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Sprinter kinetics analysis and prediction model on hectometre scores

Mingyou Gao
Department of Physical Education, Yulin University, Yulin 71900, Shanxi, (CHINA)
E-mail: 375566733@qq.com

ABSTRACT

This study conducts dynamics analysis on acceleration phase and uniform phase of the sprint, finds that athletes whose physical condition is not dominant can compensate for this deficiency by changing angle θ between the reaction force F and the ground. Build nonlinear regression models according to the scores of the top three of the past 30 years' track and field world championships men's hectometer. The research results show that the top three time and annual of men's hectometer are in negative correlation, indicating that men's hectometer scores are steadily improving. Conduct scores forecast on the top three of the 2013 track and field World Championship men's hectometer, the performance is 9.84 seconds, 9.97 seconds and 10.01 seconds respectively. This study helps athletes to strengthen the key projects training on the basis of comprehensive training, to improve their physical fitness, and thus improve competition scores on certain degree.

KEYWORDS

Kinetic characteristics;
Nonlinear regression;
Hectometer scores;
Forecast.

INTRODUCTION

Hectometer war, especially the men's hectometer war always gets attention with the fastest speed of human sport. In recent years, coaches and athletes research on hectometer technology is getting smaller. Hectometer scores also have steadily increased. Especially with the rise of Bolt, he advanced the human limit into a new level. Each of his appearances will bring one of the biggest questions to the audience: "Can he create a new miracle?" Hectometer movement as the human extreme sports, even the 0.01 seconds upgrading is a qualitative change process. So more rationally use technical movements and accurately measure the various steps in race that may affect the performance help a lot for the performance enhancement.

In recent years, related scholars have conducted a lot of forecast research on hectometer scores, such as Prendergast once have stated whether the human speed limit exists. Peronnet got the conclusion that the limit time of men's hectometer is 9 seconds through study. By studying the data of 50 years hectometer world record, obtain that the speed to increase the sprint's performance is annually increasing about one-thousandth, also point out that there is no limit for men's hectometer speed. Seile Hazelwood even predicted the men's hectometer time of 0-5038 years, but there was a contradiction in the results. Some scholars pointed out that the Hazelwood prediction model is inaccurate through theoretical and practical research.

This study first conducts dynamics analysis on acceleration phase and uniform phase of the sprint; then

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establishes a non-linear regression model according to the 1983-2011 World Championships Men's hectometer performance and proceeds prediction on future hectometer performance. The research intends to provide guidance for the technique perfection of sprint athletes, and offer certain basis for coaches and athletes to make long-term practice plans through future performance prediction.

SPRINTER KINETIC ANALYSIS

The first step for dynamic analysis is to set parameters:

m: The mass of the athletes

g: Gravity acceleration

F: The reaction force of the ground

v_1: Velocity of buildup running when the right pawing foot leaves the ground

v_2: The instantaneous speed of buildup running when the left foot landed on the ground

v_3: Velocity of buildup running when the left pawing foot leaves the ground

l: Athletes step length

h: The highest point of the Athletes gravity center

t: Athletes flight time

k: Proportionality coefficient

Athletes get reaction force F by the ground when running. Part of this force is the motive power that makes athletes run forward, part of it applies to the height change of its center of gravity, so the direction of reaction force should oblique upward, having an angle θ with the ground. The static friction force $F_f = F\cos\theta$ namely motive force $F_\perp = F\sin\theta$. Suppose: The velocity of buildup running when the right pawing foot leave the ground is v_1; the instantaneous speed of buildup running when the left foot landed on the ground is v_2; the velocity of buildup running when the left pawing foot leave the ground is v_3. The magnitude of θ determines the athletes fight time, effect the value of v_2, finally determines the time that athletes accelerate to the maximum speed. When the athletes go through steady running and body force exertion F decreases, the speed can be reduced by changing the size of θ.

Athlete's buildup running stage:

According to energy conservation theorem

$$\frac{mv_2^2}{2}-\frac{mv_1^2}{2}=-\frac{k\left(v_1^2+v_2^2\right)}{2}l$$

$$\frac{v_1}{v_2}=\sqrt{\frac{1+k\frac{l}{m}}{1-k\frac{l}{m}}}$$

We know that $\frac{v_1}{v_2}$ and $\frac{l}{m}$ are in positive proportional relationship.

When athletes rise into the sky, he only receives the resistance; it is a deceleration phase. Because v_3 is accelerated on the basis of v_2, the athletes hope the closer v_2 to v_1 the better. The value of $\frac{l}{m}$ needs to be small and has the optimal value.

Athletes flight time $t=\sqrt{\frac{8h}{g}}$, combine with the energy conservation theorem $mgh=\frac{mv_\perp^2}{2}$, t and $F_\perp$ are in positive proportion.

In order to reduce the resistance effecting time, and $t=\frac{2l}{v_1+v_2}$, compare $\frac{l}{m}$ with the optimal value, athletes with a larger value should reduce $F_\perp$ in order to reduce the flight time, i.e. reducing the intersection angle θ. The reduction of the angle θ will lead to the increase of F_f, the increase v_3 will decrease the time that athletes need to accelerate to the maximum velocity.

Athletes on the way-ran stage $\frac{F\cos\theta-kv^2}{m}=a$,

When $v=\sqrt{\frac{F\cos\theta}{k}}$, athletes speed reaches the maximum.

After a steady running, Athletes' physical exertion

F will be reduced. Due to $F_f = F\cos\theta$, appropriately reduce θ to compensate for the decrease of F, accordingly reduce the speed decreases

FORECAST MODEL RESEARCH OF HECTOMETERS SCORES

Since relationship between the previous world best hectometers scores and time is not a linear nor some kind of simple curve relation, this study established predictive models of hectometer performance using a nonlinear regression analysis method.

Brief introduction on nonlinear regression

Nonlinear regression is a nonlinear modeling method on response and independent variables. It applies for materials that even after variable transformation still cannot be converted to linear form. The nonlinear regression model is usually expressed as:

$$Y = F(X_1, X_2, \cdots, X_m; \beta_1, \beta_2, \cdots, \beta_r) + \varepsilon$$

In the formula $X_1, X_2, \cdots, X_m$ represent the independent variable, and the number of independent variables can be one or more than one. Parameters $\beta_1, \beta_2, \cdots, \beta_p$ represent the partial regression coefficient of the model, reflecting the quantity dependency relationship of independent variables and response variables. Y is the response variable, ε is the random error term. Carry out n times' independent observation on each variable, i.e. when the sample size is n, the resulting data is:

$$(x_{t1}, x_{t2}, \cdots, x_{tm}, y_t) \quad t = (1, 2, \cdots, n)$$

Substitute the above sample into the non-linear model, we can obtain:

$$y_t = F(x_{t1}, x_{t2}, \cdots, x_{tm}; \beta_1, \beta_2, \cdots, \beta_r) + \varepsilon_t \qquad t = (1, 2, \cdots, n)$$

Independent variables and the response variables in the model are all already known variables, only partial regression coefficient is unknown, so the above model can be written as:

$$Y = F(\beta) + e$$

Wherein:

$$Y = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{pmatrix}, \quad \beta = \begin{pmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_r \end{pmatrix}, \quad \mathrm{E} = \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{pmatrix}$$

We can obtain the partial regression coefficients $\beta_1, \beta_2, \cdots, \beta_p$ using the least squares criterion, and can obtain non-linear regression model. Iterative process of the least-squares method starts from certain $\beta^{(0)}$; according to X and Y calculates Δ and selects the appropriate k, so that the following equation holds:

$$L(\beta^{(0)} + k\Delta) < L(\beta^{(0)})$$

In the next iteration use $\beta^{(0)} + k\Delta$ instead $\beta^{(0)}$, repeat the above process until the error squares sum SSE reaches the minimum. The final value of β is least squares estimate value of nonlinear regression model; then build a non-linear regression model.

There are many methods to conduct iteration using least squares estimation, such as the steepest descent method, Gauss - Newton method, Newton method, Marquardt method and DUD method. Here we only introduce the iterative process of Marquardt method.

The Marquardt method is also called the damped least-squares method, the formula is:

$$\Delta = (X'X + \lambda diag(X'X))^{-1} X'e$$

In above formula λ is damping factor. When $\lambda \to 0$, this method is the Gauss - Newton method; when $\lambda \to \infty$, that is the steepest descent method.

Usually take $\lambda = 10^{-3}$ as the initial value and calculate Δ. When $L(\beta^{(0)} + k\Delta) < L(\beta^{(0)})$, take $\lambda=\lambda/10$ to conduct next iteration; when $L(\beta^{(0)} + k\Delta) > L(\beta^{(0)})$, take $\lambda = \lambda *$ 10 to re-start iteration

Data collection

Select the top three scores of the 1983-2011 World Championship men's hectometer, the data are listed in TABLE 1.

Draw scatter chart

Draw scatter chart on time and top three scores; the results are shown in Figure 1, Figure 2 and Figure 3.

We can see from the charts above that there is no linear relationship between the annual and scores, and should use nonlinear regression to analyze.

Nonlinear regression model results

Take respectively the scores of all previous champions, runner-up and second runner-up as the response variable; take year as the independent variable. Conduct non-linear regression fit, the applied non-linear function is $y = \ln gamma(a + b * x)$, fitting results are shown in TABLE 2.

TABLE 1 : Top three scores of the 1983-2011 World Championships men's hectometer

time	champion scores	runner-up scores	third place scores
1983	10.07	10.21	10.24
1987	9.93	10.08	10.14
1991	9.86	9.88	9.91
1993	9.87	9.92	9.99
1995	9.97	10.03	10.03
1997	9.86	9.91	9.94
1999	9.8	9.84	9.97
2001	9.82	9.94	9.98
2003	10.07	10.08	10.08
2005	9.88	10.05	10.05
2007	9.85	9.91	9.96
2009	9.58	9.71	9.96
2011	9.92	10.08	10.09

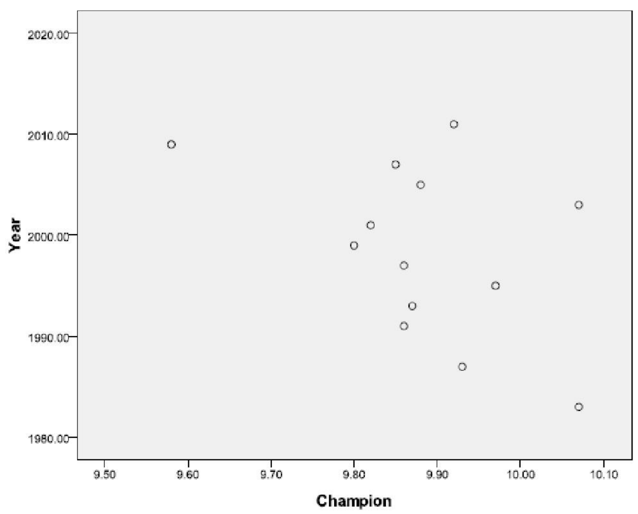

Figure 1 : Scatter chart of all previous championship scores and time

Three nonlinear regression models respectively are:

Champion: $y = \ln gamma(14.97 - 0.003x)$

Runner-up: $y = \ln gamma(14.253 - 0.003x)$

Third place: $y = \ln gamma(12.653 - 0.002x)$

As can be seen from TABLE 2, the year and hectometer time of champion, runner-up and second runner-up showed a negative correlation, indicating that as time goes on the future hectometer time will be shorter

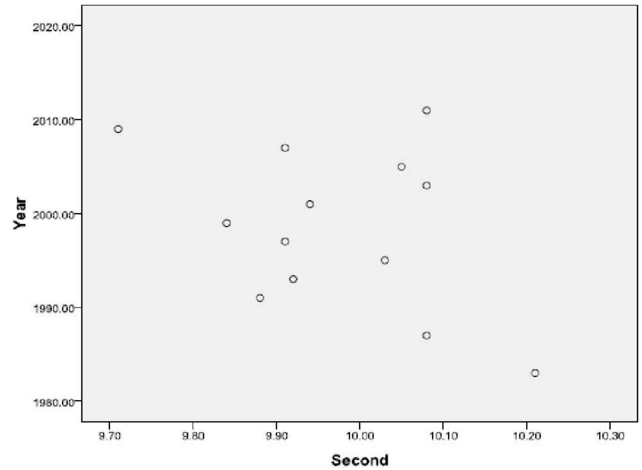

Figure 2 : Scatter chart of all previous runner-up scores and time

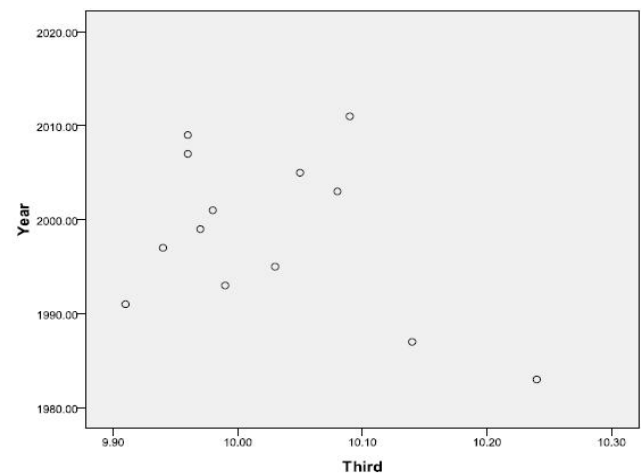

Figure 3 : Scatter chart of all previous third place scores and time

TABLE 2 : Fitting results of three nonlinear regression model

Model name	R^2	a	b
champion	0.875	14.97	-0.003
runner-up	0.832	14.253	-0.003
third place	0.837	12.653	-0.002

and shorter, i.e. men's hectometer scores will be better. Respectively use the non-linear regression model of champion, runner-up and third place to predict the performance of the top three men one hundred meters in the 2013 World Championships, calculate scores of the top three respectively are 9.84 seconds, 9.97 seconds and 10.01 seconds

CONCLUSIONS

This study conducts dynamics analysis on acceleration phase and uniform phase of the sprint. Athletes get reaction force F by the ground when running. Part of this force is the motive power that makes athletes run forward, part of it applies to the height change of its center of gravity, so the direction of reaction force should oblique upward, having an angle θ with the ground. The static friction force $F_f = F\cos\theta$ namely motive force $F_{\perp} = F\sin\theta$. Suppose: The velocity of buildup running when the right pawing foot leave the ground is v_1; the instantaneous speed of buildup running when the left foot landed on the ground is v_2; the velocity of buildup running when the left pawing foot leave the ground is v_3. The magnitude of θ determines the athletes flight time, effect the value of v_2, finally determines the time that athletes accelerate to the maximum speed. When the athletes go through steady running and body force exertion F decreases, the speed can be reduced by changing the size of θ.

Build nonlinear regression models using the scores of the top three of the past 30 years track and field world championships men's hectometer, and conduct forecast on men's hectometer scores of the 2013 track and field World Championships using the model. The results show that men's hectometer scores has steadily improved. Predicted scores of the top three of the 2013 World Championship men's hectometer is 9.84 seconds, 9.97 seconds and 10.01 seconds respectively.

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