Original research

The relation between sprint power and road time trial performance in elite para-cyclists

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ABSTRACT

Objectives: Whilst cycling performance has been studied extensively, very little is known about the performance of para-cyclists. This study assessed the relation between sprint power and road time trial performance in elite para-cyclists, and whether this relation differed based on impairment type and type of bike used.
Design: Cross-sectional.
Methods: During international para-cycling events, 168 athletes (88 bicycles, 17 tricycles, 56 recumbent handbikes and 7 kneeling handbikes) performed 20-s sport-specific sprint tests (mean power output (POmean) W), and their road time trial performance (average speed (km/h)) was taken from the official results. Multilevel regression models to assess the relation of sprint with time trial performance were composed for i. leg-cyclists: bicycle and tricycle and ii. arm-cyclists: recumbent- and kneeling handbike, adjusted for identified confounders. Furthermore, impairment type (categorized as i) muscle power/range of motion, ii) limb deficiency/leg length difference, and iii) coordination) and bike type were tested as effect modifiers.
Results: POmean ranged from 303 ± 12 W for recumbent handcyclists to 482 ± 156 W for bicyclists. POmean was significantly related to time trial performance, for both leg-cyclists ($\beta = 0.010$, SE $= 0.003$, $p < 0.01$) and arm-cyclists ($\beta = 0.029$; SE $= 0.005$, p < 0.01), and impairment type and bike type were not found to be effect modifiers.
Conclusions: Sprint power was related to road time trial performance in all para-cyclists, with no differences found in this relation based on impairment type nor bike type. For those competing on a bicycle, tricycle, recumbent- or kneeling handbike, sprint tests might therefore be useful to predict or monitor time trial performance.
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Practical implications

— Sprint power showed a strong relation with road time trial speed in para-cyclists and this relation did not differ between athletes with different impairments or between athletes competing on different bike types.
— A 20-s sprint test is an easy and standardized way for athletes and coaches to predict or monitor their time trial potential.
— The results of this study can assist in deciding which performance measures to include in para-cycling classification research.

1. Introduction

Cycling is a coordinated movement between limbs that requires the appropriate timing of muscle activation in order to manage loads imposed on each joint, the transfer of energy between joints and imparting energy to the cranks for propulsion.[1] Power production in cycling depends mainly on pedalling rate, muscle size, muscle fiber-type distribution, cycling position, and fatigue.[2] Although the biomechanics and physiology of cycling have been extensively studied, relatively little is known about cycling in persons with physical impairments,[2] especially in persons with more severe impairments as illustrated in a recent literature review on handcycling physiology.[3]

Para-cycling, i.e., cycling for individuals with impairments, is a Paralympic sport.[4] Dependent on the athletes' impairment, individuals use their legs or their arms to propel a bike, where cycling using legs is an asynchronous movement and cycling using arms typically synchronous. Competitions are organised on four different bike types: bicycle,

tricycle, recumbent handbike and kneeling handbike. Using these different bikes, athletes compete in different classes according to the degree of functional limitation. Classification in para-sports should provide the structure to ensure that winning is not determined by the impairment but by the same factors that account for success in able-bodied sports (skill, talent and training effort).[5] For those racing on a bicycle there are five classes, for tricycling two classes, for recumbent handbike four classes and for kneeling handbike one class.[4] Different impairments are mixed within classes. Eligible impairments for para-cycling are: limb deficiency (congenital or acquired amputation), muscle strength impairments, impaired passive range of motion, leg length difference, and coordination impairments including hypertonia, ataxia and athetosis. In the tricycle discipline, only athletes with coordination impairments are eligible to compete. The group of para-cyclists is thus heterogonous with regard to arm or leg propulsion, asynchronous vs synchronous propulsion, type of bike, and impairment type.

In classification research, the aim is to unravel the relation between impairment and sports performance.[6] It is easy to access race results to use as a performance measure for para-cycling.[7] However, for road events these are dependent on weather conditions, environment and the specific course characteristics at each event, interaction with other competitors, and therefore a more standardized performance measure might be desirable. A sprint test on a cycling ergometer is a short and simple standardized test for cycling performance, and previous studies indicate that sprint power is strongly related with aerobic capacity in persons with disabilities.[8–10] However, in elite para-cyclists it is unknown how the results of a sprint test relate to endurance performance in an individual time trial.

Most research in persons with physical impairments has been performed in a sedentary or inactive population, or addresses rehabilitation.[11–13] These studies show that in untrained individuals with disabilities, relations between sprint and endurance performance are strong. However, findings in untrained individuals with impairments might not be comparable to research in athletes[8,14] because cycling is assumed to improve muscle strength, balance, fitness as well as gross motor function.[15] As the range of performances is expected to be smaller in elite athletes, i.e. a more homogeneous group regarding fitness than a rehabilitation population, the relationship between sprint and endurance performance may be weaker in this population. For elite para-cyclists, the relation between a short standardized sprint test and endurance race performance is unknown.

The purpose of this study was to determine the relation between sprint power, measured with a 20-s sprint test, and road time trial performance in elite para-cyclists. To decrease the heterogeneity, this relation was assessed separately for those cycling with their legs and those cycling with their arms. Secondary analyses were conducted to confirm whether the relation of sprint power and time trial speed was different based on impairment type and bike type. Besides being valuable in para-cycling classification research, the results of this study are also relevant for testing and training for para-cycling athletes and coaches.

2. Methods

Participants

Data were collected at four Union Cycliste Internationale (UCI) international events: World Cup 2018 Emmen, the Netherlands; World Championships 2018 in Maniago, Italy; World Cup 2019 in Oostende, Belgium; and World Championships 2019 in Emmen, the Netherlands. All para-cycling athletes who signed up to compete at any of these events were invited to participate in the research on a voluntary basis. Ethical approval was granted from the Swedish Ethical Review Authority (2018/1004-31/4) for the bicyclists and

tricyclists and from the board of the Vrije Universiteit Amsterdam for the handcyclists (2018-093; 2019-052). All participants provided written informed consent.

Time trial performance

Publicly available official individual time trial results of the event at which the athlete also performed the sprint test were used to calculate average race speed in km/h.[7] Race distances ranged from 10.4 to 31.2 km, based on the event, class and sex. As individual time trial performance might be influenced by unexpected circumstances such as technical failures or injuries, outliers were identified. Following Tukey's method,[16] outliers were defined as 1.5 times the interquartile range (IQR) below the first or above the third quartile of the speed of the class the athletes were participating in, respectively. For those outliers, the other race results were controlled to assess whether the result was an exceptional outlier. If it was an exceptional outlier or no other race results were available, data of this athlete were excluded.

Sprint power

The test protocol started with a warm-up period of 5 min, followed by an isokinetic 20-s sprint test performed on the athlete's own bike mounted on a cycle ergometer (Cyclus2, RBM Electronics, Leipzig, Germany).[17] Athletes were responsible for their own bike and its condition. The tests were performed indoors. The majority of the athletes performed the test 0–4 days before the race, alternatively some athletes participated during the first three days after the race. As trikes are not compatible with the Cyclus 2 set up, tricycling athletes performed the test on a race bike owned by the university (Speedster 20 road bike 2017, Scott Sports SA, Switzerland). As the reason for riding a tricycle is increased stability, performing the test on a bicycle fixed in the stable base of the Cyclus 2 was considered as a good alternative. Saddle height was adjusted to the athletes preferred height. With a flying start, athletes were instructed to cycle as fast as possible during 20 s with verbal encouragement by the test leaders. All handcyclists started the test once they reached a cadence of 40 rpm, with a 20-N initial load. Handcyclists with arm impairments performed the test with a limiting cadence of 100 rpm. Handcyclists without arm impairments performing on a recumbent handbike had a limiting cadence of 130 rpm, and those on a kneeling handbike of 110 rpm. In bicyclists and tricyclists self-selected preferred cadence was used because of the larger range of disabilities (such as cycling with one leg) impacting cadence preference. Additionally, bicyclists and tricyclists were instructed to stay seated in the saddle. Sprint test outcomes were peak power output (POpeak) and 20-s mean power output (POmean (W)).

Possible confounding variables

Sex, age, and training hours (h/week) were noted and body mass (kg) was measured using weighing scales (leg-cyclists: Coline weighing scale, Clas Ohlson AB, Sweden, arm-cyclists: Lilypad wheelchair scale, Lilypad scales, Inc., USA). Furthermore, the seven eligible impairment types were sorted into three impairment groups: 1) MR: muscle power impairments and range of motion impairments, 2) LL: limb deficiency and leg length difference, and 3) CO: coordination impairments: hypertonia, athetosis and ataxia.

Data analysis

In order to limit the number of regression models, we aimed to analyse only one sprint power outcome, either POpeak or POmean. The PO outcome that showed the strongest correlation (Pearson r) with time

trial performance was used in the models described below. This analysis was performed in IBM SPSS Statistics version 25.

Main regression models

Only athletes with data on both sprint power and time trial performance were included in the analyses. To decrease the heterogeneity, athletes were grouped according to whether they used their legs and arms to propel their bike into two groups: 1) leg-cycling: bicycle and tricycle, and 2) hand-cycling: recumbent handbike or kneeling handbike. Multilevel regression analysis was performed to determine the relation between sprint power output (independent variable) and time trial performance (dependent variable) (MLwiN version 2.02, Centre for multilevel modelling, Bristol, UK). Two different main models were determined, one for leg-cycling and one for arm-cycling. Each model had two levels: 1) Event and 2) Athlete. Crude models were presented and additionally adjusted models were composed using the following procedure. First, time trial distance was added to each model to assess whether it had a significant effect on the time trial outcome, and if significant, it was added as a covariate to the model. Second, bike type (Bicycle = 0 and Tricycle = 1; Kneeling = 0 and Recumbent = 1), sex (Women = 0; Men = 1), age, training hours, body mass, and impairment type were added separately to the models, to study their possible confounding effects on the relationship between sprint power and time trial performance. For the leg-cycling group, impairment type was included as two dummy variables, with impairment group MR as reference (LL vs MR, CO vs MR). For the arm-cycling group, only few athletes had either LL or CO impairments and the impairment type was therefore included as a dichotomous variable (LL&CO vs MR). If after adding one of the possible confounding variables, the β of sprint power output changed with >10%, this variable was marked as a confounder and added to the final regression models.

Secondary analyses

Impairment type and bike type

To analyse whether the relation between sprint power output and time trial speed was different for athletes with different impairment types, it was assessed whether impairment type was an effect modifier by adding an interaction term of sprint power with impairment type to the final models (adjusted for confounders). To the leg-cycling model we added two interaction terms of sprint power output with each of the impairment dummy variables (LL vs MR, CO vs MR). To the arm-cycling model we added one interaction term of sprint power output with the impairment dummy variable (LL&CO vs MR).

To assess whether the relation between sprint power output and time trial speed was different based on bike type, similar models were run with interaction terms of sprint power and type of bike added to both the final leg-cycling model and arm-cycling model.

3. Results

Of the 216 athletes for which any performance data were collected, 168 para-cyclists were included in the analytical sample and their characteristics are shown in Table 1.

In the leg-cycling group, time trial results of six athletes were missing: four bicyclists and one tricyclist did not start and one bicyclist did not finish. For the arm-cycling group, results were missing of three athletes competing in recumbent handbikes because they did not start. For two bicyclists with outlying time trial performance, no other race results were available and these athletes were therefore excluded. One tricyclist was twice as slow at the other three events (event measured average speed = 13.4 km/h, all other events average = 26.1 km/h) and was therefore excluded.

Sprint power data were missing in two bicyclists, one tricyclist not willing to perform the test and four tricyclists who were not able to ride the provided bicycle as their body measurements were not suited for the provided bicycle. A total of 29 handcyclists did not perform the sprint test, of which one had a technical failure during the test, 14 had handbikes that did not fit in the Cyclus system, five did not have a bike available at the test location, and nine were not willing to do the test.

POmean was used as an indicator for sprint power as correlations with time trial performance were found to be slightly stronger compared to POpeak (Leg-cyclists: POpeak: $r = 0.54$, POmean: $r = 0.57$; Arm-cyclists: POpeak: $r = 0.64$, POmean: r = 0.64). Fig. 1 shows individual athlete's results on time trial performance and sprint power for Leg-cyclists (Fig. 1-Left) and Arm-cyclists (Fig. 1-Right).

Main regression models

The crude models showed that mean sprint power output was significantly related to time trial speed for both Leg-cyclists: $\beta = 0.015$; SE = 0.002 ($p < 0.01$, constant $\beta = 28.474$; SE = 2.104, $R^2 = 61\%$), and for Arm-cyclists: $\beta = 0.030$; SE = 0.004 (p < 0.01, constant $\beta = 21.915$; SE = 1.739, $R^2 = 56\%$). After adjusting for race distance and confounders in each of these models, sprint power remained significantly related to time trial speed (Table 2). The coefficients from the models can be used as an indication of the strength of the relations, using the following formulas based on the crude models:

Estimated time trial speed leg − cyclists

$$= 28.374 + 0.015 * \text{sprint power}$$

Table 1
Characteristics of leg-cyclists and arm-cyclists.

	Leg-cyclists $n = 105$		Arm-cyclists $n = 63$	
	Bicycle $n = 88$	Tricycle $n = 17$	Recumbent handbike $n = 56$	Kneeling handbike $n = 7$
Sex, % (n) female	23% (20)	47% (8)	27% (15)	14% (1)
Age in years, mean (SD)	31 (9)	37 (12)	39 (10)	40 (8)
Training in h/week, mean (SD)	16 (7)	10 (4)	13 (4)	15 (9)
Body mass in kg, mean (SD)	67 (11)	65 (13)	63 (9)	67 (7)
Impairment type				
% (n) MR	44% (39)	N.E.	89% (50)	29% (2)
% (n) LL	42% (37)	N.E.	5% (3)	71% (5)
% (n) CO	14% (12)	100% (17)	5% (3)	0%
Sprint power (POmean, W), mean (SD)	482 (156)	322 (153)	303 (122)	445 (113)
Time trial performance (km/h), mean (SD)	38 (5)	28 (4)	31 (6)	34 (6)

MR = muscle strength impairments and range of motion impairments, LL = limb deficiency and leg length difference, CO = coordination impairments: hypertonia, athetosis and ataxia. N.E. = not eligible to compete.
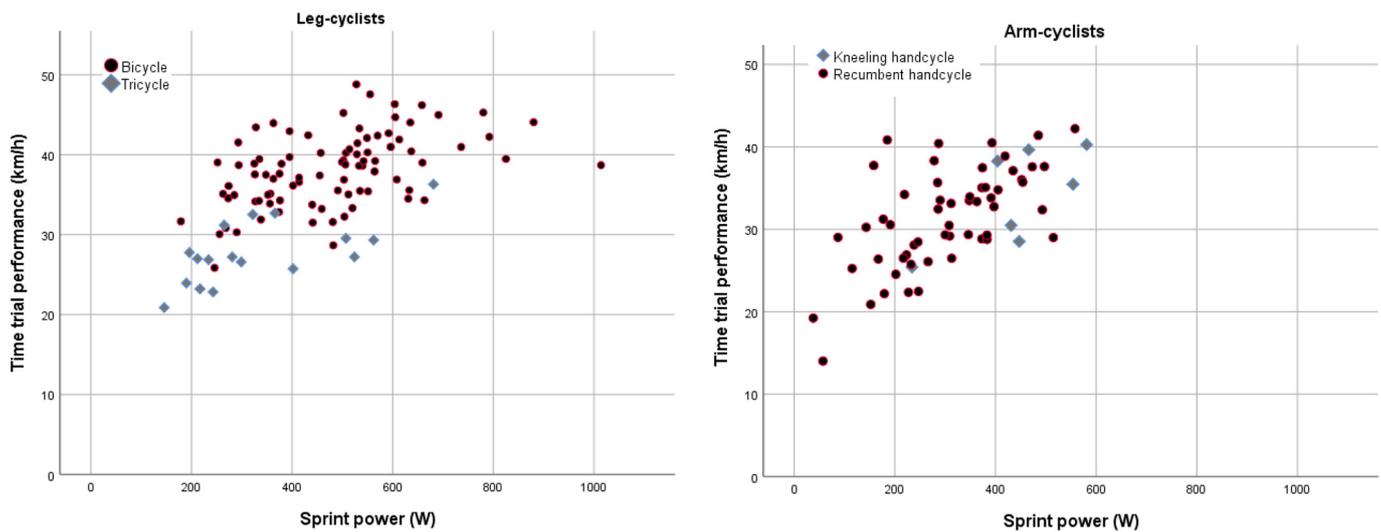
Fig. 1. Time trial performance (km/h) and sprint power output (W) of individual athletes.
Left: Leg-cyclists (bicycle and tricycle, n = 105). Right: Arm-cyclists (recumbent and kneeling handbikes, n = 63).

Estimated time trial speed hand − cyclists
= 21.915 + 0.030 ∗ sprint power

For example: for leg-cyclists the average sprint power of 457 W can be expected to result in a time trial speed of: 28.374 + 0.015 ∗ 457 = 35.2 km/h, and for arm-cyclists the average sprint power of 319 W can be expected to result in a time trial speed of 21.915 + 0.030 ∗ 319 = 31.5 km/h. Confounders can be taken into account by filling out the models presented in Table 2.

Secondary analyses

The secondary analyses showed that impairment type and bike type were not significant effect modifiers on the relation between sprint power output and time trial speed, for both leg- and arm-cyclists. In the adjusted model interaction terms of sprint power with impairment type were LL vs MR: $\beta = 0.342$, SE = 2.676, $p = 0.90$; CO vs MR: $\beta = -0.752$, SE = 2.882, $p = 0.80$ for leg-cyclists, and (LL&CO vs MR) $\beta = 0.017$, SE = 0.010, $p = 0.09$ for arm-cyclists. Interaction terms of sprint power with bike type in the leg- and arm-cyclists were respectively: $\beta = 0.008$, SE = 0.006, $p = 0.18$ and $\beta = -0.011$, SE = 0.014, $p = 0.43$.

4. Discussion

Although cycling performance has been extensively studied, this study is the first to report on the relation between a standardized sprint test and road time trial performance in a large group of elite para-cyclists. Sprint power from a standardized 20-s sprint test was significantly related to the time trial performance for those cycling with leg power and those cycling with arm power. The relation between sprint power and time trial performance was not different for athletes with muscle strength or range of motion impairments, limb deficiency or leg length difference, or coordination impairments (hypertonia, ataxia athetosis). Furthermore, for those cycling with leg function, this relation was not different for athletes competing on a bicycle or tricycle, and for those cycling with arm function, the relation was not different for athletes competing on a recumbent or on a kneeling handbike.

For para-cyclists competing on a bicycle, tricycle, recumbent- or kneeling handbike, sprint tests can be used to monitor performance. To assess the impact of impairments on cycling performance, a 20-s sprint test is standardized and a good indicator of biomechanical possibilities without being dominated by factors one would like to limit the influence of such as cardiovascular fitness.[6] Unexpected events in a time trial, such as a breakdown of material or a crash, could impact time trial results. Furthermore, compared to elite para-cyclists, the performance of those who are more untrained or unexperienced might be more affected by aerobic capacity or race strategies such as pacing.[18]

Although a large proportion of the variance in time trial performance could be explained by sprint power and identified confounders, certain aspects that we did not consider in the analyses might have influenced time trial performance more than sprint power. For endurance sports such as a time trial, aerobic capacity, ventilatory/lactate thresholds and efficiency also play key roles in endurance performance.[19]

First, aerodynamics, rolling resistance, mechanics and ergonomics might be different based on the bike. Recumbent handbikes are

Table 2
Adjusted multilevel regression models to assess the relation between sprint power output (W) and time trial performance (km/h), for leg-cyclists and arm-cyclists respectively.

Time trial performance (speed in km/h)	Constant		Sprint power (POmean)			Race distance		Confounders			R^2
	B	SE	B	SE	p	B	SE		β	SE	
Bicycle and tricycle	26.045	3.087	0.010	0.003	<0.01	0.153	0.087	Sex	2.884	0.934	69%
								Body mass	−0.022	0.039	
								Training hours	0.123	0.054	
								LL vs MR	−1.210	0.824	
								CO vs MR	−1.691	1.215	
Recumbent and kneeling handbike	15.559	4.395	0.029	0.005	<0.01	0.127	0.223	Sex	2.332	1.279	61%
								Bike type	3.333	1.705	

β = unstandardized regression coefficient, SE = standard error, p = significance level, R^2 = explained variance. MR = muscle strength impairments and range of motion impairments, LL = limb deficiency and leg length difference, CO = coordination impairments: hypertonia, athetosis and ataxia.

known to be most aerodynamic,[20] whereas bicycles can be expected to have the lowest rolling resistance.[21] Also, impairments could limit cycle handlings skills (taking corners, braking etc.) and decrease the ability to get into an optimal aerodynamic position. Both of these might be affected by the use of prostheses, as well as material and design of the prosthesis.[22] Furthermore, handcyclists who have a higher level of spinal cord injury might have an impaired autonomic nervous system which could affect their endurance capacity due to limitations in thermoregulation capacity, blood pressure and cardiac output.[23]

Athletes might also have primary or secondary brain injuries that could affect cognitive ability which in turn could influence their pacing ability.[18] Another aspect concerns fatigue of cyclists with coordination impairments as fatigue might lead to increased activity limitations and could therefore impact endurance performance more than sprint performance in these athletes.[15] Related to fatigue is the concept of critical power which is defined as the maximal power output that can be maintained without exhaustion.[24] Using critical power or combining data on mean power output and critical power, might even explain a larger proportion of the variance in time trial performance. When monitoring performance, athletes and coaches should be aware of these aspects and future studies should further investigate the impact on para-cycling performance.

When analysing race performance, results are often adjusted for body mass, e.g. expressing the outcome of the sprint test in W/kg. However, in para-cyclists this relation is rather complicated as some impairments might result in lower body mass. Although this is the case amongst athletes with different impairment types, an obvious example are those who have an amputated leg and race on a bicycle. In this case, the athlete has a relatively low body mass due to the impairment which on the one hand disadvantages the athlete's performance due to the ability to use only one leg, but on the other hand advantages the athlete's performance with a lower rolling resistance. Stronger correlations were found between physiological parameters normalized to body mass and handcycling performance in wheelchair users with impaired muscle power.[25] The adjustment for body mass of performance measures in para-cyclists is thus complex. Although it was included as a confounder in the current analyses, we do not have a full understanding of the interaction between body mass and impairments.[26] Further research should aim to better understand how body mass should be considered when analysing performance in para-sports.

In able-bodied cyclists, the relation between sprint and endurance performance has been found to be low to moderate.[27,28] How able-bodied cyclists compare to cyclists with physical impairments have hardly been studied. One previous study that did include both groups found that those with cerebral palsy (both athletes and non-athletes) showed strong associations between sprint power and aerobic capacity, whereas the same relation in those without cerebral palsy was only weak.[8] In line with the current results, previous studies in wheelchair athletes and hand cyclists reported that the relation between sprint and aerobic power was strong.[10,29] The variation in biomechanical possibilities is larger in para-cyclists compared to able-bodied cyclists, potentially affecting both the outcomes on a standardized sprint test as well as time trial speed which might result in stronger relationships between sprint power and time trial performance. More studies that directly compare able-bodied cyclists and para-cyclists are warranted.

Besides the different types of bike cyclists might compete on in para-cycling, many athletes also have custom-made adaptations on their bikes that facilitate a better fit of the bike considering their impairment. These technologies are developing vastly, e.g. the use of prostheses in bicycling for those with lower limb deficiencies,[30] or adapting the foot rests of a recumbent handcycle to make a closed chain.[31] The impact of these adaptations on sprint power as well as time trial performance should be continuously monitored.

Limitations

Although this was the first large field study on para-cycling performance and elite athletes were measured at international events, not all athletes had the same amount of support from a team or could afford the most optimal bike. Furthermore, the large range of impairments made it impossible to use standardized mechanics in bikes as well as a strictly standardized sprint protocol. Our sample is a good representation of the currently competing para-cyclists but since certain groups are underrepresented in competition only a limited number of female cyclists as well as athletes with coordination impairments competing on a handbike could be included. A continued development of the sport, including its classification system could lead to an increasing number of para-cyclists competing with the potential for future studies to be more representative for all.

5. Conclusion

Power output from a 20-s sprint test was significantly related to road time trial speed for para-cyclists with all eligible impairment types competing on a bicycle, tricycle, recumbent- or kneeling handbike. Therefore, this sprint test can be an easy and standardized way for athletes and coaches to predict or monitor endurance performance.

Declaration of interest

None.

Confirmation of ethical compliance

All para-cycling athletes who signed up to compete at any of these events were invited to participate in the research on a voluntary basis. Ethical approval was granted from the Swedish Ethical Review Authority (2018/1004-31/4) for the bicyclists and tricyclists and from the board of the Vrije Universiteit Amsterdam for the handcyclists (2018-093; 2019-052). All participants provided written informed consent.

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