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Different distance track events competitions' physical ability distribution and performance correlation research

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ABSTRACT

The competition of athletics track events is fierce, and sometimes the difference among opponents is less than 1/1000s, therefore reasonable strategy and tactics is very important. This paper quotes Keller's thought, according to athlete physiological status, establishes primary model. For sprint, it establishes three relations: First is the relation between impulse force and speed; Second is relations among impulse force works and two energies (one of them is the intake oxygen equal energy that generated by breathe and circulatory system through oxygen metabolism); the third is relations between speed and competition performance. Through fitting partial athletes' performance, get that it is workable to finish the full distance by maximum impulse force in 100m, 200m and can get good results. While for 400m; it is not suitable to adopt whole journey all-out sprint strategy. For middle-distance race model, through analyzing world champion tactics, find that all these athletes adopt whole journey variable-pace running tactics. It is found from advantages and disadvantages analysis that model is not the optimal one, so that put forward middle-distance race optimal strategy model.

Key words: Physical ability distribution, physiological indicator, least square method, energy conservation

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INTRODUCTION

Sprint is finish specified distance at the fastest speed, its competition events are 100m, 200m and 400m. According to records, sprint events have been already present at the 1st ancient Olympic Games held at Olympia, Greece in 776B.C. In the beginning, it adopted small stride "step style" running, start is "stand" posture. In 1887, it begun to adopt crouch start, later it got starting block that formally adopted in 11th Olympic Games in 1936. During the stage, sprint techniques have been largely evolved, which is changing from heel landing to forefoot landing and form into a kind of "swing" running. Due to improvement of sprint techniques, it propels to sprint performance rapidly improving. Sprint is human motor organ and visceral organ finish largest intensity work under lots of oxygen shortage status, it belongs to extreme intensity sports and can effectively develop speed quality that is basic event in athletics. Sprint schedule is very short, so that speed is obviously one of the important factors that affect sprint performance. Sprint technique is an inseparable totality [1, 2]. To easier analysis, it can be divided into start and after start accelerative running, midway running and finish running such 3 parts. Presently world records of 100m is 9.74s, national records is 10.17s. Middle-distance running events including 800m and 1500m, which is in great request of mixing speed, strength and endurance. On one hand, it requires reducing energy consumption as much as possible and maintaining a certain running speed; while on the other hand, it requires possessing ability of accelerative running in whole journey running according to competition status [3, 4]. Therefore, athletes correctly master techniques and make reasonable distribution of physical ability is very important in the whole journey of running. It should take relaxing and coordinated running, keep stable gravity center shift, with stronger linear and in good rhythm; it should improve muscle exertion and ability of relaxed alternating , which is strict with motions effects and also focus on physical ability saving. Technique of each distance running is basically the same. However,

due to distance and running intensity differences, there are some differences in the techniques details of running. Long-distance running is called for long race for short, which divides into 5000m and 10000m.Modern earliest formal long race competition is the professional game that has been held in London, Britain in April.5th, 1847.Long –distance running is a sports event that very helpful for body, but it may let body into extremely tired state without mastering some techniques. It must take warm-up before long-distance running, and it is crucial to master breathing during running process [5].

In recently years, our country middle-distance race competitive levels have been unprecedentedly developed, and sprint has also been developed to some extent. In the fierce competition of international game, it must get a further understanding of sprint in the quantity aspect so as to get good results in sprint. For middle-distance race , in order to get good competition ranks, except for focusing on talent selecting and scientific training, correctly and rationally make use of technology and tactics is also very important. In major competitions at home and abroad, it can found by carefully analyzing that in competition almost every high-level athletes have more than one set of strategies that conform to themselves. Therefore, solve middle-distance race strategic problems must not be overlooked.

Lu Sheng-Han, Tai Chong-Xi [1] mention in the article of‘ World men 100 meters running development tendency analysis” that normally the highest speed is in direct proportion of 100 meters running performance, most of athletes highest speeds correspond to their 100 meters performance and ranks. But for individuals, on the condition that no great difference of highest speed, highest speed is not the sole factor to get good results, except for highest speed essential conditions, it should also consider whole journey speed anti-cooperation response time and other factors. Ai Kang-Wei[2] makes research from “World excellent 100m sprint athletes speed features” get that men athletes in better performance group present stride frequency are higher , with higher speed in start acceleration 30m, larger acceleration distance and higher spur speed; Better performance women group have stronger start acceleration ability and possess of higher maximum speeds. Similar to men group result, better performance women group have longer acceleration and maximum speed stage distance, while speed endurance stage distance is relatively short. Niu Jing[3] mentions in the article of “Explore and analyze middle-distance race strategies application” that for middle-distance runners, in order to get good results in competition process, they should work out multiple tactics according to themselves features, and make trial training and summarizing on designed tactics in daily training. In competition process, it should fix their attention on opponents changes, combine active measurements counter to dynamics and resourcefulness together.

For sprint, when schedule is shorter, finish the full distance with maximum impulse force is surely can get optimal results. Therefore, it is crucial to pursuit all-out sprint distance; For middle-distance race, not only test their speed ,but also test a people endurance to greater extent, therefore adopt necessary tactics to master techniques and reasonable distribute physical ability is very important to get good results. For sprint and middle-distance race, this paper respectively establishes models and puts forward optimal scheme under theory.

KELLER SIMPLIFIED MODEL CONSTRUCTION

For running, athletes speed distribution in competition process should consider they themselves physiological statuses. To avoid biomechanical complicated problems, this paper according to Keller model, defines speed functions in schedule with 4 physiological parameters from optimal controlling perspectives.

Athletes overcome body inside and outside resistance during running process so as to achieve or keep a certain speed, which needs to bring forward impulse force into play. There are two sources that supply energy for impulse force working, one is intake oxygen equal energy that generated by breathe and circulatory system by oxygen metabolism; the other is competition usage energy that stored in body before competition. To former, it can reasonable assume that it keeps constant in competition process, while to later, it have a problem that is how to distribute stored energy into every stage of schedule and consume it just when arrive at the end .

The model needs to define three relations. First is a relation between impulse force and speed, second is relations among impulse force work and above two energy sources, the third is relations between speed and competition performance. Though competition performance refers to time used in certain schedule, it can equal to distance that ran in a certain time when use mathematical tools for handling. So optimal performance will be concluded as distance targeted speed, impulse force, stored energy and other function relative extreme value problems. Normal solution of the problem is too complicated; it can use Keller to simplify it.

From above analysis, it can see that model needs 4 physiological parameters: maximum impulse force that athletes can play, resistance index inside and outside body, energy supplied in unit time by oxygen metabolism, initial value of body stored energy. In model, these parameters can be fitted out according to athletes’ average statistical data.

Given the time that athlete's complete schedule D with speed function $v(t)$ is T, then:

$$D(v(t)) = \int_0^t v(t)dt \tag{1}$$

When D is known, determine $v(t)$ to make T arrive at the minimum, that is equal to T fixed to determine $v(t)$ so as to make D arrives at the maximum, the later question is easier to research.

Record athletes' impulse force as $f(t)$, by hypothesis 1, according to Newton's Second Law can get:

$$\dot{v}(t) + \frac{v}{\tau} = f(t) \tag{2}$$

$$v(0) = 0 \tag{3}$$

$$0 \le f(t) \le F \tag{4}$$

Record athletes' body stored energy as $E(t)$, its change rate is the difference between supplied energy σ and consumed energy fv in unit time, that is:

$$\dot{E}(t) = \sigma - fv \tag{5}$$

$$E(0) = E_0 \tag{6}$$

$$E(t) \ge 0 \tag{7}$$

In this way it construct fun-function functional extreme value problem with formula(1) $D(v(t))$ as objective functions under conditions(2)-(7), from which $F,\ \tau,\ \sigma,\ E_0$ are regarded as known parameters.

The solution of such normal model is difficult, because once optimal solution appears on the border of condition (4), (7) (From below analysis can know that it's the actual status), variation method would not be adapted any more. Besides, it combines (1), (2), (5) and get fun-functions express formula:

$$D(E(t)) = \sqrt{2}\int_0^T e^{-\frac{t}{\tau}}[\int_0^t (\sigma - \dot{E}(t))e^{\frac{2s}{\tau}}ds]^{\frac{1}{2}}dt \tag{8}$$

Formula (8) is too complicated, even use other methods to solute are also quite inconvenient. In the following, it divides Keller simplified method into two models for statement.

SPRINT MATHEMATICAL MODEL ESTABLISHMENT

When schedule is short, it can use maximum impulse force F to finish the full distance, which surely can get optimal results. As for what distance schedule can apply such method for running, it should take body stored energy $E(t)$ no less than 0 as criterion, which depends on parameters $F,\ \tau,\ \sigma,\ E_0$.

Bring $f(t) = F$ into equation (2), solution on initial condition (3) is:

$$v(t) = F\tau(1 - e^{-\frac{t}{\tau}}) \tag{9}$$

It can know that speed is increasing. Bring (9) and $f = F$ into formula (5) get:

$$\dot{E}(t) = \sigma - F^2\tau(1 - e^{-\frac{t}{\tau}}) \tag{10}$$

Solution of equation (10) under initial condition (6) is:

$$E(t) = E_0 - (F^2\tau - \sigma)t + F^2\tau^2(1 - e^{-\frac{t}{\tau}}) \tag{11}$$

From formula (10), (11) can draw $E(t)$ schematic figure (refer to Figure1), in a short time $0 \le t \le t_e$ after starting, due to speed v is very small, partial of σ make up for $E(t)$ (refers to formula(5)), so $E(t)$ increases; Then, with v quickly enlarge , $E(t)$ reduces. When $t = t_c$, $E(t) = 0$. It is easily get $t_c = t\big|_{E(t)=0}$ $t_e = t\Big|_{E(t)=0} = \tau \ln \dfrac{F^2\tau}{F^2\tau - \sigma}$, And the farthest distance that can run in this case is :

$$D_c = \int_0^{t_c} v(t)dt = F\tau^2(e^{\frac{t_c}{\tau}} + \frac{t_c}{\tau} - 1) \tag{12}$$

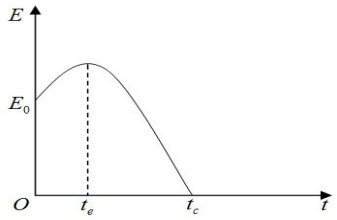

Figure 1: Body energy $E(t)$ changes schematic figure

In order to estimate parameters in model and work out t_c and D_c , use some athletes average performance (refer to Table 1) according to MATLAB program (Appendix one) to fit, From formula(12) calculated theoretical results ,get F, τ estimated values as $F \approx 11.8483\ N/\text{kg}$ (to quality $m = 1kg$) , $\tau \approx 0.8808\ s$.

Table 1- One athlete performance

x/m	10	20	30	40	50	60	70	80	90	100
t_1/s	1.84	2.86	3.80	4.67	5.53	6.38	7.23	8.10	8.96	9.83

Input F, τ into formula(11),(12)work out $t_c \approx 27.63s$, $D_s \approx 291m$. That is when distance is less than 291m ,use maximum impulse force to finish the full distance is workable and can get optimal performance(of course that is for world records creators)

MIDDLE-DISTANCE RACE MODEL ESTABLISHMENT

Through world champion relative data analysis, find out current optimal tactics and put forward new tactics, make analytic comparison with original tactics, work out new tactics speed change timing, it takes 800m, 5000m as examples.

Current middle-distance race tactics

For middle-distance race, tactics application has play an important role in middle-distance race events, whose good and bad application have directly effect on competition ranks or performances, current normal tactics are:

(1)Lead running tactics. Lead running tactics is also called “create optimal performance tactics”, it refers to a strategy method that athletes take leading position after start, distribute speeds according to appointed plan, initiative control running speed and rhythm, and keep the leading advantages to the end of competition. The running method is adapted to athletes that his training levels are obviously higher than other opponents or with good special endurance while poor speed and spurt ability. Someone also call it as “Record breakthrough method”, which refers to athletes fully play their optimal competitive ability on the condition that they possess higher strength in order to break the records. For instance, Morocco athlete Said Aouita in 1985, who created 5000m world record by whole

distance lead running, and "Oriental Magic Deer" Wang Jun-Xia adopted such tactics breaking world record.
(2)Follow running tactics. Follow running tactics is also called "shadow tactics" that is athlete closely follow behind one athlete in competition or just maintain the position which not leading, choose proper time to spurt and get expected result tactics. The tactics is adapted to athlete that he has slight difference with major opponents on competitive ability, and with higher speed and speed endurance advantages as well as possessing good competitive state and stronger willpower quality. But the tactics normally cannot get good results, because his running speed and rhythm is constrained by leader to great extent which will break his competition plan. Any carelessness might cause him being led by others and end up with failure.

(3)Varied pace running tactics. Varied pace running refers that athletes in competition according to prearranged design continuously change running speed and rhythm, fulfils expected results tactical scheme. The purpose the tactics is to disrupt opponents' competition rhythms and psychological states, increase opponents' energy consumption and tension, drag opponents down and pull them away underway so as to win the game. The tactics is adapted to athlete who is well trained in daily training, with higher energy metabolism conversion ability while total performance is a little lower. For example, in 16th Olympic Games men 10000m competition, Russian athletes F. Kurz used varied pace running drag down main competitor Pirri, and won the first prize.

(4)Steady running tactics. Steady running tactics refers that athletes in competition according to speed designed before competition, reasonable distribute physical ability, strictly follow such plan finish the full distance rhythmically. The tactics mainly is used to striving for breaking through records or creating good results. The tactics require athletes have higher self-control ability, which cannot easily be broken by opponents' competition rhythm and other conditions.

Analysis of middle-distance race tactics
Observation statistics of recent years' world athletics championship, Olympic Games and other 5 sessions' major competitions' middle-distance race top 8 athletes' tactics as Table 2, Table 3.

Table2- Men middle-distance race top 8 status

Name	KangiRah		Allengel		KangiRach		Tanui		Ruto	
Events	Split time	Time difference	Split time	Time difference	Split time	Time difference	Split time	Time difference	Split time	Time difference
200m	24"32	24"32	24"1	24"1	25"2	25"2	24"	24"	24'7	24"7
400m	50"59	24"27	51"1	27"	51"5	26"3	49"99	25"99	51"2	26"5
600m	1'16"85	26"21	1'18"	26"9	1'18"3	26"8	1'17"09	27"1	1'17"9	26"7
800m	1'43"06	24"26	1'43"45	25"5	1'43"99	25"7	1'43"30	26"21	1'44"71	26"8

Table 3- Women middle-distance race top 8 status

Name	WoodDash		WoodDash		Lunudynova		Langen		Mutola	
Events	Split time	Time difference	Split time	Time difference	Split time	Time difference	Split time	Time difference	Split time	Time difference
200m	26"9	26"9	27"1	27"1	26"8	26"8		26"1	27"3	27"3
400m	56"3	29"4	56"4	29"3	56"4	29"6	55"73	29"63	56"3	29"0
600m	1'29"	32"7	1'27"7	31"3	1'28"7	32"3	1'26"74	31"01	1'26"0	29"6
800m	1'55"26	26"3	1'56"10	28"4	1'57"50	28"8	1'55"54	28"8	1'55"43	29"4

Through analysis of current middle-distance tactics and Olympic Games athletes, it is found that lead running and follow running are not selected by most of athletes, because both lead running and follow running have something to do with opponents running speed not belongs to athletes themselves rhythms.

Through Table 2, Table 3 data can deduce that champion athletes long-distance running tactics are basically the same (therefore it can regard it as the best tactics), apply basic tactics into running, and the most quickly is the previous 200m in first stage. Athletes in order to take up the good position, take all-out sprint in first stage; while in the second ,third stage, athletes in order to maintain physical strength, run with lower speed; In fourth stage, though is extremely tired, start all-out print so as to fight for champion ranks. According to above analysis, can draw figure of speed- time as Figure 2.

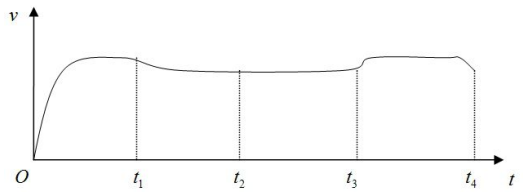

Figure 2: Long distance running speed-time figure

Analysis of the tactics: Due to all-out sprint hasn't been done in the second, third stage, athletes still maintains a certain physical strength, and then they can take all-out sprint in the fourth stage. For 800m, champion fighting is fierce, sometimes difference among opponents less than 1 second, athletes maintain physical strength for the fourth stage all-out sprint is conform to psychological features. However, the optimal strategy in running is it should consume all stored running usage energy. Now that all-out sprint still can be done in the fourth stage, it indicates that athletes still have lots of energy in body. Use such tactics dash to the end without consuming up available energy, that is to say athletes body still have energy which can be used and it not fully converted into speed. Some waste in energy and cannot bring full athletes strength into play, so the model is not the optimal one.

Optimal model put forward

Therefore, this paper puts forward middle-distance race model. Divides the model into 3 stages, the first stage takes all-out sprint so that get highest speed in short time; the second stage keeps steady , consume up body energy running usage energy; the third stage relies on inertial sprint, speed time image as Figure 3.

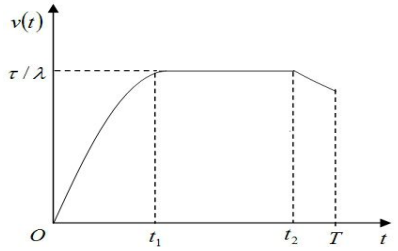

Figure 3: Middle-distance race model optimal speed schematic figure

First stage $0 \le t \le t_1$ (t_1 define afterwards) $v_1(t)$ represents by formula (9) (Write $v(t)$ as $v_1(t)$).

Third stage $t_2 \le t \le T$ (t_2 define afterwards) Input $E(t) = 0$ into formula(5),(2)get:

$$\frac{1}{2}\frac{d}{dt}v_3^2 + \frac{v_3^2}{\tau} = \sigma \tag{13}$$

Solution of equation (13) under condition that $v_3(t_2) = v_2$ is:

$$v_3(t) = [(v_2^2 - \sigma t)e^{-\frac{2(t-t_2)}{\tau}} + \sigma\tau]^{\frac{1}{2}} \tag{14}$$

$v_3(t)$ is monotone decreased and lower protrude $(\dot{v}_3(t) < 0, \ddot{v}_3(t) > 0)$.

Second stage $t_1 \le t \le t_2$ v_2 is defined by objective functional formula(1) $D(v(t))$ arrives at the maximum, and :

$$D(v(t)) = \int_0^{t_1} v_1(t)dt + v_2(t_2 - t_1) + \int_{t_2}^{T} v_3(t)dt \tag{15}$$

In order to get condition that $E(t_2) = 0$,by equation (2),(5)as well as initial condition(6)solve $E(t)$,get:

$$E(t) = E_0 + \sigma t_2 - \frac{v^2(t)}{2} - \frac{1}{\tau}\int_0^t v^2(t)dt \tag{16}$$

Let $t = t_2$ and bring it into formula (9) get:

$$E(t_2) = E_0 + \sigma t_2 - \frac{v_2^2}{2} - \int_0^{t_1} F^2\tau(1 - e^{-\frac{t}{\tau}})dt - \frac{v_2^2(t_2 - t_1)}{\tau} \tag{17}$$

The problem is concluded that determine v_2 on the condition $E(t_2)=0$, v_2 let formula (15)'s $D(v(t))$ arrives at the maximum. Use undetermined constant λ construct function:

$$I\left(v(t),t_2\right)=D(v(t),t_2)=D(v(t))+\frac{\lambda}{2}E(t_2) \tag{18}$$

It can ignore right endpoint v_2 and t_2 irrelevant items, write as:

$$I\left(v_2,t_2\right)=\int_{t_2}^{T}v_3(t)dt+\frac{\lambda\sigma}{2}t_2-\frac{\lambda}{4}v_2^2+(v_2-\frac{\lambda v_2^2}{2\tau})(t_2-t_1) \tag{19}$$

The necessary condition of letting v_2, t_2 be the optimal solution is:

$$v_2=\frac{\tau}{\lambda} \tag{20}$$

$$2\int_{t_2}^{T}[(V_2^2-\sigma\tau)e^{-\frac{2(t-t_2)}{\tau}}+\sigma\tau]^{-\frac{1}{2}}e^{-\frac{2(t-t_2)}{\tau}}dt=\lambda \tag{21}$$

Then, 3 stages $v(t)$ are respectively provided by (9),(14) and (20), the rest problems is to define t_1, t_2 and λ.

Define t_1, t_2, λ: Make use of continuity of $v(t)$ under $t=t_1$, by formula (9) and (20) get:

$$\lambda F(1-e^{-\frac{t_1}{\tau}})=1 \tag{22}$$

Input (20) into (17), then let it to be as 0,get:

$$E_0+\sigma t_2-\frac{\tau^2}{2\lambda^2}-\int_0^{t_1}F^2\tau(1-e^{-t/\tau})^2dt-\frac{\tau}{\lambda^2}(t_2-t_1)=0 \tag{23}$$

Bring (20) into (21) and make integration can get:

$$2[(\tau^2-\lambda^2\sigma\tau)e^{-\frac{2(T-t_2)}{\tau}}+\lambda^2\sigma\tau]^{\frac{1}{2}}-2\tau=\lambda^2\sigma-\tau \tag{24}$$

Above modeling parameter F,τ is already estimated in model one ,then use some middle-distance champions data(Table2 men)get estimated value of σ and E_0 as $\sigma=41.5,\ E_0=2403.5$.

Make parameters back substitution of $\sigma=41.5,\ E_0=2403.5$, $F\approx 11.8483\ N/\mathrm{kg}$, $\tau\approx 0.8808s$,the concrete steps as following.

By continuity of $t=t_1$ get formula:

$$\lambda F(1-e^{-\frac{t_1}{\tau}})=1 \tag{25}$$

First bring formula(25)into formula (23) $\int_0^{t_1}F^2\tau(1-e^{-t/\tau})^2dt$ parts, get:

$$\int_0^{t_1}\frac{\tau}{\lambda^2}dt=\frac{\tau}{\lambda^2}t_1 \tag{26}$$

Then input formula (26) into formula (23), can get:

$$\lambda^2 = \frac{\tau\ (\ \tau + t_2)}{E_0 + 6t_2} \tag{27}$$

In the following, it simplify formula(24),get $2[(\tau^2 - \lambda^2\sigma\tau)e^{-\frac{2(T-t_2)}{\tau}} + \lambda^2\sigma\tau]^{\frac{1}{2}} = \lambda^2\sigma + \tau$,continue to simplify and get:

$$t_2 = T + \frac{\tau}{2}\ln\frac{(\lambda^2\sigma - \tau)^2}{4(\tau^2 - \lambda^2\sigma\tau)} \tag{28}$$

Input formula(27)into formula(28)can determine value of t_2 ,back substitute t_2 into formula(27),can get λ ,input solved t_2 and λ into formula(23)can determine t_1 .In this way back substitute parameters so that define values of t_1 、 t_2 、 λ and τ/λ in Figure 4.

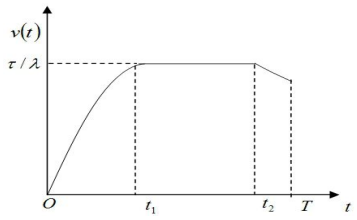

Figure 4: Numerical results

CONCLUSION

What optimal model use is average data of consuming time that multiple athletes took in competition, utilized above model and combined with each athlete its own status could get the concrete value of each athlete σ, E_0 and t_1, t_2, λ , from which defined 800m running athletes speed statuses. The model can guide athletes carry out competition plan so that get good results. Of course, it can predict competition performance without considering other accident factors.

Optimal model requires that athletes in competition according to appointed speed before competition, reasonable distribute physical ability, and strictly follow the plan rhythmically finish the full distance. The tactics requires athletes possess higher self-control ability, not easily be affected by opponents' competition rhythms and other conditions. One athlete only with stronger psychological quality can get good results when applying the tactics into competition. In addition, the tactics is more adapted to athletes who want to break through records or create good results.

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