Submitted: 28 October, 2024 Accepted: 24 January, 2025 Published: 30 April, 2025 DOI:10.22514/jomh.2025.053

JOMH
Journal of Men's Health

ORIGINAL RESEARCH

The predictive effect of well trained elite men road cyclists' anthropometry values and strength endurance on climb time trial performance

Esra Kürkcü Akgönül[1], Gökmen Özen[2,*], Tarkan Havadar[3], Ali Coşkun[4], Metin Özlü[3]

[1]Physical Education and Sport, Necat Hepkon Sport Science Faculty, Dokuz Eylul University, 35000 Izmir, Türkiye
[2]Physical Education and Sport, Sport Science Faculty, Canakkale Onsekiz Mart University, 17000 Canakkale, Türkiye
[3]Physical Education and Sport, Sport Science Faculty, Kafkas University, 36000 Kars, Türkiye
[4]Bayramiç Vocational School, Sport Science Faculty, Canakkale Onsekiz Mart University, 17000 Canakkale, Türkiye

***Correspondence**
gokmenozen@comu.edu.tr
(Gökmen Özen)

Abstract

Background: Cycling performance is primarily determined by endurance, with both lower and upper extremity muscle strength having a decisive impact on race performance. No studies have examined the relationship between strength values and field performance, especially in elite level male road cyclists. The aim of this study was to explore and the relationship between anthropometric values, strength endurance and climb time trial (TT) performance in elite male road cyclists. **Methods**: A total of 36 male road cyclists volunteered to participate (age: 21 ± 2 year, height: 175 ± 3 cm, weight: 70 ± 4 kg; body fat ratio: 8 ± 2%). The athletes underwent five visits: for demographic data collection, height and body weight measurements, body composition analysis, strength assessment (plank, push-up, pull-up, squat, barbell curl) and a TT test. **Results**: The results of multiple linear regression analysis revealed a statistically significant prediction formula, showing that plank duration and push-up repetitions could predict hill TT performance time ($r = 0.66$ and $r^2 = 0.44$ (t (2, 33) = 13.099, $p < 0.001$) and average cycling speed at ($r = 0.69$ and $r^2 = 0.48$ levels (t (2, 33) = 9.149, $p < 0.001$). However, no significant prediction formula was found for the anthropometric parameters (body weight, body fat ratio, muscle mass, bone mineral content, total body water, muscle mass ratio). Anthropometric values were not predictive of hill TT duration (t (2, 33) = 2.132, $p = 0.070$) and average speed (t (2, 33) = 1.519, $p = 0.297$). **Conclusions**: In conclusion, the duration of plank and push-up endurance movements are significantly related to hill time trial performance and these exercises serve as predictors for cycling performance.

Keywords

Cycling; Elite men; Endurance; Exercise physiology; Performance; Strength

1. Introduction

Cycling performance is fundamentally based on endurance [1, 2], with both lower and upper extremity muscle strength having a decisive effect on race performance. Strength training during the pre-season general preparation period improves cycling endurance performance. Incorporating strength training into the training regimen of elite, well-trained cyclists may positively impact time trial performance. However, the mechanisms underlying this improvement in the race performance, particularly in time trials, remain unclear [3, 4]. Generally, cyclists tend to priortize enduarnce over muscle strength; however, high levels of muscle strength are especially required for explosive power, sprinting, short-term maximum efforts and balance [4, 5]. The strength of the knee, hip ankle flexor and extensor muscles, which play a functional role in pedal dynamics, is effective for the torque applied to the pedals [6]. In cycling, upper extremity strength is also important as it supports the lower extremities. Upper extremity strength is important in cycling because it supports the lower extremities. Studies have shown that the strength of the arm and shoulder joint muscles are related to performance in tasks involving the use of arm and shoulder muscles, such as handling the handlebars, navigating obstacles, and making turns. While the arm and shoulder muscles control the handlebars, developed abdominal and back muscles are necessary to support the arm muscles, which in turn support the leg muscles [7].

In recent years, many studies have investigated the effects of strength training on cycling performance [8–10]. One such study reported that adding strength training to ongoing endurance training may increase muscle-tendon system stiffness; however, tendon stiffness is likely to develop only up to an individual optimal value, beyond which muscle-tendon stiffness may be advantageous [8]. One of these studies reported that the addition of strength training to ongoing endurance training may improve endurance performance, accompanied by delayed activation of type II fibers or improved muscle-tendon stiffness [8]. Another review study found that endurance athletes improved their time trial performance and economy when they did strength training; therefore, it was suggested that strength training should be added to the program to improve economy, muscle strength and performance [9]. Similarly, a review of studies on running, cycling, cross-country skiing and swimming athletes supported strength training in addition to medium or long-distance training for the purpose of improving movement economy and maximum power [10]. Studies have reported that high-intensity strength training with 4–12 repetitions added to cycling training increases performance [3, 11, 12]; whereas, short-term, low-volume strength training is not effective in enhancing performance [13–15]. Considering that high-intensity strength training positively influence cycling economy of elite-level road cyclists after prolonged maximal cycling performance [16], it can be inferred that strength development also positively affects performance. Supporting this hypothesis, Silva *et al.* [17] reported that strength training produced acute improvements in 20 km time trial performance. Based on this evidence, it is believed that both strength levels and muscle endurance positively impact cycling performance.

It is believed that in sports requiring high physiological strain on both the lower and upper extremities, depending on the specific discipline, maintaining optimal body composition and developing motor skills are essential for performing movements at an elite level—correctly, efficiently and successfully. In particular, due to the positive effect of strength, it is necessary to strengthen the muscles needed for the movements specific to each [12]. Aagaard *et al.* [18] found that increasing strength through maximum strength training with 5–12 repetitions improved the 45-min time trial (TT) performance of amateurs cyclists. Individual time trial races are a type of competition in which athletes race alone on a track, aiming to cover a specified distance in the shortest possible time, requiring maximum performance from the cyclist. The best performance in a time trial may vary depending on the course profile, slope conditions and strategic performance. During time trials, athletes must generate high power output to complete the specific distance in the shortest possible time. In this context, field-based tests are considered more important than laboratory-based tests for monitoring performance changes, as they are easier, more economical and more practical than laboratory tests. In this context, it is thought that field-based tests as well as laboratory-based tests will provide important data in monitoring performance changes. Field tests are mostly conducted with time trials at different durations or distances [18, 19].

Studies have shown that anthropometric characteristics of cyclists such as weight and fat-muscle ratio may differ depending on whether they are climbers, sprinters or time trialists [19, 20]. From a general perspective, cycling requires endurance; explosive power is important for winning sprint competitions, aerobic endurance is crucial for climbing and maximum oxygen capacity is critical for time trials [4, 6]. Thus, it can be stated that physical and anthropometric characteristics are significantly effective for specific performances such as time trials in cycling. In different studies on the subject, it has been reported that anthropometric characteristics such as height, body weight, fat ratio and leg length are factors that have a positive effect on running economy and running performance [21–23]. However, the number of studies examining the relationship between anthropometric characteristics and cycling performance remains relatively low.

Various studies have investigated the relationship between anthropometric, aerobic and anaerobic variables and time trial performance [19–22], with most focusing on physiological responses. Among these studies, Antón *et al.* [19] reported that flat road time trial performance in elite cyclists was related to absolute maximum workload and anthropometric variables; climbing time trial performance was related to body weight, normalized power and anthropometric variables. Bentley *et al.* [20] reported that the relationship between maximum power obtained as a result of incremental testing and power output at the lactate threshold in sub-elite cyclists may vary depending on the length of the TT. Davison *et al.* [21] reported that relative mean power in simulated climbing time trial testing and Wingate performance in competitive cyclists were related. Costa *et al.* [22] showed that there are significant relationships between 10 km hill climbing performance and laboratory test results, specifically relative maximal oxygen uptake (VO_{2max}–$Watt_{max}$) values. Although studies have mostly focused on physiological responses and the effects of strength training on performance; the relationship between strength endurance and time trial performance in elite-level cyclists has not been examined. Additionally, scientific findings in the literature suggest that the cyclists' performance in outdoor races may differ from their performance in indoor races. It has been noted that environmental factors such as weather, ground and slope conditions significantly affect cyclists' cadence and workload. Research has demonstrated that cyclists exert higher efforts during time trial races compared to group stages. Therefore, analyzing laboratory tests, indoor race performances, and outdoor time trial performances conducted outside of group stages is essential for a comprehensive performance analysis of elite cyclists. The necessity for such studies has been emphasized in existing literature on this topic [23–27]. Therefore, the purpose of the study was to examine the relationship between anthropometric values, strength endurance and climb time trial performance in elite men road cyclists. The findings obtained from this research will contribute to the literature for a clearer analysis of the relationship between physical performance parameters and competition performance in road cycling. The hypothesis of the study is: "There is a relationship between strength values and individual time trial performance of elite male road cyclists".

2. Materials and methods

2.1 Participants

Ethical approval was received for the research from Çanakkale Onsekiz Mart University Graduate Education Institute, Scientific Research and Publication Ethics Committee. Participants were selected from volunteer cyclists who do cycling sports individually and in sport clubs. A total of 36 elite male road cyclists (age: 21 ± 2-year, height: 175 ± 3 cm, weight: 70 ± 4 kg; body fat ratio: 8 ± 2%) who are racing at national and international competitions, voluntarily participated in the research in 2024. Participants only do strength training at the beginning of the season. This research was conducted at the beginning of the season. Therefore, although the participants are accustomed to strength training, the participants do not have a recent history of strength training. Criteria for inclusion; having been participating in competitions for at least two years, having a cycling license, being between 19–29 years of age and volunteering to participate in the study. Criteria for not being included in the study are; having been racing for less than two years, having any health problems, being under the age of 19 or older than the age of 29, not volunteering or not having a cycling license. G-power 3.1 (G*Power Version 3.1.0, Franz Faul, Düsseldorf, NRW, Germany) analysis program was used to calculate the sample size in the study; it was calculated that the sample size should be at least 31 people for 85% power, effect size f^2 0.35 and 95% confidence interval. The sample selection was made from tier 4 (elite/international) athletes according to the participant classification framework flowchart. 36 volunteer cyclists over the age of 18 who met the participation criteria were informed about the study and allowed to participate in the study. In the study, the "correlational research" method was used to reveal whether there is a relationship between the variables and, if so, the direction and level of the relationship.

2.2 Data collection tools

In the study, participants were informed and introduced about the test environment, tools and protocols before the tests and applications. The athletes participating in the research had five visits in Fig. 1. At the first visit, demographic information was collected, and height, body weight and body composition analysis were measured. Strength measurements were performed on second and third visits. In the second visit, plank, push-up, pull-up and at the third visit squat, barbell curl measurements were taken. 8 min of active rest was given between measurements in the day. On the fourth visit, climb time trial, and on the fifth and last visit, the flat time trial was conducted. A 72-hour recovery period was allowed between all visits. Before coming to visit, participants were directed to not do heavy exercise for 48 hours, should not consume food or beverages containing caffeine, alcohol, *etc.*, should not disrupt their sleep patterns and sleep for at least eight hours, and should not change their diet programs between the visits.

2.2.1 Body height measurement

The height of the athletes participating in the study was recorded by measuring the distance between the top of the head and the sole of the feet after a deep inspiration, with the head upright, and after a deep breath, with a stadiometer (Seca, Germany) with a sensitivity level of 0.01 m.

2.2.2 Body composition analysis

Body weight and body composition measurements were determined with the Inbody 170 Bioelectrical Impedance (BEI) analyzer (Biospace LTD, Seoul, South Korea). The BEI analysis, which was performed with a device that operates in the range of 5–250 k/Hz and has 8 electrodes, was performed with the participants wearing only shorts and T-shirts. During the measurement, all participants were asked to remove all metal objects. After the athletes got on the device, age, gender and physical activity level were entered into the computer, following which hand electrodes were attached to the athlete from both sides and measurements were made for approximately 10 seconds with the arms opened to the sides at 30°. Participants were advised to refrain from eating and drinking at least four hours before measurement. Following the analysis, the athletes' body weight (BW), muscle mass (MM), bone mineral content (BMC), total body water (TBW), body mass index (BMI) and body fat ratio (BFR) values were recorded.

2.2.3 Strength measurements

In measuring the strength values of the athletes, first warmed up with 10 min jogging and after that 3 min static stretching and 2 min they had the movement, without weight. Participants had 15 min warm up in total. 8 min rest periods were given between all exercise tests. Plank (PLA); the maximum time, athlete could stand in the push-up position, with elbows on the floor and at a 90-degree angle, ankles at a 90-degree angle and the body parallel to the ground, was recorded. Push-up (PSP); stand face down, parallel to the ground, with your arms open shoulder-width apart. It is an up and down movement of the body with the arms, and each movement is done for two seconds concentrically and eccentrically. Pull-up (PLP); the bar is held above the head by jumping upwards with the palms facing forward. It is a movement of pulling the body up with the arms flexed, with the hands positioned slightly wider than shoulder width and the feet intertwined. Squat (SQ); it is a squatting movement with the feet shoulder-width apart, the body upright, and the knees at a 90-degree angle. Athletes repeated the movement, with a bar weighing 50 kg in total, for two seconds eccentrically and two seconds concentrically, until exhaustion. Barbell Curl (BC); feet shoulder-width apart, a total of 40 kg barbell is used with elbow flexion, two seconds of concentric and two seconds of eccentric contraction, and the movement is repeated until the athlete is exhausted. The maximum number of repetitions, for PSP, PLP, SQ, BC movements, athletes could perform was recorded.

2.2.4 Time trial (TT) performance measurements

Before the tests, the athletes were allowed to warm up for 20 min at low intensity at the cadence they determined and at the end of the tests they were allowed to cool down at low intensity for 10 min. The tests are against time; TT tests were carried out in accordance with race procedures. Accordingly, the athletes' starting times were planned the day before and notified to each one, and each athlete started with a one-min interval. In time trials, athletes started at the starting time and raced individually against the clock to get to the finish line as quickly as possible. The time between the athletes' crossing of the starting and finishing lines was recorded; average speeds were calculated according to distance and time. During the tests, the air temperature was between 15–18 °C and the humidity rate was measured as 68%. Hill test length is 7.7 km, the total elevation is 680 meters and the average slope of 6%. Cyclists started their tests at an altitude of 104 m above sea level and ended at an altitude of 784 m.

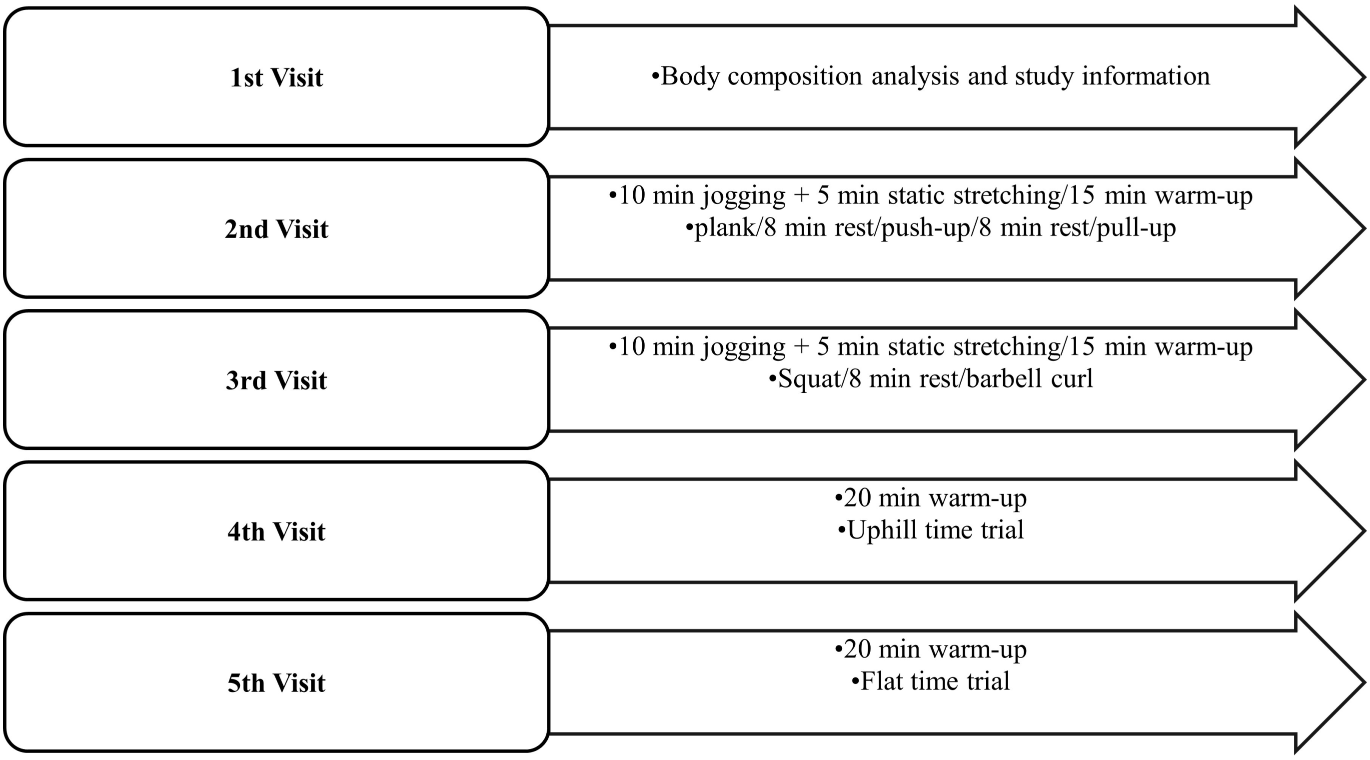

FIGURE 1. Study design and protocol process.

2.3 Data analysis

SPSS 22.0 (IBM SPSS Statistics, Chicago, IL, USA) package program was used for statistical analysis of the data obtained in the study. In the analysis of the data, mean ± standard deviation (M ± Sd), minimum (min) and maximum (max) values were calculated from descriptive statistics. In the study, normality analyzes of the distribution of the data were evaluated with the "Shapiro-Wilk" test. "Multiple Linear Regression" analyzes were performed to determine the effect and predictive power of the participants' strength (plank, push-up, pull-up, squat and barbell) test parameters on the 7.7 km hill time trial (TT) time and average speed. In the regression analysis, the plank, push-up, pull-up, squat and barbell strength parameters and anthropometric values were accepted as predictors by using the stepwise selection method and the 7.7 km hill TT time and average speed were considered as dependent variables. The significance level in statistical analysis was accepted as $p < 0.05$.

3. Results

Descriptive data on the general anthropometric characteristics of the participants, 7.7 km hill TT duration, and strength performance test results are presented in Table 1.

As a result of multiple linear regression in Table 2, a statistically significant prediction formula was developed to determine the effect and predictive power of participants' strength test parameters (plank, push-up, pull-up, squat and barbell) on 7.7 km hill TT race duration, (t (2, 33) = 13.099, $p < 0.001$). Using this prediction formula, it was determined that plank duration and push-up repetition could predict 7.7 km hill TT performance duration at $r = 0.66$ and $r^2 = 0.44$ levels. 7.7 km TT duration (min) = 42.058 − (0.011 × Plank (s) − (0.205 × Push-up (rep)).

In Table 3, as a result of multiple linear regression analyses conducted to determine the effect and predictive power of participants' strength (plank, push-up, pull-up, squat and barbell) test parameters on 7.7 km hill TT performance average speed, a statistically significant prediction formula was obtained (t (2, 33) = 9.149, $p < 0.001$). According to this formula, it was determined that plank duration and push-up repetitions could predict 7.7 km hill TT performance average speed at $r = 0.69$ and $r^2 = 0.48$ levels. 7.7 km TT average speed (km/h) = 10.932 + (0.004 × Plank (s) + (0.084 × Push-up (rep)).

In Table 4, multiple linear regression analyses performed to determine the effect and predictive power of the participants' anthropometric measurement and calculation parameters of height, BW, BFR, MM, BMC, TBW and MMR on the 7.7 km hill TT average duration did not reveal a statistically significant regression formula (t (2, 33) = −2.132, $p = 0.070$). As a result of the analyses, it was seen that these anthropometric parameters were not predictive of 7.7 km hill TT average duration performance.

In Table 5, multiple linear regression analyses applied to estimate the effect and predictive power of the participants' anthropometric measurement and calculation parameters of height, BW, BFR, MM, BD, TBW and MMR on the 7.7 km hill TT average speed, no statistically significant prediction formula was derived (t (2, 33) = 1.519, $p = 0.297$). According to multiple linear regression analyses, it was determined that these anthropometrics are not estimate of the 7.7 km hill TT average speed.

TABLE 1. Descriptive statistics of participant's physical characteristics and performance parameters.

Variables	Min	Max	Mean ± Sd
Age (yr)	19	26	21.39 ± 2.29
Height (cm)	160	181	175.25 ± 3.34
Body weight (kg)	58.0	76.6	70.48 ± 4.53
Body fat ratio (%)	5.04	12.80	8.45 ± 2.37
Muscle mass (kg)	49.50	64.50	59.54 ± 4.20
Bone mineral content (Ib)	2.60	3.40	3.12 ± 0.21
Total body water (%)	59.70	67.00	63.51 ± 1.96
Muscle mass ratio (%)	0.83	0.90	0.87 ± 0.02
Plank (s)	60	960	312.86 ± 251.23
Push-up (n)	19	65	32.17 ± 10.62
Pull-up (n)	2	45	10.36 ± 7.86
Squat (n)	27	231	73.44 ± 39.14
Barbell (n)	7	37	19.00 ± 8.42
TT average duration (min)	19	26	21.39 ± 2.29
TT average speed (km/h)	9.42	18.25	14.54 ± 2.28

n: repetition; Sd: Standard deviation; TT: Time trial; Min: minimum; Max: maximum.

TABLE 2. Multiple linear regression analysis of hill TT duration and strength parameters.

Predictor	B	SE	β	t	p	r	r^2	SEE
	42.058	3.211	-	13.099	<0.001**			
Plank (s)	−0.011	0.004	−0.447	−2.805	0.009**	0.66	0.44	4.798
Push-up (n)	−0.205	0.083	−0.368	−2.475	0.019*			
Pull-up (n)	−0.197	0.114	−0.261	−1.720	0.096			
Squat	0.014	0.024	0.093	0.595	0.556		N.S.	
Barbell	0.080	0.110	0.114	0.732	0.470			

**: $p < 0.05$; **: $p < 0.01$; N.S.: Non significant; SE: Standart error; SEE: Standart Error of the Estimated; B: Unstandardized Beta; β: Standardized Beta.*

TABLE 3. Multiple linear regression analysis of hill TT average speed and strength parameters.

Predictor	B	SE	β	t	p	r	r^2	SEE
	10.932	1.195	-	9.149	<0.001**			
Plank (s)	0.004	0.001	0.461	−2.765	0.005**	0.69	0.48	1.785
Push-up (n)	0.084	0.031	0.390	−2.409	0.011*			
Pull-up (n)	0.068	0.043	0.234	1.598	0.121			
Squat	−0.004	0.009	−0.067	−0.441	0.663		N.S.	
Barbell	−0.044	0.041	−0.161	−1.076	0.290			

**: $p < 0.05$; **: $p < 0.01$; N.S.: Non significant; SE: Standart error; SEE: Standart Error of the Estimated. B: Unstandardized Beta; β: Standardized Beta.*

4. Discussion

The study found that while the exhaustion time in plank and push-up movements predicted the hill performance of male cyclists, the exhaustion time in pull-up, barbell and squat movements was not predictive. The plank exercise is believed to influence time trial performance because it is a movement that activates the core region. By strengthening the core muscles, athletes can better perform movements that require coordination, balance and technical skills; because although the core muscles stabilize the spine and pelvis, they also transfer energy to the extremities [28]. From another perspective, it can be concluded that the role of the abdominal, chest and shoulder muscles, which connect the lower extremities to the upper extremities, is important in uphill climbing. This connection may explain why the push-up movement also predicts time trial

TABLE 4. Multiple linear regression analysis of hill TT average duration and anthropometric parameters.

Predictor	B	SE	β	t	p	r	r^2	SEE
	−1638.360	768.35	-	−2.132	0.070	0.77	0.59	2.009
Height (cm)	0.038	0.241	0.084	0.16	0.878			
BW (kg)	4.093	5.793	10.147	0.707	0.503			
BFR (%)	13.405	5.688	14.351	2.357	0.051			
MM (kg)	−4.232	6.929	−8.027	−0.611	0.561			
BMC (Ib)	−11.718	22.398	−1.117	−0.523	0.617			
TBW (%)	1.086	1.158	0.965	0.938	0.379			
MMR (%)	1708.61	865.41	17.058	1.974	0.089			

SE: Standart Error; SEE: Standart Error of the Estimated; BW: Body Weight; BFR: Body Fat Ratio; MM: Muscle Mass; BMC: Bone Mineral Content; TBW: Total Body Water; MMR: Muscle Mass Ratio; B: Unstandardized Beta; β: Standardized Beta.

TABLE 5. Multiple linear regression analysis of 7.7 km hill average speed and anthropometric parameters.

Predictor	B	SE	β	t	p	r	r^2	SEE
	1013.830	425.99	-	1.519	0.297	0.77	0.60	1.114
Height (cm)	−0.010	0.133	−0.040	−0.077	0.941			
BW (kg)	−2.239	3.212	−9.833	−0.697	0.508			
BFR (%)	−8.200	3.154	−15.556	−2.600	0.035			
MM (kg)	2.362	3.842	7.938	0.615	0.558			
BMC (Ib)	5.506	12.418	0.930	0.433	0.671			
TBW (%)	−0.574	0.642	−0.904	−0.894	0.401			
MMR (%)	−1028.43	479.81	−18.192	−2.143	0.069			

SE: Standart Error; SEE: Standart Error of the Estimated; BW: Body Weigth; BFR: Body Fat Ratio; MM: Muscle Mass; BMC: Bone Mineral Content; TBW: Total Body Water; MMR: Muscle Mass Ratio; B: Unstandardized Beta; β: Standardized Beta.

performance. Supporting this, previous studies have primarily focused on physiological responses and the effects of strength training on cycling performance. However, there is limited data available showing the relationship between maximal cycling performance and strength parameters. From the available studies, Cesanelli *et al.* [29] showed that one-year of strength and conditioning training had beneficial effects on cycling performance indicators. There was a relationship between functional threshold power (FTP), lactate threshold (LTR) and one repetition maximum (1 RM) and body composition, and especially the threshold power value corresponding to relative power was strongly related to body mass and BMI. Since the hill time trial performance used in the current study lasted over 20 min at the maximal level, it can be said that it has similar characteristics to the functional threshold power and lactate threshold test. In this context, the relationship between the strength parameter and TT performance observed in the current study aligns to the findings of the study by Cesanelli *et al.* [29]. Bentley *et al.* [20] reported that the relationship between the maximum power value obtained as a result of the incremental test and the power value at the lactate threshold and the TT performance in sub-elite level cyclists may vary depending on the length of the TT. In the literature, it has been reported that the average power value in the simulated climbing time trial test is related to the average power value in the Wingate test result in competitive cyclists [21] and that there is a significant relationship between 10 km hill climbing performance and relative VO_{2max}–W_{max} values [22]. Power output is widely accepted as one of the best reliable physiological indicators for evaluating time trial test performance. In this respect, it can be expected that the relationship between the plank and push-up strength performance (in terms of time) and average speed as the time trial performance variable in our study would also correlate with power output. However, as a power meter was not used in the current study, this relationship could not be directly demonstrated. This limitation highlights an area for improvement in future studies and underscores the importance of including power measurement for a more comprehensive analysis.

Similar results have been obtained in literature studies that support our findings. Støren *et al.* [30] revealed that power, strength and anthropometric variables were not related to TT laboratory performance in competitive male cyclists. Consistent with this, our study found no predictive relationship between anthropometric parameters and race performance. It is notable that in cycling, time trial tests mostly focus on physiological parameters. The relationship between physiological parameters and performance may result differently depending on the track length and even the slope. In this regard, it can be argued that the characteristics of track used for TT performance testing particularly its length must be carefully considered as these factors could influence research outcomes. For senior men, where race lengths typically exceed 150 km and stages often include climbs of 10 km or more in hilly segments, our study's use of a 7.7 km course or a 24–25 min uphill TT can be considered reasonable. Although physiological parameters are a limitation in the current study, it is worth noting that the selected course length aligns well with the demands of such hilly stages.

Competitive performance in cycling is affected by anthropometric, biochemical, biomechanical, aerodynamic, psychological and environmental factors. Body composition is considered an important factor in competitive cyclists. Previous studies have indicated a relationship between anthropometric values and competition level for road cyclists competing at the best levels [31, 32]. Studies show that anthropometric values are important in cyclists performing at an elite level. Given this, future studies should investigate physical characteristics related to hill time trial performance. Studies have shown that anthropometric characteristics of cyclists such as weight and fat-muscle ratio may differ depending on whether they are climbers, sprinters or time trialists [33, 34]. From a general perspective, cycling requires endurance; explosive power is important for winning sprint competitions, aerobic endurance is crucial for climbing, and maximum oxygen capacity is critical for time trials [4, 6]. Thus, it can be stated that physical and anthropometric characteristics are significantly effective for specific performances such as time trials in cycling. In different studies on the subject, it has been reported that anthropometric characteristics such as height, body weight, fat ratio and leg length are factors that have a positive effect on running/cycling economy and cycling performance [35–37]. However, the number of studies examining the relationship between anthropometric characteristics and cycling performance remains relatively low. In this study, it was concluded that anthropometric values of cyclists competing in elite men category did not predict hill time trial performance.

There are several literature studies showing that anthropometric characteristics such as skinfold thickness, body fat ratio and body mass are related to race performance in endurance athletes such as swimmers, road cyclists, mountain bikers, runners and triathletes [38, 39]. It has been reported that body mass is related to race performance in road cyclists in particular, but this relationship is not valid in ultra-distance male road cyclists [39]. Knechtle and colleagues [39], who examined the relationship between anthropometry, training volume and performance in triathletes, found that body fat percentage and total race time were significantly related in male athletes; however, there was no relationship in female athletes. As a result of this research, they revealed that the relationship between body fat percentage, training volume, and race performance is genetically determined. Anton and colleagues [19] reported that climbing time trial performance in elite level cyclists was related to body weight, normalized power and anthropometric variables. While most literature studies suggest that there is a relationship between anthropometry and maximal performance in cyclists, the current study found no relationship. This discrepancy is likely due to the fact that the athletes participating in our study were at an elite level and their physical and physiological characteristics were close to each other, as well as low and homogeneous fat mass and percentages.

In amateur mountain bikers, incremental laboratory tests have shown that there is a relationship between exhaustion time and body mass (BM) and free fat mass (FFM) [40]. Since the slope is steeper and fluidity is lower in mountain bikes, pedaling and maintaining cadence are less economical than on road bikes. In this context having less body mass, including lower fat mass, may be considered an advantage. Supporting this notion, another study reported that the body weights of elite mountain bikers are related to upper extremity maximum muscle strength; and BMI is related to shoulder, trunk and leg maximum strength [41]. Based on these results, while BM is considered an important parameter in evaluating strength performance in mountain bikers, the current study found that anthropometric values do not correlate with strength endurance in male road cyclists. These results suggest that the effect of BM on lower or upper extremity strength in men road cycling provides less advantage than in mountain biking. However, in order to obtain clearer results on this subject, the relationship between 1 RM values and anthropometric characteristics in road cyclists should be examined.

It is believed that in sports requiring high physiological strain on both the lower and upper extremities, depending on the specific discipline, maintaining optimal body composition and developing motor skills are essential for performing movements at an elite level—correctly, efficiently and successfully. In particular, due to the positive effect of strength, it is necessary to strengthen the muscles needed for the movements specific to each [41]. Aagaard *et al.* [18] found that increasing strength through maximum strength training with 5–12 repetitions improved the 45-min time trial (TT) performance of amateurs cyclists. In a study conducted on elite female road cyclists regarding strength and anthropometric characteristics, it was concluded that there was a significant and moderate relationship between right and left hand-grip strength and biceps muscle and wrist circumference [42, 43]. Since hand-grip strength generates power from the wrist and biceps muscles, it is expected that the characteristics of these regions will be related. Applying a similar logic to the current study, considering that the waist, abdomen and shoulder regions support the leg and hip muscles during hill climbing, it is an expected result that plank, and push-up movements would be related to the level of strength endurance. On the other hand, the fact that there is no relationship in pull-up, barbell and squat movements may have resulted in the athletes being at an elite level, being a homogeneous group, not doing plank and push-up movements in routine training; but doing squat, barbell and pull-up movements in the winter season brings previously acquired strength and therefore there is no significant relationship. Future studies could benefit from including criteria whether or not participants engage in specific strength training, which could provide clearer results.

Although our study revealed findings that will make important contributions to the literature, some limitations were also identified. First, this study only examined the effect of anthropometric and strength parameters on race performance in elite men cyclists and is therefore limited to male and female athletes in young or other categories. Additionally, the strength training experience of the athletes was not determined. Additionally, the cyclist's individual strength training frequency and training routine were not taken into account prior to this research. Conducting new analyses that addresses these limitations will further enrich the literature in future studies.

5. Methodological considerations and practical implications

Time trial and strength tests can be used as evaluation criteria in decision-making processes such as talent or national team selection for elite cyclists. However, it may not be practical to apply these evaluations frequently throughout the season due to the high number of race days at the elite level. Since field-based tests are easier to apply for performance observation, they are both economical and time-efficient for coaches and athletes. The results of this research have revealed valuable evidence regarding the relationship between general strength and cycling time trial performance, and plank and push-up movements are related to hill time trial performance. On the other hand, it was found that squat, barbell and pull-up movements are not related to time trial performance. It is suggested that field-based tests for cyclists should be further explored and other related parameters should be identified. In addition, although the participants had a strength training background, their focus on strength training only at the beginning of the season may have had an effect on the results. Therefore, it is recommended that this study be conducted with athletes who do strength training throughout the season and have a higher level of training consistency, and the results should be compared to assess any differences.

6. Conclusions

The main result of this study is that the plank and push-up movements from the strength parameters are related to the exhaustion time and the hill time trial performance and can serve as predictive factors. This study only examined the effect of anthropometry and strength parameters on race performance in elite men cyclists. Factors that could affect performance, such as training intensity, motivational elements before and during the climbing test and nutrition, were not included in the study. Therefore, it is suggested that the observed effect and effect size can be strengthened by employing multiple regression modeling in future studies. The participation of male cyclists in the elite level and adult category in international grand tours and competitions is accepted as having developed the high aerobic power and related muscle strength required for climbing. Based on the results of this research, movements requiring whole body strength such as "Plank" and upper extremity strength such as "Push-up" can be considered as performance predictors for road bike climbing performance in the elite men category. These parameters should also be taken into consideration in talent selection within the subcategories.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on request from the corresponding author.

AUTHOR CONTRIBUTIONS

EKA and GÖ—design; writing–original draft preparation; conceptualization the research study. TH and MÖ—software; validation; resources; supervision. GÖ and AC—formal analysis; data curation; visualization. EKA, AC and GÖ—writing–review and editing. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

For the research, ethical approval was received from "Canakkale Onsekiz Mart University Graduate Education Institute Scientific Research Ethics Committee" with the decision numbered 12/23 on 22 August 2024 and the study was carried out in accordance with the 2008 Principles of the Declaration of Helsinki. Consent forms were obtained from the participants.

ACKNOWLEDGMENT

We would like to thank all participants who contributed to the research.

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Bláfoss R, Rikardo J, Andersen AØ, Hvid LG, Andersen LL, Jensen K, *et al*. Effects of resistance training cessation on cycling performance in well-trained cyclists: an exploratory study. The Journal of Strength & Conditioning Research. 2022; 36: 796–804.
[2] Röthlin P, Wyler M, Müller B, Zenger N, Kellenberger K, Wehrlin JP, *et al*. Body and mind? Exploring physiological and psychological factors to explain endurance performance in cycling. European Journal of Sport Science. 2023; 23: 101–108.
[3] Schumann M, Feuerbacher JF, Sünkeler M, Freitag N, Rønnestad BR, Doma K, *et al*. Compatibility of concurrent aerobic and strength training for skeletal muscle size and function: an updated systematic review and meta-analysis. Sports Medicine. 2022; 52: 601–612.
[4] Ozen G. Investigation of the influence of elite mountain cyclists' physical and physiological characteristics on field performance parameters. 1st edn. Efeacademy Publishing: Istanbul. 2019.
[5] Sachet I, Brochner Nygaard NP, Guilhem G, Hug F, Dorel S. Strength capacity of lower-limb muscles in world-class cyclists: new insights into the limits of sprint cycling performance. Sports Biomechanics. 2023; 22: 536–553.
[6] Holliday W, Theo R, Fisher J, Swart J. Cycling: joint kinematics and muscle activity during differing intensities. Sports Biomechanics. 2023; 22: 660–674.
[7] Hurst HT, Swarén M, Hébert-Losıer K, Ericsson F, Sinclair J, Atkins S, *et al*. Influence of course type on upper body muscle activity in elite cross-country and downhill mountain bikers during off road downhill cycling. Journal of Science and Cycling. 2012; 1: 2–9.
[8] Rønnestad BR, Mujika I. Optimizing strength training for running and

cycling endurance performance: a review. Scandinavian Journal of Medicine Science in Sports. 2014; 24: 603–612.

[9] Beattie K, Kenny IC, Lyons M, Carson BP. The effect of strength training on performance in endurance athletes. Sports Medicine. 2014; 44: 845–865.

[10] Berryman N, Mujika I, Arvisais D, Roubeix M, Binet C, Bosquet L. Strength training for middle- and long-distance performance: a meta-analysis. Internatonal Journal Sports Physiology Performance. 2018; 13: 57–63.

[11] Vikmoen O, Rønnestad BR. A comparison of the effect of strength training on cycling performance between men and women. Journal of Functional Morphology and Kinesiology. 2021; 6: 29.

[12] Bompa TO, Buzzichelli C. Periodization of strength training for sports. 4th edn. Human Kinetics Publisher: Champaign, IL. 2021.

[13] Giessing J, Eichmann B, Steele J, Fisher J. A comparison of low volume "high-intensity-training" and high volume traditional resistance training methods on muscular performance, body composition, and subjective assessments of training. Biology of Sport. 2016; 33: 241–249.

[14] Bastiaans JJ, Van Diemen AB, Veneberg T, Jeukendrup AE. The effects of replacing a portion of endurance training by explosive strength training on performance in trained cyclists. European Journal Applied Physiology. 2001; 86: 79–84.

[15] Psilander N, Frank P, Flockhart M, Sahlin K. Adding strength to endurance training does not enhance aerobic capacity in cyclists. Scandinavian Journal of Medicine Science in Sports. 2014; 25: e353–e359.

[16] Rønnestad BR, Hansen EA, Raastad T. Strength training improves 5-min all-out performance following 185 min of cycling. Scandinavian Journal of Medicine Science in Sports. 2011; 21: 250–259.

[17] Silva RA, Silva-Júnior FL, Pinheiro FA, Souza PF, Boullosa DA, Pires FO. Acute prior heavy strength exercise bouts improve the 20-km cycling time trial performance. The Journal of Strength & Conditioning Research. 2014; 28: 2513–2520.

[18] Aagaard P, Andersen JL, Bennekou M, Larsson B, Olesen JL, Crameri R, *et al*. Effects of resistance training on endurance capacity and muscle fiber composition in young top-level cyclists. Scandinavian Journal of Medicine & Science in Sports. 2011; 21: e298–e307.

[19] Antón MM, Izquierdo M, Ibanez J, Asiain X, Mendiguchía J, Gorostiaga EM. Flat and uphill climb time trial performance prediction in elite amateur cyclists. International Journal of Sports Medicine. 2007; 28: 306–313.

[20] Bentley DJ, McNaughton LR, Thompson D, Vleck VE, Batterham AM. Peak power output, the lactate threshold, and time trial performance in cyclists. Medicine & Science in Sports & Exercise. 2001; 33: 2077–2081.

[21] Davison RC, Swan D, Coleman D, Bird S. Correlates of simulated hill climb cycling performance. Journal of Sports Sciences. 2000; 18: 105–110.

[22] Costa VP, Pertence LC, Paton CD, De Matos DG, Martins JAN, De Lima JRP. Physiological correlates of 10-km up-hill cycling performance in competitive cyclists. Journal of Exercise Physiology. 2011; 14: 26–33.

[23] Jeffries O, Waldron M, Patterson SD, Galna B. An analysis of variability in power output during indoor and outdoor cycling time trials. International Journal of Sports Physiology and Performance. 2019; 14: 1273–1279.

[24] Blake OM, Wakeling JM. Muscle coordination during an outdoor cycling time trial. Medicine Science Sports Exercise. 2012; 44: 939–948.

[25] Pallares JG, Hernández-Belmonte A, Valenzuela PL, Muriel X, Mateo-March M, Barranco-Gil D, *et al*. Field-derived maximal power output in cycling: an accurate indicator of maximal performance capacity? International Journal of Sports Physiology and Performance. 2022; 17: 1558–1564.

[26] Nimmerichter A, Eston R, Bachl N, Williams C. Effects of low and high cadence interval training on power output in flat and uphill cycling time-trials. European Journal of Applied Physiology. 2012; 112: 69–78.

[27] Jobson SA, Nevill AM, Palmer GS, Jeukendrup AE, Doherty M, Atkinson G. The ecological validity of laboratory cycling: does body size explain the difference between laboratory- and field-based cycling performance? Journal of Sports Sciences. 2007; 25: 3–9.

[28] Chok S. Effects of 8 weeks core strength training on core muscle strength among young male cyclists. Malaysian Journal of Movement, Health & Exercise. 2020; 9: 9–16.

[29] Cesanelli L, Ammar A, Arede J, Calleja-González J, Leite N. Performance indicators and functional adaptive windows in competitive cyclists: effect of one-year strength and conditioning training programme. Biology of Sport. 2022; 39: 329–340.

[30] Støren Ø, Ulevåg K, Larsen MH, Støa EM, Helgerud J. Physiological determinants of the cycling time trial. The Journal of Strength & Conditioning Research. 2013; 27: 2366–2373.

[31] Leo P, Spragg J, Mujika I, Menz V, Lawley JS. Power profiling in U23 professional cyclists during a competitive season. International Journal of Sports Physiology and Performance. 2021; 16: 881–889.

[32] Knechtle B. Relationship of anthropometric and training characteristics with race performance in endurance and ultra-endurance athletes. Asian Journal of Sports Medicine. 2014; 5: 73–90.

[33] Impellizzeri FM, Ebert T, Sassi A, Menaspa P, Rampinini E, Martin DT. Level ground and uphill cycling ability in elite female mountain bikers and road cyclists. European Journal Applied Physiology. 2008; 102: 335–341.

[34] Menaspà P, Rampinini E, Bosio A, Carlomagno D, Riggio M, Sassi A. Physiological and anthropometric characteristics of junior cyclists of different specialties and performance levels. Scandinavian Journal of Medicine & Science in Sports. 2012; 22: 392–398.

[35] Sánchez-Muñoz C, Mateo-March M, Muros JJ, Javaloyes A, Zabala M. Anthropometric characteristics according to the role performed by World Tour road cyclists for their team. European Journal of Sport Science. 2023; 23: 1821–1828.

[36] Sitko S, Cirer-Sastre R, López-Laval I. Time to exhaustion at estimated functional threshold power in road cyclists of different performance levels. Journal of Science and Medicine in Sport. 2022; 25: 783–786.

[37] Lucia A, Esteve-Lanao J, Olivan J, Gomez-Gallego F, San Juan AF, Santiago C, *et al*. Physiological characteristics of the best Eritrean runners–exceptional running economy. Applied Physiology Nutrition and Metabolism. 2006; 37: 1231–1236.

[38] Phillips KE, Hopkins WG. Determinants of cycling performance: a review of the dimensions and features regulating performance in elite cycling competitions. Sports Medicine. 2020; 6: 23.

[39] Knechtle B, Wirth A, Baumann B, Knechtle P, Rosemann T, Oliver S. Differential correlations between anthropometry, training volume, and performance in male and female Ironman triathletes. The Journal of Strength & Conditioning Research. 2010; 24: 2785–2793.

[40] Arriel RA, Graudo JA, Oliveira JLDD, Ribeiro GGS, Meireles A, Marocolo M. The relative peak power output of amateur mountain bikers is inversely correlated with body fat but not with fat-free mass. Motriz Journal of Physical Education. 2020; 26: e10200034.

[41] Boyraz OC, Kürkcü Akgönül E, Ozen G. Investigation of the relationship between anthropometric characteristics and muscular strength in elite Turkish mountain bikers. Human Sport Medicine. 2022; 22: 61–69.

[42] Sanders D, Taylor RJ, Myers T, Akubat I. A field-based cycling test to assess predictors of endurance performance and establishing training zones. The Journal of Strength & Conditioning Research. 2020; 34: 3482–3488.

[43] Kürkcü Akgönül E. Investigation of relationship between lower and upper extremity strength, flexibility and anthropometric values of well trained female road cyclists. Meditarrenean Journal of Sport Science. 2023; 6: 711–725. (In Turkish)

How to cite this article: Esra Kürkcü Akgönül, Gökmen Özen, Tarkan Havadar, Ali Coşkun, Metin Özlü. The predictive effect of well trained elite men road cyclists' anthropometry values and strength endurance on climb time trial performance. Journal of Men's Health. 2025; 21(4): 68-76. doi: 10.22514/jomh.2025.053.