Title:

Isometric, dynamic, and manual muscle strength measures and their association with cycling performance in elite para–cyclists

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Abstract

Objective

Para–cycling classification aims to generate fair competition by discriminating between levels of activity limitation. This study investigated the relationship between lower limb Manual Muscle Tests (MMT) with ratio–scaled measures of isometric and dynamic strength, and of the ratio–scaled measures with cycling performance.

Design

Fifty–six para–cyclists (44 males, 12 females) with leg impairments performed isometric and dynamic strength tests: leg push and pull, and an all–out 20 s sprint. MMT results were obtained from the classification database (n = 21) and race speeds from time trials (n = 54).

Results

Regression analyses showed significant associations of MMT with isometric push (R^2 = .49), dynamic push (R^2 = .35), and dynamic pull (R^2 = .28). Isometric strength was significantly correlated with dynamic push (ρ = .63) and pull (ρ = .54). The isometric and dynamic tests were significantly associated with sprint power and race speed (R^2 = .16–.50).

Conclusion

The modified MMT and ratio–scaled measures were significantly associated. The significant relation of isometric and dynamic strength with sprint power and race speed maps the impact of lower limb impairments on para–cycling performance. MMT and the isometric and dynamic measures show potential for use in para–cycling classification.

Introduction

Para–cycling is a Paralympic sport governed by the international cycling federation Union Cycliste Internationale (UCI). In the para–cycling C–division, athletes with physical impairments compete on standard road bicycles in five classes (C1–C5), established according to the amount of impairment (C5 athletes having the least impairments).[1] The congenital or acquired impairments that provide eligibility for the C–division are impaired muscle power, impaired passive range of motion (PROM), leg length difference, limb deficiency, hypertonia, ataxia, and athetosis. The impairments need to be within limits of the minimum impairment criteria (MIC) which define the smallest impairments eligible to compete in para–cycling. The MIC ensure that the impairments impact the extent to which athletes are able to perform the activity of cycling.[2] Further details about eligibility for para–cycling have been described by the UCI.[1]

In para–sports, athletes are allocated to different sport–classes to minimize the impact of impairments on the outcome of competition.[2,3] Each class is intended to consist of athletes with levels of impairments with similar impact on cycling. The classification process consists of a medical and a technical assessment. The medical assessment aims to determine the level of activity limitation by assessing muscle strength, joint range of movement, neurological function, and more, and the technical assessment consists of examining the equipment and observing the athletes' abilities to use the equipment. Athletes are thereafter allocated to a sport–class based on the results of the assessments.

Manual muscle testing (MMT) with modifications to tested range and resistance is currently used to assess muscle strength in para–cycling classification in athletes with musculoskeletal impairments.[4] However, the ordinal–scaled MMT has not been proven to be a valid assessment for para–cycling classification. To ensure fair competition, the International Paralympic Committee (IPC) requires para–sports included in the Paralympics to develop evidence–based classification systems.[2] It is suggested that evidence–based classification systems should use classification methods that are reliable,[3] training–resistant,[3] and ratio–scaled.[5] Training–resistant measures are required to ensure that the outcome of classification will not be affected by the training status of an athlete. Thus, the methods currently used need to be validated and, if necessary, substituted. To assess the impact of muscle strength impairments on para–sport performance, isometric strength tests are considered the most training–resistant and have been suggested to increase validity.[6] Therefore, methods with potential to assess muscle strength in classification need to be investigated to understand the associations between impairment, muscle strength measurements, and cycling performance.

Muscle volume, coordination, and fiber composition are factors that determine cycling performance.[7,8] The most central muscle groups to create power during the downstroke of the pedal are the knee and hip extensors[9,10] In the lower leg, the plantarflexion and dorsiflexion muscle groups are activated during and just after the bottom dead center.[11,12] It is uncertain how cycling performance is impacted by physical impairments because of limited research in para–cycling. It has been established that the fastest para–cyclists reach 90% of the race speed of non–impaired cyclists.[13] Furthermore, average power output in non–impaired cyclists is associated with time trial (TT) speed,[14,15] which is also the case in para–cycling.[16] Regarding differences between consecutive para–cycling classes, data on track para–cyclists in the men's C–division have shown that the classes C4 and C5 do not differ in race speed,[13] while data from men's road races have shown significant differences between each consecutive C–class.[17] As it is yet unclear how impairments affect para–cycling race performance and consequently how to allocate athletes to classes, further research is required.

The aim of this study was to evaluate three new types of leg strength measures for the purpose of a valid para–cycling classification system: a variation of the currently used MMT, the isometric strength measure which is recommended for muscle strength assessments in para–sport, and a dynamic strength measure to evaluate its potential use in classification. The objectives were to: 1) evaluate MMT in relation to objective and ratio–scaled isometric and dynamic strength measures, 2) investigate the relationship between isometric and dynamic strength measures, and 3) investigate the association between isometric and dynamic strength measures with cycling performance.

Methods

A convenience sample of 56 para–cyclists (44 males, 12 females) participated in the study (Table 1). Data were collected in 2018 and 2019 at four major UCI–sanctioned para–cycling events: two road World Cups and two road World Championships. The inclusion criteria were internationally competing C–division para–cyclists, classified by international classifiers, with at least one of the following impairments in one or both legs: impaired muscle power, impaired PROM, limb deficiency, or leg length difference. Exclusion criteria were athletes with only upper body impairments and athletes with concurrent hypertonia, ataxia, or athetosis, i.e., impairments caused by brain injury which require different assessment methods. Of the participants included in the study, 32 athletes (10 females) had impaired muscle strength and/or impaired PROM, of which 15 (one female) had impairments in both legs. Seven athletes (one female) had a transtibial amputation in one leg and one male athlete had transtibial amputations of both legs. Sixteen athletes (one female) had a transfemoral amputation of which one male had additional strength impairments in the non–amputated leg. Twenty–one athletes had available MMT data and were included to answer the first objective. Fifty–six athletes had complete data to answer objective two and 54 athletes had data to answer objective three.

To reach as many para–cyclists as possible, the national federations received emails from the research team through UCI, inviting athletes to sign up for research via an online booking system. The research was conducted at the event area in the days prior to competition. Onsite, participants received verbal and written information about the research and participants provided their informed written consent to the study. The test protocol was designed with consideration of the upcoming races, i.e., no strenuous exercises, invasive procedures, or other testing that could affect race performance were conducted. Ethical approval was granted by the Stockholm Regional Ethical Review Board, Sweden (approval no: 2018/1004–31/4).

Data collection procedure

The most recent MMT results of participants who had given written consent to share their classification data with the reporting research group were retrieved from the UCI classification database (n = 21), i.e., the MMT assessments had been previously conducted at international classifications. The results of hip, knee, and ankle extension and flexion in both legs were used for the analysis.

The isometric strength tests were performed in a custom–built strength set–up. Force was measured with 3D piezoelectric force transducers (type 9347B, Kistler Instruments AG, Switzerland) connected to an amplifier (type 9865E, Kistler Instruments AG, Switzerland). The sampling frequency was 1500 Hz and signals were A/D converted. Isometric leg strength was measured with two tests: leg push and pull (Figure 1). The tests were assessed unilaterally with two trials per test. Instructions were to sit upright with arms crossed over the chest, a belt fastened over the hips to avoid changes in position, the non–tested foot on the floor, and the tested leg in 50° knee flexion (Figure 1). The participant built up muscle force during two seconds until maximal voluntary contraction was reached and this was maintained during a minimum of three seconds. The push test measured the positive force applied to the footrest while the pull test measured negative force applied by strapping the foot to the footrest and performing a pulling motion. The test outcome was peak force measured in N/kg body mass.

The dynamic strength tests were performed on the participant's personal road bicycle mounted on a cycling ergometer (Cyclus2, RBM Electronics, Germany). Two dynamic tests were conducted: leg push and pull (Figure 2). Both tests were performed from a dead start. To decrease involvement of the non–tested leg, this was positioned with the hip extended and the toes placed on a box adjacent to the rear wheel. Instructions were to stay seated on the saddle with the hands in a preferred position on the handlebars. Participants had the tested leg clipped to the pedal which was positioned at the top position of a pedal revolution (top dead center: 0°). In the first test (dynamic push), the participant pushed the pedal in a downstroke motion to the bottom position (bottom dead center: 180°). The second test (dynamic pull) was performed by pulling the pedal in an upstroke motion from the bottom position to the top position (360°). The starting pedal resistance in each test was 100 N, increasing with 100 N in each trial until the participant no longer improved peak power (typically 3–4 trials, i.e., 300–400 N) which was controlled by real–time results from the Cyclus2 ergometer. If the participant could not overcome 100 N, it was lowered to 50 N, 25 N or 0 N. The test outcome was peak power (W), expressed in W/kg body mass.

The Cyclus2 pre–programmed *Isokinetic maximum strength test* was used to perform the 20 s sprint test on the participant's personal road bicycle mounted on the Cyclus2. During the test, forces applied to the pedals were counterbalanced by the ergometer which changed pedal resistance in relation to cadence. If the participant tried to pedal faster than the set cadence, the resistance increased to prevent higher cadence. If the participant could withstand the added resistance, higher power output was achieved. Cadence was chosen by the participants, typically 80–120 revolutions per minute (RPM). Instructions were to stay seated and position the hands on the handlebars as preferred to optimize the ability to produce maximal power. From a flying start, the test started when the ergometer registered 40 RPM below the chosen cadence. Participants were given verbal encouragement from the test investigators throughout the test. Verbal information was given at 10 and 15 s and the last five seconds were counted down. The measurement outcome was mean power output (PO_{mean}) produced during 20 s, measured in W/kg body mass.

Official and publicly available time trial results of race distance and time to finish, corresponding to the event at which participants were involved in data collection, were retrieved from the internet.[18]

Data processing

The MMT is assessed on a 0–5 point scale. Zero points is no muscle function, 3 points is limb movement against gravity, and 5 points is normal muscle strength against resistance. Each muscle group in each leg is rated on the 0–5 point scale. For this study, to allow interpretation of association with the ratio–scaled isometric and dynamic push, MMT scores of hip extension, knee extension, and plantarflexion of both legs were summarized into one variable, MMT push (0–30 points). MMT scores of hip flexion, knee flexion, and dorsiflexion of both legs were summarized as MMT pull (0–30 points) to allow interpretation of association with isometric and dynamic pull.

Isometric strength data were sampled and analyzed using Spike2 (version 7.0, CED, Cambridge, UK). The data were smoothed using a digital second–order low–pass bi–directional Butterworth filter with a cut–off frequency of 30 Hz. Peak isometric force was calculated as the mean force during the two seconds when the maximal force with the least variability was produced. Results of the dynamic tests and the sprint test were exported to Microsoft Excel (version 2016, Microsoft Corporation, Washington, USA). The best results of the right and left leg of the strength tests were added together. In participants with transfemoral amputation, the non–measured leg was registered as 0 (i.e., only the measurement outcome of one leg was used for analysis). To account for varying race distances at the para–cycling events and between classes, race speed results were expressed in km/h. All statistical analyses were performed in IBM SPSS Statistics for Windows (version 26.0, Armonk, New York, USA).

Statistical analysis

The Shapiro–Wilks test was used to examine the results for normal distribution. Outlying data points were defined as points exceeding the interquartile range times three. The influence of body mass in the isometric and dynamic tests and the sprint test was examined with

Spearman's correlation coefficient, which was also used to assess the correlation between isometric and dynamic strength.

Multiple linear regressions were performed to determine the association between MMT and isometric and dynamic strength (n = 25), and between PO_{mean} and race speed with the isometric and dynamic tests (n = 54). The regression analyses were adjusted for sex (male = 0, female = 1), and in the cases of race speed the models were also adjusted for event (Event 1, 2, 3, and 4), using Event 2 as the control event as it was the event with the greatest number of participants and the fastest race speeds. The significance level was set to $\alpha \leq .05$. To perform the regression analyses, the assumptions of regression analysis were examined as follows. Normal distribution of residuals was tested with the Shapiro–Wilks test and by examining Cook's values for influential cases (values accepted when < 1.00). Absence of measuring errors was controlled with the Durbin–Watson statistic (values of 1.50–2.50 were accepted). Homoscedasticity was investigated visually by plotting the standardized predicted values to the standardized residuals, and tested statistically with Spearman's correlation coefficient (homoscedasticity was assumed when $p > .05$). Multicollinearity between variables was assessed by examining the variance inflation factors (absence of multicollinearity assumed when values were < 5.00 and the average variance across all variables was > 1.00). Finally, linearity was examined visually by plotting the dependent variable by the independent variable.[19]

Results

There were no outliers observed in the dataset. The isometric and dynamic strength tests and the sprint power performance test were significantly correlated to body mass (ρ = .47–.71) and were therefore adjusted accordingly for all participants (n = 56). All variables included in the regression analyses met the criteria to perform the analyses.

The results of the MMT showed that the points assigned to hip and knee extension and flexion ranged from 6–10 points. Eighty–one percent of participants scored 8–10 points in hip extension, 100% scored 8–10 points in hip flexion, 90% scored 8–10 points in knee extension, and 90% scored 8–10 points in knee flexion. The points assigned to plantarflexion and dorsiflexion showed a large variation, ranging from 0–10 points: median scores of plantarflexion and dorsiflexion were 6 points, respectively. Regression analyses showed that the MMT push was significantly associated with isometric push ($R^2 = .49$, $p = .004$) and dynamic push (R^2 = .35, p = .002), and MMT pull were significantly associated with dynamic pull (R^2 = .28, p = .041) (Table 2). MMT pull was not significantly associated with isometric pull (R^2 = .21, p = .075) (Table 2).

Isometric and dynamic push were significantly correlated with each other (ρ = .63, $p < .001$), as were isometric and dynamic pull (ρ = .54, $p < .001$) (Figure 3). The regression analyses of PO_{mean} and race speed both showed significant associations with isometric and dynamic strength (Table 3). The largest associations with PO_{mean} were the isometric push (R^2 = .35, $p <$ .001), dynamic push (R^2 = .41, $p < .001$), and dynamic pull (R^2 = .32, $p < .001$). The isometric pull showed a lower but significant association with PO_{mean} (R^2 = .16, p = .003). For race speed, the largest association was with dynamic push (R^2 = .50, $p < .001$).

Discussion

The aim of this study was to evaluate the relationships between three new leg strength measures and their association with cycling performance for the purpose of developing an evidence–based para–cycling classification system. This study showed that MMT measures of hip, knee and ankle extension and flexion were associated with isometric and dynamic strength, except for the isometric pull. The correlation analysis showed a significant correlation between isometric and dynamic strength, and regression analyses showed that isometric and dynamic strength were associated with cycling performance.

In para–cycling classification, other MMT assessments of the legs are hip abduction and adduction, and foot pronation and supination. Research on the impact of these muscle groups on cycling performance is scarce. Therefore, MMT tests of extension and flexion that have been clearly shown to contribute to cycling performance and are performed in the sagittal plane to mirror the isometric and dynamic tests, were included in this study. The results showed that MMT was associated with ratio–scaled strength measurements of the lower limbs, except for the isometric pull. The relationship between MMT push and isometric and dynamic push indicated that the MMT measures of hip, knee, and ankle extension rated on the 0–5 point scale have potential to be used in the classification of muscle strength. By examining scatterplots of each component of MMT pull (i.e., dorsiflexion, knee flexion, and hip flexion) with the isometric and dynamic test results, the results indicated that isometric pull strength was dependent on MMT dorsiflexion strength. The design of the isometric pull test required dorsiflexion strength to perform the pulling motion. In the dynamic pull, the cycling shoe was clipped to the pedal and therefore did not require dorsiflexion strength to perform the test, which was also confirmed by the scatterplots. This presumably explained the low association of MMT pull with isometric pull. Although the number of athletes with MMT results was low (n = 21), it was appreciated that it was enough to perform regression analyses with two independent variables. These 21 participants did not include all athletes that were part of the regression analyses (n = 54) and associations between the two analyses should be considered with caution. Furthermore, MMT is not ratio–scaled and some care may be needed before confirming that the modified MMT analyzed in this study could be part of the para–cycling classification.

In para–sport classification, it has been recommended to use isometric strength measurements as these have been suggested to be the most training–resistant measures.[6] However, isometric strength has been shown to correlate with cycling power output in cyclists.[7] It was therefore of interest to evaluate isometric and dynamic strength in association with cycling performance and in correlation to each other. The results of this study showed that isometric and dynamic strength were similarly associated with PO_{mean} and race speed, which confirms that leg strength is a determining factor of para–cycling performance. The significant correlations between isometric and dynamic strength were in line with previous research on isometric and dynamic strength measurements.[20,21] The results suggest that both the isometric and dynamic test could be used to assess muscle strength in athletes with musculoskeletal impairments. However, the execution of the dynamic tests was similar to the activity of cycling, as pedaling comprises the movements of dynamic push and pull. It is therefore possible that the association of dynamic strength with PO_{mean} and race speed are caused by this similarity and further investigations of the dynamic tests are needed. It also remains to be explored whether the tests are training–resistant.

In the current study, self–reported training hours were used to describe the participants' training level. It cannot be ensured that all participants have given the same effort to maximize their physical capacity and therefore, the quality of the reported training hours cannot be verified. It could be expected that internationally competing para–cyclists are at, or close to their peak physical capacity. However, it does not take certain qualifications to participate in the international para–cycling World Cup,[1] which may result in less experienced athletes competing at the World Cup level. However, the self–reported training levels were relatively homogenous across participants and were not significant when included in the regression models, and therefore, training level was not included as an independent variable.

The associations with performance showed that both the isometric and dynamic tests have potential to discern between strength levels. To estimate the boundaries between para–cycling classes, cluster analyses of the test results need to be performed as one of the next steps to create an evidence–based classification system.[22]

The race speed results were expressed in km/h with regards to different race distances based on sex, class, and event. The race speeds analyzed in this study were obtained from four different courses and occasions, which could be a limitation when analyzing race speed. As race performance is dependent on environmental factors such as wind, temperature and course topography,[23] the regression analyses of race speed were adjusted for the event at which the participant partook in data collection. In para–cycling, men typically compete in longer race distances than women and C4–C5 typically compete in longer race distances than C1–C2, while C3 sometimes compete on the same distance as C4–C5 and sometimes as C1–C2. Although it would be expected that longer distances will result in slower race speeds, this is not the case in para–cycling where the longest distances are raced by the least impaired and thus the fastest athletes.[13,17] Consequently, the distance variable is an indirect measure of activity limitation. While taking into account collinearity, the distance variable was analyzed before conducting the regression models including race speed and displayed significant correlations with both isometric and dynamic push. Therefore, distance was not included in the analyses of race speed.

A possible limitation to this study was that the MMT results were not conducted as part of the study protocol but collected beforehand for classification purposes. Therefore, the MMT tests have been conducted by several para–cycling classifiers which potentially limits the inter–rater reliability. Consequently, intra–rater reliability could not be evaluated in this study. However, the manner in which MMT assessments were conducted in this study mirrors how assessment methods are conducted in classification.

Another limitation to this study was that it included participants with upper body impairments. Literature on the upper body influence on cycling performance is limited but shows that the upper body does contribute to different tasks during cycling, for example, alternating between seated and standing cycling to maintain speed while riding uphill,[24] and standing out of the saddle at high power outputs.[25] To adjust for upper body impairments, para–cyclists often have adaptations on their bicycles to better suit their individual needs. Therefore, participants used their own road bicycle for the standardized performance test of sprint power (PO_{mean}), to allow participants to perform maximally in the sprint test and to allow for comparison with race speed in the data analyses.

Even though the sample size of the current study was rather large for a study in para–sport, athletes often have unique combinations of impairments and therefore, it remains complicated to make comparisons among impairment types. For example, athletes in the C–division have impairments in one or both legs with or without upper body impairments. Future research focusing on the details of impairments would contribute to the full understanding of the different impairments' impact on cycling performance. This study is an important initial step to begin unraveling the impact of impairments on para–cycling performance in competitive para–cycling athletes.

Conclusion

This study showed that MMT was associated with isometric push strength and dynamic push and pull strength, and that the isometric and dynamic tests were correlated with each other and were associated with para–cycling performance. These results indicate that leg strength affects para–cycling performance and stresses the importance to continue the assessment of leg strength in classification. Although the MMT is an ordinal–scaled measure, it is an easily administered and low–cost test which is beneficial for classification, which often takes place in the field. Should MMT be considered for the para–cycling classification protocol, additional research is needed to understand the link between ordinal–scaled and ratio–scaled measures.

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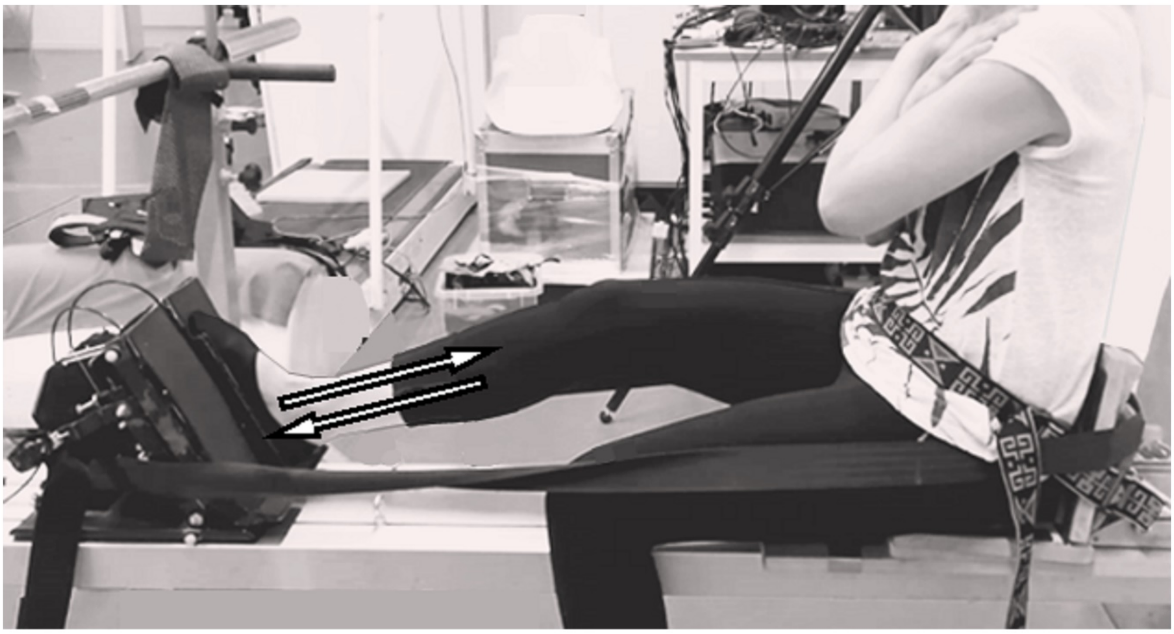

Figure 1. The isometric leg strength test with white arrows indicating the direction of force. Leg push (left–pointing arrow) and leg pull (right–pointing arrow) isometric leg strength were measured with force transducers installed in the footrest. The foot was strapped onto the footrest when performing the pull.

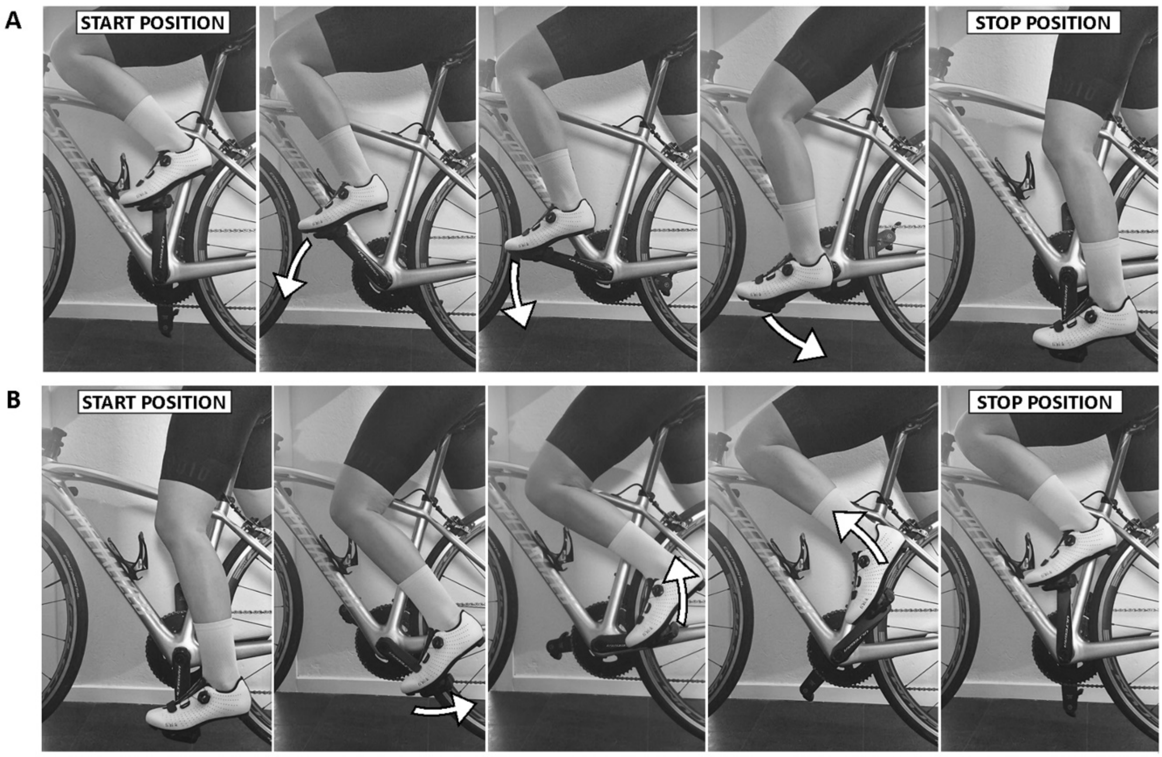

Figure 2. The dynamic leg strength tests, white arrows indicating the direction of force. A: Dynamic push, in which the pedal is pushed from a dead start from top to bottom position of one pedal revolution. B: Dynamic pull, in which the pedal is pulled from a dead start from bottom to top position of one pedal revolution.

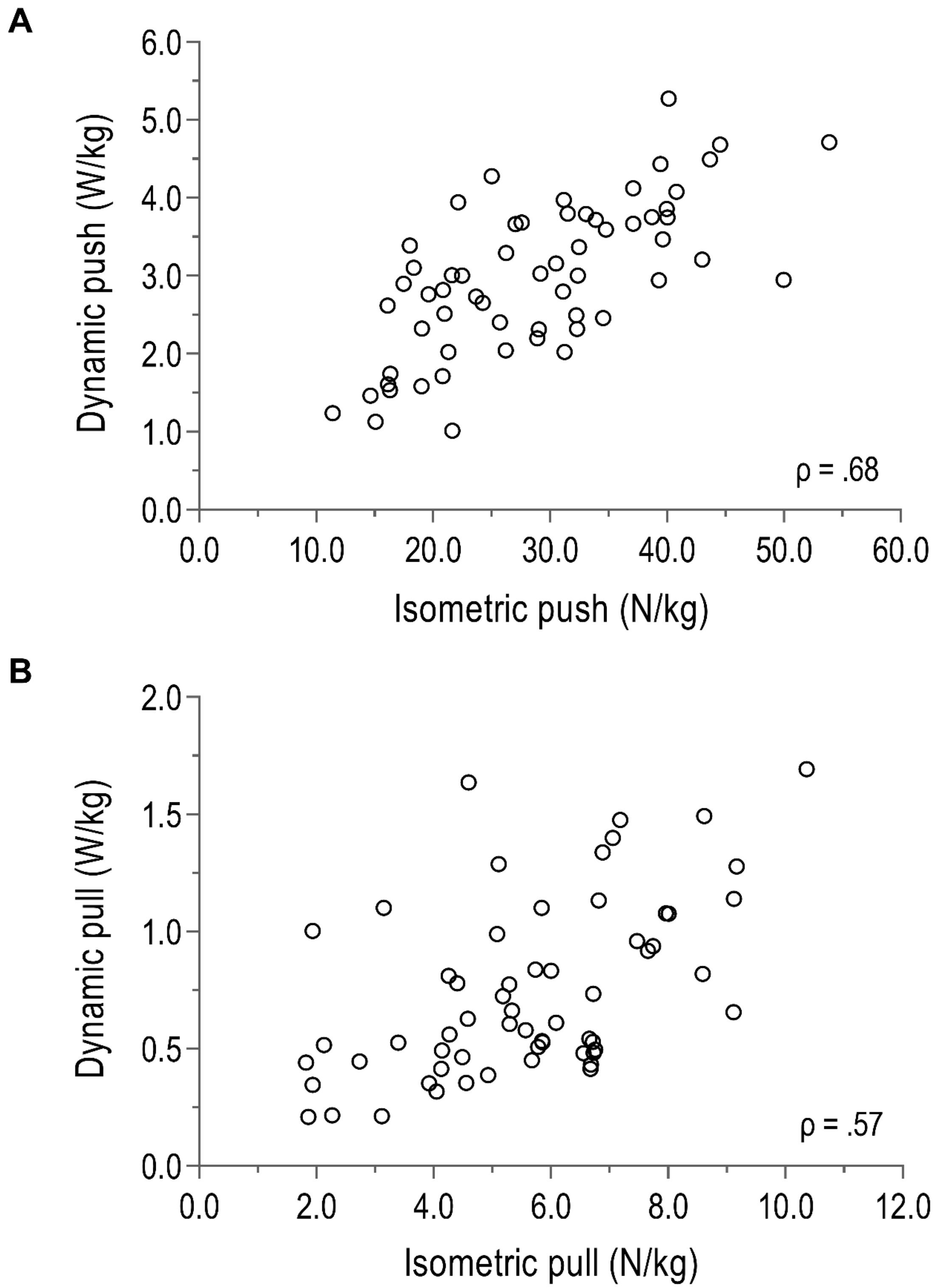

Figure 3. Scatterplots presenting the relationship between isometric and dynamic push (A) and isometric and dynamic pull (B) (n = 56).

Table 1. Participant characteristics expressed in mean ± standard deviation.

Characteristics	Male, n = 44	Female, n = 12	Total, n = 56
Age (years)	32.6 ± 9.5	28.7 ± 8.9	31.7 ± 9.4
Height (cm)	175.9 ± 7.8	161.6 ± 6.8	172.8 ± 9.6
Body mass (kg)	67.5 ± 9.2	55.1 ± 6.3	64.9 ± 10.0
BMI (kg/m^2)	21.8 ± 2.0	21.1 ± 1.4	21.6 ± 1.9
Competitive experience[a] (years)	5.2 ± 5.9	3.7 ± 3.8	4.9 ± 5.5
Training level[b] (hours/week)	16.1 ± 5.5	16.2 ± 5.3	16.1 ± 5.5
Class	Male (n)	Female (n)	Total (n)
C1	3	0	3
C2	16	4	20
C3	10	2	12
C4	10	2	12
C5	5	4	9

[a]On international level.

[b]Self–reported.

[c]No other amputation types than transtibial and transfemoral amputations were represented in the data set.

Table 2. Association of MMT (0-30 points) with the isometric (N/kg) and dynamic (W/kg) strength tests assessed with hierarchical multiple linear regression analyses (n = 21, cases excluded list–wise).

Dependent variable	**Independent variables**	**R^2 adj.**	**B**	***p*–value**
Isometric push	Sex		−12.42	.001
	MMT push	.49*	1.21	.004
Isometric pull	Sex		−0.70	.032
	MMT pull	.21	0.07	.075
Dynamic push	Sex		−0.80	.441
	MMT push	.35*	0.46	.002
Dynamic pull	Sex		−0.44	.022
	MMT pull	.28*	0.05	.041

*Statistically significant results ($p < .05$).
Abbreviations: B = Beta, R^2 adj. = Coefficient of multiple determination.

Table 3. Association of the isometric (N/kg) and dynamic (W/kg) strength tests with the performance measures PO_{mean} (W/kg) and race speed (km/h), assessed with hierarchical multiple linear regression analyses (n = 54, cases excluded list–wise).

Dependent variable	**Independent variables**	**R^2 adj.**	**B**	***p*–value**
POmean	Sex		−0.27	.655
	Isometric push	.35*	0.12	.000
POmean	Sex		−0.65	.233
	Isometric pull	.16*	0.35	.003
POmean	Sex		−0.23	.619
	Dynamic push	.41*	1.24	.000
POmean	Sex		−0.11	.835
	Dynamic pull	.32*	2.73	.000
Dependent variable	**Independent variables**	**R^2 adj.**	**B**	***p*–value**
Race speed	Sex		−3.64	.002
	Event1		−2.51	.037
	Event3		−4.94	.000
	Event4		−3.88	.004
	Isometric push	.41*	0.15	.007
Race speed	Sex		−4.22	.000
	Event1		−3.14	.014
	Event3		−5.42	.000
	Event4		−4.32	.003
	Isometric pull	.38*	0.52	.040
Race speed	Sex		−3.33	.002
	Event1		−1.69	.131
	Event3		−4.06	.002
	Event4		−2.88	.018
	Dynamic push	.50*	2.12	.000
Race speed	Sex		−3.26	.007
	Event1		−1.89	.115
	Event3		−4.13	.003
	Event4		−3.25	.012
	Dynamic pull	.43*	3.98	.004

*Statistically significant results ($p < .05$).
Abbreviations: B = Beta, R^2 adj. = Coefficient of multiple determination.