women's average velocity per class from five example events. The *y* axis represents average velocity. The *x* axis represents the five sport classes, namely, Segovia 2014 ($n = 21$), Maniago 2015 ($n = 27$), Ostend 2016 ($n = 25$), Maniago 2017 ($n = 18$), and Maniago 2018 ($n = 27$).

between H3 and H4, one could thus suggest that the involvement of the trunk muscles, that is, the main determinant to allocate athletes between H3 and H4, might not be highly relevant for the handcycling performance in a recumbent handbike, which is supported by the study of Verellen, Meyer, Janssens, and Vanlandewijck (2012). However, the relation between trunk strength and handcycling performance is unknown and should be addressed in future research.

An impaired autonomic nervous system (ANS) is another important factor to consider when discussing performance in handcycling athletes. A high spinal cord injury (above Th6) reduces the thermoregulation capacity, lowers the blood pressure, and the maximum heart rate, thus limiting the exercise capacity of the athlete and his or her performance (Krassioukov & West, 2014; Leprêtre, Weissland, Slawinski, & Lopes, 2012; West et al., 2015). Although these impairments affect handcycling performance, they are not taken into account during classification but may be present in some of the H3 athletes with higher thoracic spinal cord injuries (West et al., 2015).

The small difference in average velocity between H3 and H4 and H5 may suggest that an impaired ANS has limited impact on handcycling performance and therefore not representing a relevant disadvantage for these athletes. However, we

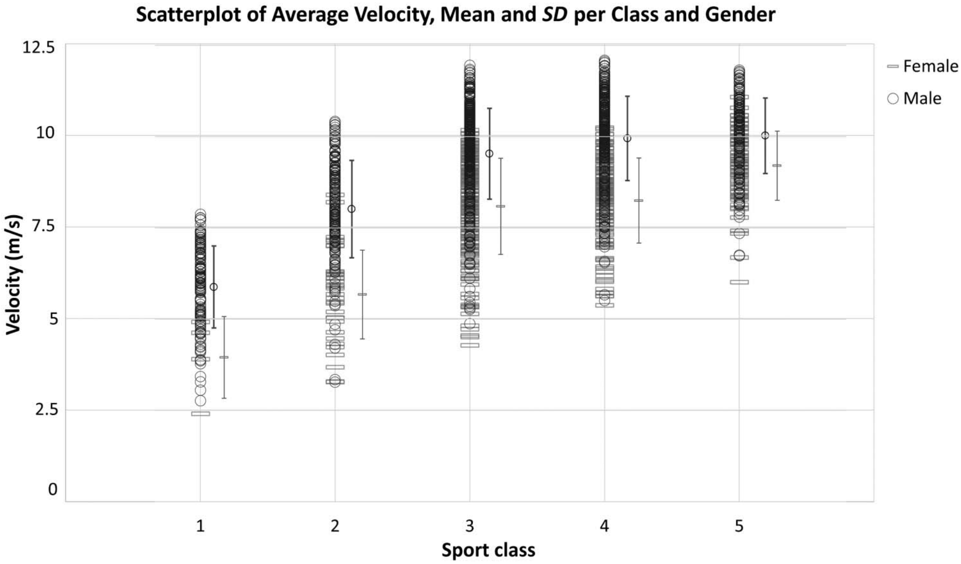

Figure 3 — Scatterplot of raw data of all events per class, with different markers for men and women, and with the addition of mean average velocity and *SD*. The *y* axis represents the average velocity. The *x* axis represents the five sport classes. *Note*. *N* = 1,807 (H1, *n* = 142; H2, *n* = 239; H3, *n* = 635; H4, *n* = 531; H5, *n* = 260).

do not know whether the athletes with impaired ANS stopped competing because of their disadvantage or are limited to the last ranking of race performance within H3. While this latter situation could emphasize the similarities between H3 and H4 athletes without an impaired ANS, it would also highlight the disadvantage faced by athletes with an impaired ANS. Therefore, it is important that future research on developing evidence-based classification studies how an impaired ANS impacts handcycling performance.

Performances of H4 and H5 classes were overall very similar, and therefore, it does not confirm our hypothesis of a hierarchical classification system, where consecutive classes of athletes with the least impairments present a faster average velocity. However, athletes in these classes race in different handbikes of which previous studies in handcycling have shown significant differences regarding the drag area of recumbent versus kneeling handbikes, with the latter ones being associated with more air resistance, which consequently will impact the required power output, and thus, the performance outcome (Belloli, Cheli, Bayati, Giappino, & Robustelli, 2014; Mannion et al., 2018). Hence, conclusions can only be very carefully formulated as air resistance will affect differently based on the type of event. In addition, it is known that racing in a kneeling handbike requires the active involvement of trunk, increasing energy expenditure and reducing gross mechanical efficiency (Verellen et al., 2012). As a consequence, when comparing the power output of athletes racing in a recumbent versus a kneeling handbike, those racing in a kneeling handbike are probably racing at a higher power output.

Table 2 Multilevel Models (Event and Athlete) Assessing the Differences in Average Time-Trial Velocity Among Pairs of Handcycling Classes, With H1, H2, H3, and H4 as a Reference After Controlling for Age, Gender, and Race Distance Differences

Model H1							Model H2						
Parameter	β	*SE*	95% CI	z	*p*	*d*	Parameter	β	*SE*	95% CI	z	*p*	*d*
Fixed effect							Fixed effect						
Constant	2.62	0.32	[2.00, 3.24]	8.24	<.00001		Constant	4.24	0.29	[3.67, 4.81]	14.53	<.00001	
H1H2	1.62	0.24	[1.15, –2.10]	6.66	<.00001	0.34	H2H1	–1.62	0.24	[–2.10, –1.15]	–6.66	<.00001	0.34
H1H3	3.26	0.22	[2.83, –3.69]	14.89	<.00001	0.53	H2H3	1.64	0.17	[1.32, 1.96]	9.93	<.00001	0.34
H1H4	3.72	0.22	[3.29, 4.15]	16.83	<.00001	0.65	H2H4	2.10	0.17	[1.76, 2.43]	12.26	<.00001	0.44
H1H5	3.59	0.25	[3.11, 4.07]	14.58	<.00001	0.73	H2H5	1.96	0.20	[1.57, 2.35]	9.86	<.00001	0.44

Model H3							Model H4						
Parameter	β	*SE*	95% CI	z	*p*	*d*	Parameter	β	*SE*	95% CI	z	*p*	*d*
Fixed effect							Fixed effect						
Constant	5.88	0.27	[5.35, 6.41]	21.78	<.00001		Constant	6.34	0.27	[5.80, 6.88]	23.13	<.00001	
H3H1	–3.26	0.22	[–3.69, –2.83]	–14.89	<.00001	0.53	H4H1	–3.72	0.22	[–4.15, –3.28]	–16.83	<.00001	0.65
H3H2	–1.64	0.17	[–1.96, –1.32]	–9.93	<.00001	0.34	H4H2	–2.10	0.17	[–2.43, –1.76]	–12.26	<.00001	0.44
H3H4	0.46	0.12	[0.22, 0.70]	3.69	.0002	0.12	H4H3	–0.46	0.12	[–0.70, –0.22]	–3.69	.0002	0.12
H3H5	0.33	0.16	[0.01, 0.64]	2.01	.045	0.07	H4H5	–0.13	0.16	[–0.44, 0.18]	–0.84	.40	0.03

Variables controlled

Parameter	β	*SE*	95% CI	z	*p*
Age	0.02	0.01	[0.01, 0.03]	2.83	.005
Gender	1.51	0.13	[1.25, 1.77]	11.27	<.00001
Distance	0.07	0.01	[0.06, 0.09]	10.14	<.00001

Note. CI = confidence interval; *SE* = standard error.

As race speeds between H4 and H5 were similar, but probably influenced by the type of circuit and atmospheric conditions, it would be important to consider in future research whether the athletes in recumbent and kneeling classes might be able to compete together or should continue competing separately. To be in accordance with the International Paralympic Committee recommendations for an evidence-based classification (Tweedy & Vanlandewijck, 2011), adaptations and the use of equipment should not affect the athlete's class, and therefore, it could be debated whether the implementation of two different classification systems, one for recumbent handcycling and one for kneeling handcycling, is necessary, stressing the need for further research on the relationship between impairments and performance in the different type of handbikes.

Another factor that might have an influence on the small differences on performance between classes is the closed-chain ability, that is, pushing off with functional lower limbs, (Kouwijzer et al., 2018), which is currently not specified in the UCI sport class descriptions. Among the different impairments possible to be found in H4 class, athletes may present amputations or incomplete spinal cord injuries, allowing some degree of lower limb function (Union Cycliste Internationale, 2019). It would be important to study the impact that this ability can have on the current classification system and whether separated disciplines could be more adequate for those who present this advantage.

Although the main aim of this study was to investigate performance differences between adjacent classes, it is important to point out the small but significant difference found between H3 and H5 ($p = .045$; $d = 0.07$). Previous discussions regarding the influence of the handbike type, the trunk involvement, and possible explanations of performance differences must be considered in this case as well. However, in addition to the small differences in average velocity of H3 and H4 and H4 and H5, the difference between H3 and H5 emphasizes the lack of distinctive performance profiles among these three classes, and interestingly shows that the difference between H3 and H5 is smaller than H3 and H4, which would not be expected in a hierarchical classification system.

Following the previous discussions on the classes with the athletes with the least impairments, our data suggest that current cutoffs between these classes (H3, H4, and H5) are not justified based on the average velocity. It is unknown whether these classes should be merged or different cutoffs should be investigated, and hence, future research is necessary in which studies could investigate the existence of patterns between athletes ranking within a class and their respective impairment.

The inclusion of different impairment types among the classes increases the difficulty to understand how handcycling performance is affected by impairment, and in addition, our results do not allow us to make strong conclusions on the reasons behind our performance results. Contrary to strength impairment and limb deficiencies, coordination impairments are less accurately described in the UCI manual (Union Cycliste Internationale, 2019). According to Tweedy et al. (2016), coordination impairments are in most Paralympic sports assessed subjectively and without meeting the standard requirements needed for an evidence-based classification (Tweedy et al., 2016).

Athletes with coordination impairments can be eligible to each one of the five sport classes based on the severity and extent of their impairment evaluation (Union Cycliste Internationale, 2019). This class allocation is based on coordination impairment scales without scientific evidence of the influence of the outcome on handcycling performance. Moreover, athletes must be considered not functionally able to ride a tricycle or a normal bicycle, increasing the complexity of the evaluation (Union Cycliste Internationale, 2019). Based on these descriptions, we cannot infer whether athletes with coordination impairment would show similar average velocity patterns among the consecutive sport classes. Future research should investigate the direct influence of coordination impairments on handcycling performance and whether there is a need to develop a specific classification protocol, distinctive to the current one that is mainly based on strength impairment.

Multilevel regression analysis is a robust method independent of the normality of the data. With the use of this statistical approach, we corrected for variables (distance, age, and gender) which had a potential impact on the results. In addition, we considered the impact of different circuits' conditions, by including events as the first level, and the influence of repeated measures within participants, by including athletes as the second level in our model. However, our results may be limited by not considering the athlete's physical fitness, the handbike technology, and the impairment type, which unfortunately we did not have access to.

Unlike a previous study in which the velocity of only the three top swimming athletes of each race was analyzed (Burkett et al., 2018), we opted to include all participants from major competitions to increase the sample size and to better represent the variability within and between sport classes. However, upper body training, muscle strength, and cardiorespiratory capacity have an influence on handcycling performance, as aerobic and anaerobic fitness is inherent to sport performance level (Chaikhot et al., 2020). As a result, future research investigating the handcycling classification system should take into account, if possible, the athlete's fitness level when interpreting the performance differences. We cannot assume that in our data set only highly trained athletes are present in the analyses although we increased this probability by analyzing only major international competitions (world cups and world championships). Furthermore, we have no reasons to believe that there were more untrained athletes in certain classes, and therefore, we do not think this imposed an unbalanced influence on our results.

Technology development and its accessibility to all athletes may impact the outcome average velocity and disturb the classification system if regulations are not adequately imposed. In our study, it was not possible to collect information regarding the design characteristics, quality, and maintenance of the handbikes used during the time-trial competitions. To diminish this possible effect, we previously checked for the influence of the athlete's country socioeconomic development, which we assumed as a potential factor influencing the handbike technology used during competition and consequent average velocity; however, this was not found to be significantly related to average velocity and therefore not included in the models to correct for differences between classes.

In a recent study focusing on handbike configuration for optimal sports performance, it was found that manufacturers, coaches, and handcycling athletes consider that the handbike-user interface, more specifically, the user's stability and position, crank axis position and length, and handgrip width have a significant impact on the performance achieved (Stone, Mason, Bundon, & Goosey-Tolfrey, 2019). Although there are limits to the width and the length of the handbike, the crank height, and the minimum height of the handbike frame according to the UCI manual (Union Cycliste Internationale, 2019), a range of handbike designs exists and little is known regarding the effect of the equipment setup on performance and sport classes differences. Another practical example is the absence of regulation on the footrest placement, which may be used to form a closed chain while pushing off with the lower limbs.

Conclusion

Our retrospective descriptive study in a large group of elite handcyclists showed significant differences in race performance between consecutive recumbent handcycling classes. However, differences in the actual race velocity between classes H3 and H4 were small and, as a consequence, do not justify this class division. These classes are comprised of athletes with less severe impairment, and therefore, future research should prioritize the underlying impairments and/or methods used to classify these athletes. Whether these two classes should compete together or a different cutoff should be determined is unknown and should be based on future findings that investigate the relationship between impairment and performance. Finally, performance of athletes racing in a recumbent handbike (H4) and in a kneeling handbike (H5) was very similar, and one could thus argue whether athletes could compete against each other or whether a different classification system should be implemented depending on the type of handbike.

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