Experimental Study on Speed Fatigue Time Relationship Model in Wheelchair Racing Athletes

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Abstract

Wheelchair racing originated from the rehabilitation movement of wounded soldiers after World War II. It is a sport that requires high aerobic ability of athletes. Critical power theory is an evaluation method to evaluate the aerobic capacity of human body. At present, a large number of studies have used the critical power model to predict the training effect, sports performance and sports potential of athletes in different sports (such as swimming, cycling, rowing, etc.), and achieved a certain prediction effect. At the same time, the advantage of using critical power theory to evaluate athletes' aerobic ability is that the test process is convenient and simple, and the test process will not cause any harm to athletes. In the current research, there is a lack of direct research on the speed fatigue time relationship model of wheelchair racing athletes through the critical power theory. The purpose of this study is to investigate the effectiveness of establishing the critical speed model by using six full-strength exercise tests with different constant speeds (80%, 85%, 90%, 95%, 100%, 105% of the speed at exhaustion in the exhaustion speed test); Evaluate the application of these different critical speed models in wheelchair racing; The prediction effect of the parameters obtained from the six exercise tests on the subjects' actual exercise performance of 5000m, as well as the formulation of 5000m competition strategy and training plan were observed.

Keywords

Critical Speed; Anaerobic Working Ability; Speed Fatigue Time Relationship; Maximum Speed; Wheelchair Racing.

1. Introduction

Wheelchair racing originated after the Second World War. It is a sport gradually carried out by veterans injured in the war in order to promote rehabilitation and improve their self-confidence caused by physical disability[1]. It officially became a Paralympic event in 1964. After more than 70 years of development, wheelchair racing has become one of the sports with the highest participation rate of the disabled. Wheelchair racing events are periodic physical events dominated by the force of the upper limbs[2]. Athletes have some problems, such as lack of lower limb function, muscle atrophy, spinal cord injury, nerve coordination and control ability disorder and so on[3]; Athletes need to participate in sports with the help of racing wheelchair. At the same time, the project has high requirements for athletes' aerobic ability[4].

The proposal of critical power theory provides people with a new evaluation method of aerobic capacity[5]. At present, a large number of studies have used the critical power model to predict the training effect, sports performance and sports potential of athletes in different sports (such as swimming, cycling, rowing, etc.)[6], and achieved a certain prediction effect[7]. According to the research of physics, power can be converted with speed. Therefore, some researchers convert the

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critical power model into the critical speed model in order to make the experimental test process more convenient, and prove that its prediction effect is consistent with the critical power model[8].

In the current research, there is a lack of direct research on the speed fatigue time relationship model of wheelchair racing athletes through the critical power theory. According to the critical power (speed) theory, the mathematical model is used to describe the relationship between athletes' speed and fatigue time, which can quantitatively evaluate athletes' aerobic and anaerobic sports ability, provide accurate indicators for wheelchair racing coaches in formulating long-distance wheelchair racing strategies, and formulate corresponding training plans for different athletes. There are three different critical velocity models, including two parameter hyperbolic model, three parameter hyperbolic model and three parameter exponential model. In this paper, wheelchair racing events and critical power theory will be comprehensively summarized, so as to provide wheelchair racing coaches, athletes and researchers with a more systematic understanding of wheelchair racing events and critical power theory.

2. Research Objects and Methods

2.1 Research Objects

There are 10 active T54 male wheelchair racing athletes, including one with Paralympic experience, seven with international competition experience and two with national competition experience. Before the test, the basic information of all subjects was interviewed. The average age of all subjects was 25.30 ± 4.10 years, the weight was 60.8 ± 5.34kg, the sitting height was 60.80 ± 1.60cm, the number of years of injury was 22.60 ± 6.31 years, and the age of exercise was 7.20 ± 2.89 years. See table for details. In addition, before the test, all subjects have been informed of the whole test process, requirements and existing risks, and signed the informed consent form.

2.2 Research Methods

2.2.1. Time Test

1500m and 5000m timing exercise tests were carried out on the plastic track and field. The test purpose of 1500m is the initial speed value in the activity increment test, and the test purpose of 5000m is to obtain the actual value of 5000m sports performance and compare it with the predicted values of different models.

Test steps:

The subjects did not perform any vigorous exercise within 24 hours before the test;

Before the test, the subjects shall warm up for 15 minutes at their own intensity;

Record the athletes' final sports performance.

Test instrument: stopwatch.

2.2.2. Exhaustion Rate Test

Test steps:

The subjects first performed 15 minutes of self selected intensity preparation activities until the athletes sweated;

After the preparation activity, sit still in the wheelchair for 5 minutes. During this period, the subjects began the test after wearing the heart rate belt. In order to ensure the normal operation of the instrument and the accuracy of test data, the instrument shall be calibrated in strict accordance with the manufacturer's requirements before the test. During the test, the equipment will not bring changes in movement amplitude or other discomfort when it is carried on the athlete's back;

The initial speed is set to 85% of the test speed of 1500m, i.e. 21.5km/h. Every two minutes, the athlete is prompted to increase 1km / h until the athlete reaches exhaustion. The test speed of the final stage completed by the athlete is the subject's exhaustion velocity (exhaustion velocity = EV).

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Athletes can use the real-time speed display on the racing wheelchair to detect and control speed. During the test, coaches and researchers kept giving oral encouragement and tips to the subjects. The test is terminated if the subject stops with fatigue or the subject cannot maintain the given speed for more than 5 seconds.

2.2.3. Constant Speed Test

Subjects: T54 male wheelchair racing athletes of a team.

Exercise mode: perform six full-strength exercises at different speeds on the wheelchair racing car. Preset exercise speed: Six constant speeds are set to 80%, 85%, 90%, 95%, 100% and 105% of the speed (EV) at exhaustion.

Test indexes: exercise performance, heart rate immediately after exercise, blood lactic acid.

2.2.4. Maximum Speed Test (Vmax)

Sports mode: conduct the maximum speed test (Vmax) of 100m between travel on the wheelchair racing car.

Test index: maximum speed.

2.3 Statistical Method

Data processing the CV and AWC obtained by different formulas (formulas 1, 2 and 3) in the two parameter model were analyzed by spss22 statistical software. The significant difference was set as $P < 0.05$. Bonferroni multiple comparison method was used for multiple comparison test. For the comparison between models, according to gaesser et al., the formula of "real" hyperbolic relationship between speed and time (formula 1) is the standard formula of the traditional two parameter model. Two way ANOVA was used to compare Formula 1 with formula 4 and formula 5. The data processed in this way can evaluate the potential interaction between the effects of different models and different test speeds. In formula 1-5, 6 sets of CVs and AWC obtained through constant speed test are used to predict the fatigue time and speed of 5000m test. After setting the test distance of 5000m, the fatigue time is calculated by using the formula. The predicted value is compared with the actual value by using the linear regression in SPSS.

3. Results

Consult the literature on critical power at home and abroad, and refer to the papers and books on sports physiology, sports training and sports biochemistry to understand the application of critical power theory in different sports and the development process of wheelchair racing mobilization at home and abroad. According to the characteristics of wheelchair racing, power can be converted into speed, work into distance, and critical power into critical speed[9][10]. In this paper, the speed fatigue time (V-T) relationship model of wheelchair racing athletes will be established according to the formula of critical speed[11]. The formula is as follows:

$$T=AWC/(V-CV) \tag{1}$$

$$D=T\times V+AWC \tag{2}$$

$$V=CV+AWC\times(1/T) \tag{3}$$

$$T=AWC/(V-CV)-AWC/(Vmax-CV) \tag{4}$$

$$V=CV+(Vmax-CV)\times e-t/tau \tag{5}$$

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Formulas 1, 2 and 3 are two parameter models, and formulas 4 and 5 are three parameter models.

3.1 Results of Time Test, Exhaustion Speed Test and Maximum Speed Test

Table 1 shows the test results of time test, exhaustion speed test and maximum speed test. Through the exhaustion speed test, it is obtained that the speed (EV) of the subject at exhaustion is 9.72 ± 0.31m/s, and through the maximum speed test, it is obtained that the maximum speed of the subject is 10.13 ± 0.53m/s; Through the time test experiment, the average speed of 1500m is 6.90 ± 0.49m/s, and the average speed of 5000m is 8.66 ± 0.26m/s.

Table 1. Results of time test, exhaustion speed test and maximum speed test

variable	Mean±SD
Exhaustion speed (M / s)	9.72±0.31
maximum speed (M / s)	10.13±0.53
5000m average speed (M / s)	8.66±0.26
1500m average speed (M / s)	6.90±0.49

3.2 Changes of Test Indexes of Six Different Constant Speed Movements

Spss22 was used to analyze the results of six different speed exercise tests, heart rate immediately after exercise and blood lactate concentration after exercise. The results showed that with the increase of sports speed, the sports performance of T54 male wheelchair racing athletes decreased significantly, and the sports distance of athletes decreased significantly, that is, there were significant differences in fatigue time and sports distance after each test ($P < 0.001$); At the same time, there was significant difference in the immediate heart rate of athletes after exercise test ($P < 0.001$); After each exercise test, the blood lactate concentration of athletes increased significantly compared with that at rest, but there was no significant difference between each exercise test ($P > 0.05$). Therefore, it can be seen that the setting of six different constant speed exercise tests is in line with the rules of human exercise metabolism.

Table 2. Six different constant speed exercise test scores, exercise distance, heart rate immediately after exercise and blood lactate value after exercise

EV%	Average score (s)	Average distance (m)	Heart rate immediately after exercise (b·min-1)	Blood lactate concentration after exercise (mmol·L-1)
When quiet	-	-	-	2.33±1.36
80%	224.32±120.41	1838.19±986.73	193.70±12.70	11.06±1.33#
85%	177.71±89.59a	746.62±236.10a	189.90±9.00a	10.33±1.32a#
90%	105.45±56.55ab	893.43±479.07ab	181.70±10.68ab	10.79±1.88a#
95%	87.40±57.45abc	752.57±494.75abc	175.20±5.79abc	11.64±2.38a#
100%	73.97±41.78abcd	647.27±365.59abcd	170.50±5.05abcd	10.98±2.67a#
105%	48.87±18.56abcde	434.36±164.97abcde	167.90±10.15abcde	10.40±2.16a#
a Compared with 80%		b Compared with 85%		c Compared with 90%
a: P<0.001		b: P<0.001		c: P<0.001
d Compared with 95%		e Compared with 100%		#Compared with quiet
d: P<0.001		e: P<0.001		#: P>0.05

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3.3 The Equation Graph of Velocity Fatigue Time and the Values of Each Parameter are Obtained by Using the Two Parameter Model

Taking the measured value of a typical subject as the original test data, take the six exercise test results of 80%, 85%, 90%, 95%, 100% and 105% of the speed (EV) at exhaustion into three two parameter models respectively, and the corresponding regression equation diagram (see Figure) will be obtained. At the same time, the corresponding calculated values of CV and AWC will also be obtained.

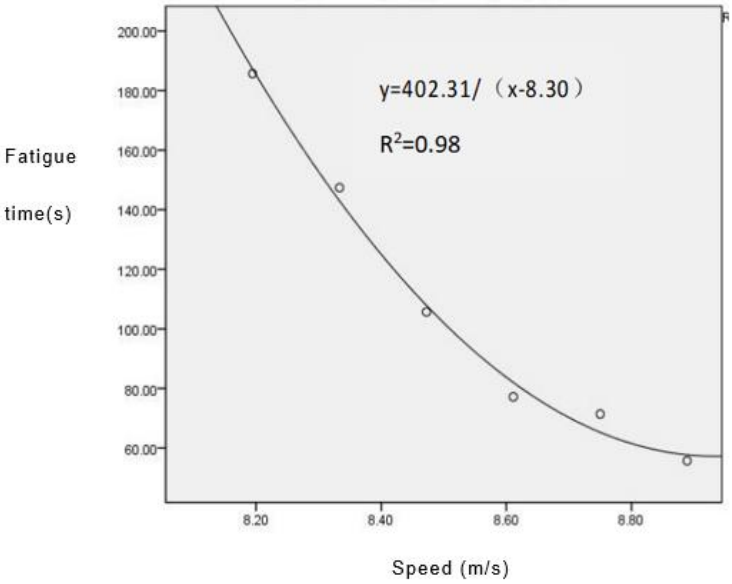

Figure 1. two parameter velocity fatigue time nonlinear relationship

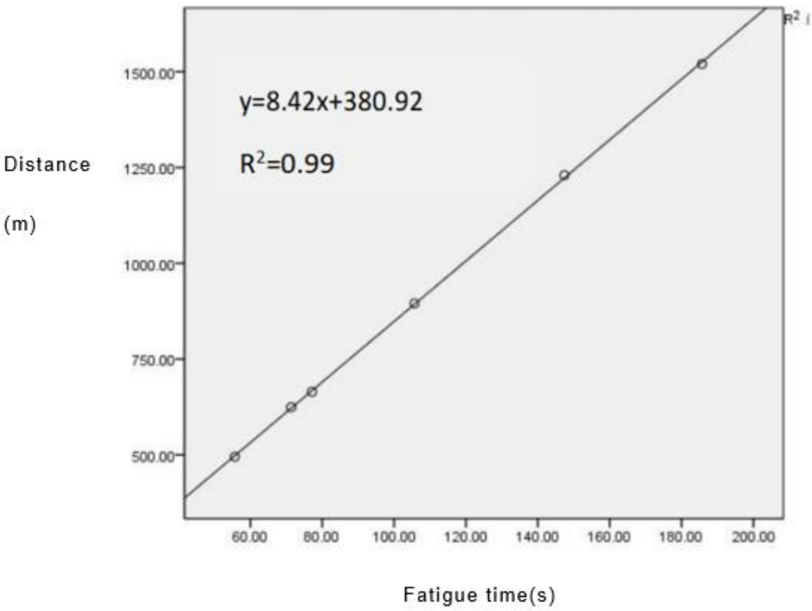

Figure 2. linear relationship between two parameter distance and fatigue time

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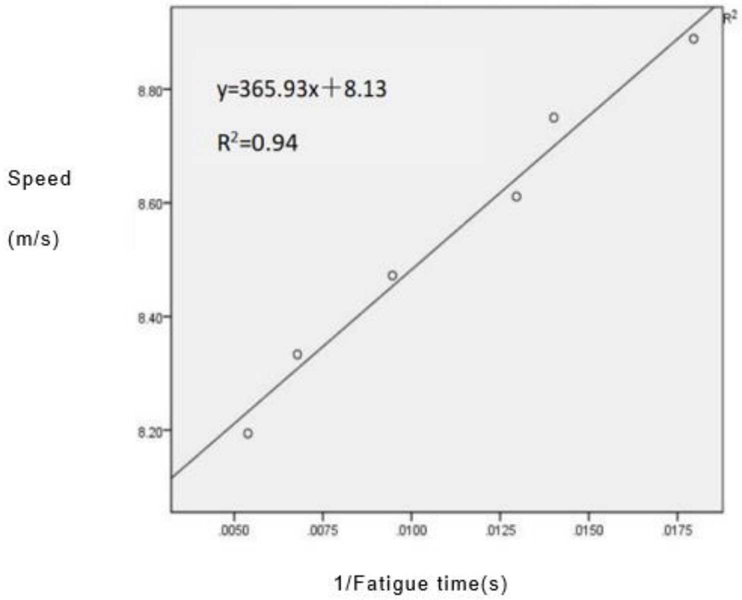

Figure 3. linear relationship between two parameter speed-1 and fatigue time

Figures 1, 2 and 3 are the two parameter speed fatigue time relationship model established based on the data of a typical subject. Figure 1 shows the nonlinear relationship between two parameter velocity and fatigue time. The goodness of fit with formula 1 is R2 = 0.97. Therefore, it can be concluded that the calculated value of CV of the athlete is 8.30m/s and the calculated value of AWC is 402.31m; Figure 2 shows the linear relationship between two parameter distance and fatigue time. The goodness of fit with formula 2 is R2 = 0.99. Through calculation, the CV of the athlete is 8.42m/s, AWC is 380.92m; Figure 3 shows the linear relationship between two parameter speed-1 / fatigue time, and the fitting degree with formula 3 is R2 = 0.94. Calculated CV = 8.13m/s, AWC = 365.93m.

3.4 Parameter Calculation Values Obtained by the Three Two Parameter Models and the Differences between the Models

Table 3. The calculated values of critical speed (CV) and anaerobic exercise capacity (AWC) obtained by three two parameter models

	CV(m/s)	SEE	r2	AWC(m)	SEE
Linear model(D-T)	8.29±3.06	0.14±0.01*	0.99±00	373.12±175.40	89.17±23.68
linear model(V-1/T)	8.34±3.02	0.25±0.07	0.94±0.33	359.71±181.70	79.50±13.86
non-linear model (V-T)	8.26±3.03	0.10±0.02*	0.97±0.02	390.42±170.23	85.11±18.73

And two parameter linear velocity-1 / fatigue time model (V-1 / T) * P < 0.05.

It can be seen from table 3 that the calculated values of CV and AWC obtained by the three two parameter models. In the distance fatigue time (D-T) model, the calculated value of CV is 8.29 ± 3.06m/s, and the standard error see = 0.14 ± 0.01; The calculated value of AWC is 373.12 ± 175.40m, and the standard error is see = 89.17 ± 23.68; In the model of linear speed-1 / fatigue time, the calculated value of CV is 8.34 ± 3.02m/s, and its standard error see = 0.25 ± 0.07; The calculated value of AWC is 359.71 ± 181.70m, and the standard error see = 79.50 ± 13.86; In the nonlinear velocity fatigue time (V-T) model, the calculated value of CV is 8.26 ± 3.03m/s, and its standard error see = 0.10 ± 0.02; The calculated value of AWC is 390.42 ± 170.23m, and its standard error is see = 85.11 ± 18.73. The calculated values of CV and AWC and goodness of fit R2 of the three two parameter models were tested for homogeneity of variance. The results showed that there was no significant difference between the calculated values of CV and AWC of the three parameter models

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(P > 0.05); The goodness of fit (R2) in linear model (V-1 / T) was significantly different from linear model (D-T) and nonlinear model (V-T) (P < 0.05).

3.5 Equation Graphs and Reference Values Obtained by Three Parameter Model and Exponential Model

Similarly, taking the test data of a typical subject as the original value, take the six exercise test results of 80%, 85%, 90%, 95%, 100% and 105% of the speed (EV) at exhaustion into the three parameter model and the exponential model respectively, and the corresponding regression equation diagram (see Figure) and the calculated values of CV and AWC will be obtained.

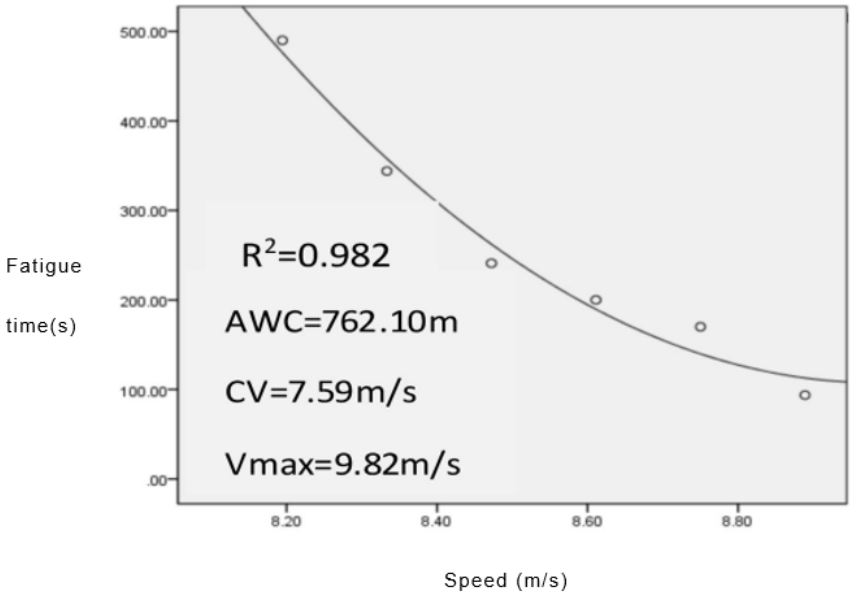

Figure 4. nonlinear relationship between speed and fatigue time of three parameters

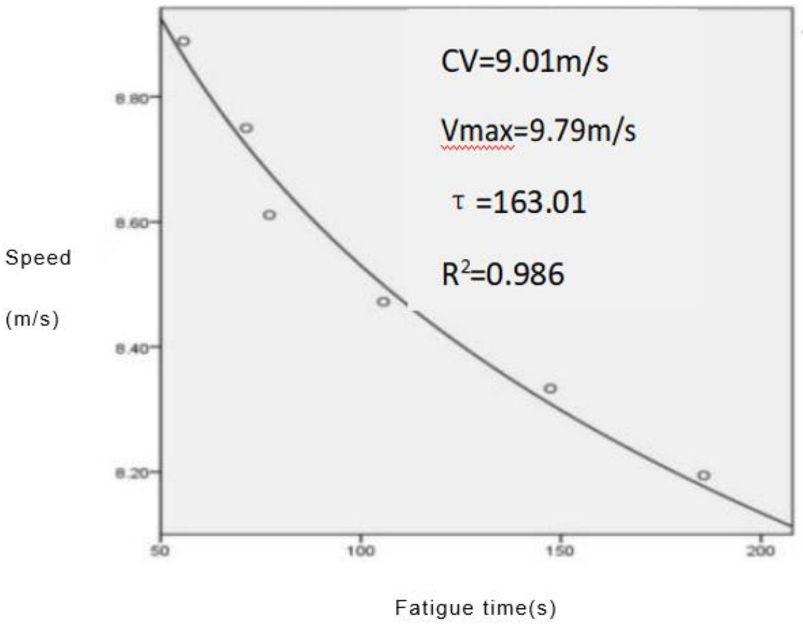

Figure 5. three parameter velocity fatigue time exponential relationship

Figures 4 and 5 are two three parameter nonlinear relationship models of speed fatigue time established based on the test data of a typical subject. Figure 4 shows the nonlinear relationship model

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of three parameter speed fatigue time. The goodness of fit with formula 4 is R2 = 0.998. Therefore, the calculated CV of the athlete is 7.59m/s. The calculated value of AWC is 762.10m, and the calculated value of Vmax (maximum speed) is 9.82m/s; Figure 5 shows the exponential relationship model of three parameter distance fatigue time. The fitting degree with formula 5 is R2 = 0.986. Through calculation, the athlete's CV = 9.01m/s, Vmax = 9.79m/s τ= 163.01.

3.6 The Calculated Values of Various Parameters in the Three Models and the Differences between the Models

Table 4. The calculated values of parameters in two parameter model, three parameter model and index model and the differences between the three models

Parameter calculation value	Two parameter nonlinear model	Three parameter nonlinear model	exponential model
CV(m/s)	8.26±3.03a	7.03±0.18b	8.92±0.54c
AWC(m)	390.42±170.23a	723.10±260.42b	-
Vmax(m/s)	-	9.63±0.42a**	9.02±0.31b**
τ	-	-	170.01±44.32
R2	0.97±0.02	0.998±0.032	0.986±0.009

The actual value of Vmax: 10.13±0.53;

a, b and c indicate that there is a significant difference between the calculated values obtained by different models, $P < 0.05$;

* * indicates the comparison with the actual value of Vmax: $P < 0.01$.

From table 4, we can clearly see that the calculated CV values of the three models are significantly different. Through the variance homogeneity test, there is a significant difference between the three models ($P < 0.05$). In addition, the AWC obtained by the two parameter model is 390.42 ± 170.23m, and the calculated value of AWC obtained by the three parameter model is 723.10 ± 260.42m, which is 2-3 times that of the two parameter model. Through one-way ANOVA, $P = 0.003 < 0.05$, it shows that the AWC obtained by the two models is significantly different. Compare the maximum velocity calculation values of formula 4 and formula 5. The maximum velocity calculation value of three parameter nonlinear model is 9.63 ± 0.42m/s, and the maximum velocity calculation value of three parameter exponential model is 9.02 ± 0.31m/s. Conduct one-way ANOVA for the two models, P = 0.027 ﹤0.05, It shows that there is a significant difference in the calculated value of the maximum speed between the two models.

3.7 Compare the Difference between the Calculated Value of V5000m and the Actual Value of V5000m between Different Models

Table 5. Compare the difference between the calculated value of v5000m and the actual value of v5000m between different models

Model	CV(m/s)		The correlation coefficient of CV	The correlation coefficient of V5000m-cal and V5000-act
Two parameter nonlinear model (V-T)	8.29±3.06	8.47±0.72	0.95	0.94
Two parameter linear model (D-T)	8.34±3.02	8.50±0.61	0.97	0.95
Two parameter linear model (V-1 / T)	8.26±3.03	8.39±0.64	0.94	0.96
Three parameter nonlinear model (V-T)	7.03±0.18	8.94±0.54	0.32	0.88
Three parameter exponential model (V-T)	8.92±0.54	8.20±0.60	0.47	0.78

The actual value of V5000m: 8.66 ± 0.26.

It can be seen from table 5 that the five models (three two parameter models, one three parameter model and one three parameter index model) correspond to formulas 1, 2, 3, 4 and 5 respectively. Through the critical power (CV), anaerobic exercise capacity (AWC), maximum speed (Vmax) and other parameters obtained by each of the five models, the average speed of 5000m of the subject is calculated, which is 8.66 ± 0.26m/s with the actual speed of 5000m of the subject, and the correlation with the critical speed (CV) is analyzed, It can be found that there is a high correlation between the calculated value of the subject's 5000m speed and the actual value (P = 0.94, 0.95, 0.96, 0.88 and 0.78 respectively); There is also a high correlation between the critical velocity obtained by the two parameter model and the actual value of 5000m velocity (P = 0.95, 0.97 and 0.94 respectively); The correlation between the critical velocity obtained by the three parameter model and the three parameter exponential model and the actual value of 5000m velocity is low (P = 0.32 and 0.47, respectively). This is consistent with the results of Laurent bosquet, Hill et al.

4. Discussion

Through the comparison of three two parameter mathematical models, this study studies the speed time relationship model of wheelchair racing athletes in field sports. Because the damage of neurophysiological system of T54 athletes will affect athletes' exercise tolerance, the feasibility of speed time relationship model and the negative impact on health.

Therefore, this study provides information on the applicability of speed time relationship in this population. Based on different mathematical models, we found differences in accuracy when comparing the three models, such as two parameter distance fatigue time linear model (R2 = 0.99), two parameter velocity-1 / fatigue time linear model (R2 = 0.94) and two parameter velocity fatigue time nonlinear model (R2 = 0.97). In general, the fitting degree of the established models is quite high, but when different models are analyzed separately, the fitting degree of all subjects in the two parameter distance fatigue time linear model is the highest (R2 = 0.99).

In previous studies, there are many studies on the accuracy of two parameter distance fatigue time model for wheelchair athletes in different events. For example, in the study of wheelchair movement on the treadmill, the model fitting degree of distance fatigue time is R2 = 0.99, and in the study of outdoor field (R2 = 0.99). The results are consistent with the results of the two parameter distance fatigue time model[12].

In addition, there is no significant difference in the CV derived from the three mathematical models. Although the three models selected in this study are equivalent to the mathematical function formula. However, according to the research of Bergstrom, nimmerichter and bull, it is found that the estimation of CV in sports models such as some sports with legs (such as bicycle, running, football, etc.) is different[13]. Using the two parameter model, we can use simple excel office software to calculate the critical speed and anaerobic exercise ability through field test. It is worth noting that in the article on the difference between the critical speed estimated by cyclists on the treadmill and on the field published by Karsten et al. In 2014, the results show that the CV value estimated in the laboratory is highly consistent with that on the field[14]. this study supports the feasibility of putting the experimental test on the field in this paper. In addition, according to the research of Muniz pumares et al., the fitting degree of the two parameter model can be proved by the low standard error of critical speed and anaerobic exercise ability. According to the research of hill, Stevens and Morgan in 2005 and 2019 respectively, the two parameter speed fatigue time model can be established through ultra-high intensity exercise (exercise duration is 2-15 minutes)[15][16].

The results of this study are as follows:

The setting of 6 exercise tests conforms to the law of human energy metabolism; There are some differences in the parameters (critical speed, anaerobic working capacity, maximum speed, etc.) obtained by different models[17];

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It is found that the calculated value of the maximum velocity (Vmax) of the three parameter nonlinear model is significantly higher than that of the exponential model ($P < 0.001$), and the calculated value of the maximum velocity (Vmax) of the two models is significantly lower than the actual maximum velocity;

There is a high correlation between the 5000m speed calculated by the two parameter, three parameter and exponential models and the actual 5000m speed (two parameter model P = 0.94, 0.95, 0.96; three parameter model P = 0.88; exponential model P = 0.78). However, in comparison, the prediction effect of the two parameter model for 5000m motion performance is better than that of the three parameter model and exponential model.

5. Conclusions and Suggestions

In this study, the speed fatigue time (V-T) model of T54 male wheelchair racing athletes can be established through six full-strength exercise tests at different constant speeds; Using the critical speed test model, we can predict the 5000m performance of T54 male wheelchair racing athletes; Using different mathematical formulas, three types of speed fatigue time relationship models (two parameter speed fatigue time nonlinear model, three parameter speed fatigue time nonlinear model and three parameter speed fatigue time exponential model) are obtained in this paper, It is found that the two parameter speed fatigue time relationship number model is better than the three parameter model in predicting the performance of T54 male wheelchair racing athletes; Through the two parameter speed fatigue time relationship model, it can provide a new means for wheelchair racing coaches to formulate the 5000 meter competition strategy and the training plan of long-distance athletes.

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