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Testing a Model to Monitor Training Effect in Distance Running

by Ari Nummela and Ville Vesterinen

ABSTRACT

A new way to determine training-induced changes in maximal aerobic running speed (MAS), the MAS Training Effect Model, has been developed. In addition to the effect of single exercise induced fatigue and adaptation on MAS, the model takes account of individual training status, specificity of training, decreased training and detraining. After describing the model in detail, the authors present the results of a study to evaluate the validity of the model's ability to estimate training effect through changes in MAS during a long-term training period. Fifty-three recreational distance runners took part in a 28-week training programme, during which endurance performance characteristics like MAS and VO-2max were determined three times for each runner. The changes in MAS did not correlate with any variable describing the volume or intensity of the training followed, but a significant correlation was observed between the measured and estimated changes in MAS using the new model (r = 0.364, P = 0.007). It was concluded that the model is valid for monitoring changes in MAS in a long-term training period, even if it does not account for all the individual and non-training stress factors that impact training effect in endurance running.

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Introduction

The main idea of training is to facilitate biological adaptations in the body that lead to improvement in the performance of specific tasks. Current knowledge about the application of training and the anticipated training effect is based on stress theory and what is known as the overload principle. Physical exercise is a stress to which the body responds with acute reactions, like recruitment of muscles, increased energy production, increased heart rate and functional changes in respiration and circulation. Repeated exercise leads to training-induced adaptations resulting in an improved capacity of the body to react acutely to exercise induced overload.

Optimal adaptations require carefully planned training programmes, with attention focused on factors such as the frequency, duration and intensity of exercises, the type of training, the repetition of an activity, the rest intervals, periodisation of training, and, in the case of athletes, appropriate competitions. For middle- and long-distance runners one of the most important training aims is to increase maximal aerobic work capacity, defined as the maximal aerobic speed (MAS), which is determined by VO_2max, running economy (RE), and neuromuscular performance (PAAVOLAINEN et al., 1999).

The types of training that can contribute to improvements in MAS are well known, but just as well known, by experienced athletes and coaches at least, are the dangers of trying to improve physical capacity and performance by simply doing more training or more of any particular type of training. It is essential to train in a controlled way and to get a correct balance of the amount of stress, type of exercise and recovery if one is to maximise the training effect while avoiding over-training and training induced illness or injuries. This balance is normally managed through the application of training theory, personal experience, subjective feelings and instinct. In our work we are aware of the shortcomings of these approaches and of the need for improved means to monitor and control the effect of training in a more systematic and quantifiable way.

In this paper we describe a new model for monitoring the effect of training on MAS, the MAS Training Effect Model, and a study to test whether the model is a valid and reliable method to detect changes in MAS in recreational distance runners during a long-term training period.

The Model

The MAS Training Effect Model includes five main elements: 1) the formula of MAS training effect of a single exercise, 2) the formula of the training load of a single exercise, 3) the formula of the effect of training status, 4) the formula of decreased training effect, and 5) the formula of detraining effect.

Training effect of a single exercise

In endurance running there are four major aspects that determine the training effect of a single exercise: 1) velocity or intensity, 2) volume or distance, 3) training mode, and 4) individual factors. These are briefly explained in the following points:

Intensity - Running velocity has been shown to be the most important factor in developing MAS (HICKSON et al., 1978; MCNICOL et al., 2009). In training, the running velocity should be as close to VO_2max as possible, equal or higher than the intensity of maximal lactate steady state (i.e. respiratory compensation threshold or anaerobic threshold). The relationship between intensity and the MAS training effect is an S-shape, since there is almost no effect on MAS at very low running velocities (0 – 40 % of MAS) and velocities above MAS do not produce any additional training effect compared to speeds just below MAS (Figure 1A). However, it has been observed in previous studies that high-intensity interval running can improve aerobic power and capacity as well as traditional constant-velocity endurance training programmes (KUBUKELI et al., 2002; LAURSEN & JENKINs, 2002; ROSS & LEVERITT, 2001).

Distance - The relationship between running distance and MAS training effect is very similar to the VO_2–curve during the exercise (Figure 1B). In the beginning of the constant speed exercise, VO_2 increases relatively quickly to attain a new steady state within a few minutes of the onset of the exercise (WHIPP & WASSERMAN, 1972). The rate of the VO_2 increase depends on the intensity of the exercise so that an increase in work rate speeds up the VO_2 (BARSTOW et al. 1993). If the work rate is above the lactate threshold, the attainment of a steady state in VO_2 is delayed owing to the emergence of a supplementary, slowly developing component of the VO_2 response (BARSTOW & MOLÉ, 1991). When the work rate is above critical power, no steady state is achievable, but VO_2 continues to rise with time until the VO_2max is reached, resulting in the eventual termination of the exercise.

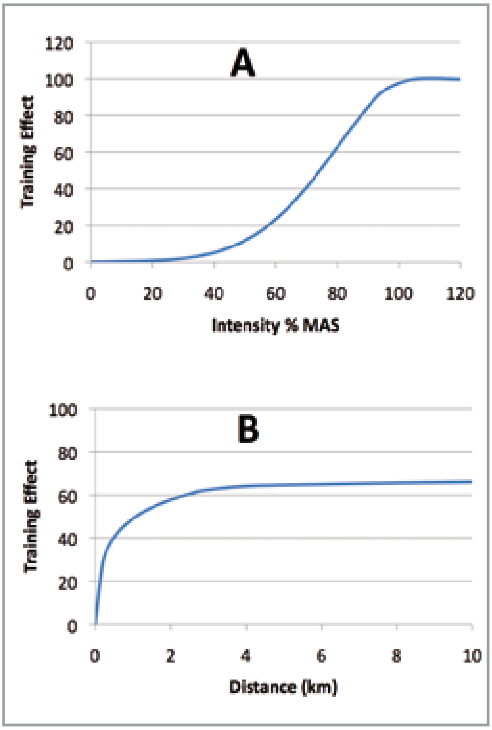


Figure 1: The relationships between intensity of exercise (A) and distance (B) and training effect on maximal aerobic speed (MAS)

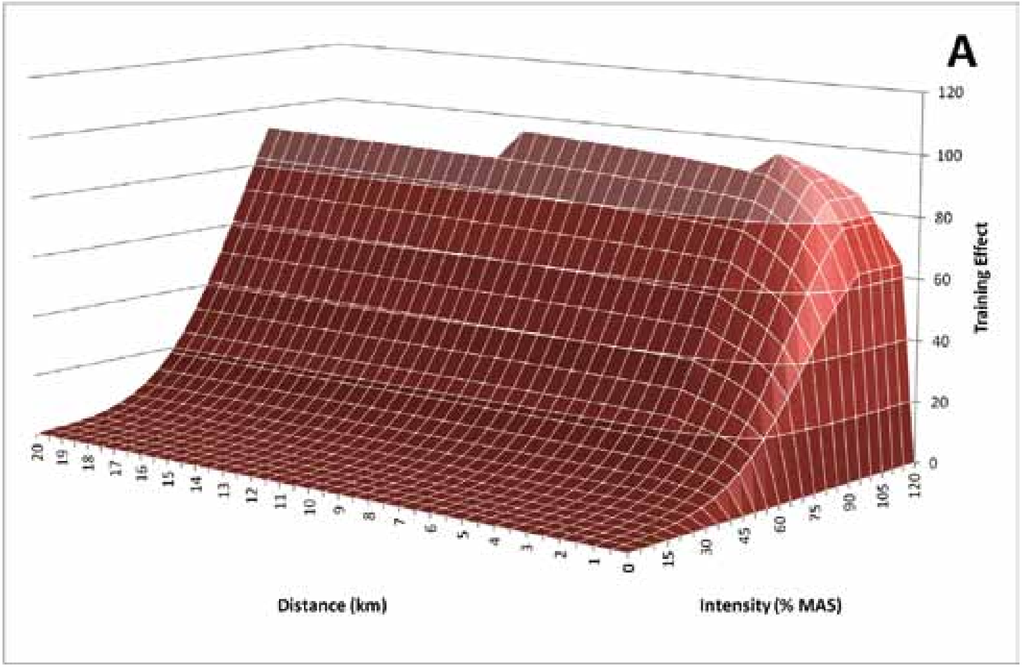
Mode – The training mode also influences the training effect, since training adaptations depend on what is known as the principle of specificity. When applied to training, specificity means that adaptations in the metabolic and physiologic systems are specific to the type of overload imposed. Because aerobic fitness for swimming, bicycling and running is most effectively improved by training the specific muscles involved in the desired performance, the best effect on a runner's endurance performance characteristics can be produced by running and other training modes that induce adaptations in running-related performance characteristics. In other words, the amount of influence of different training modes on a runner's MAS depends on how similar they are to running.

Individual Factors – A number of factors contribute to individual variations in training response and training effect. The most important of these is the absolute fitness level of the runner. For a novice runner, the MAS could be 12 km·h^{-1} but for an elite runner this velocity is clearly below lactate threshold, suggesting that training at the same velocity cannot produce a similar training effect on MAS for all runners. Therefore instead of absolute running speeds, relative running velocities (% of MAS) have been used in the model (Figure 1A). However, the use of relative intensities does not remove all the individual differences in the training response, as shown in the study of KAIKKONEN et al., 2010. The reason for this is that a great variation in lactate threshold (% of VO_2max) can be observed even in a relatively homogeneous group of well-trained male and female distance runners (MCLAUGHLIN et al., 2010). The variation would be much higher if novice or sprint runners had been included in the calculation. Therefore, the aerobic training background and performance profile of the runner have been included in the model (Figure 2).

Although the magnitude of training effect is determined during the exercise done by the individual, the adaptation processes in the body are time dependent and the increase in MAS is attained within a week of the training stimulus. When all the factors (intensity, distance, training mode and individual factors and time for adaptation) determining the MAS training effect of a single exercise have been included we have the first formula (F1) in the MAS Training Effect Model.

Effect of fatigue and recovery

In addition to an appropriate stimulus relative to the physical fitness and training status of the individual, a successful training programme for endurance running must be coupled with adequate recovery periods. Physical exercise is a stressor for the body and as such causes fatigue. The factors of the training (intensity, duration, mode, individual factors) necessary to induce the desired adaptation processes in the body also determine the training



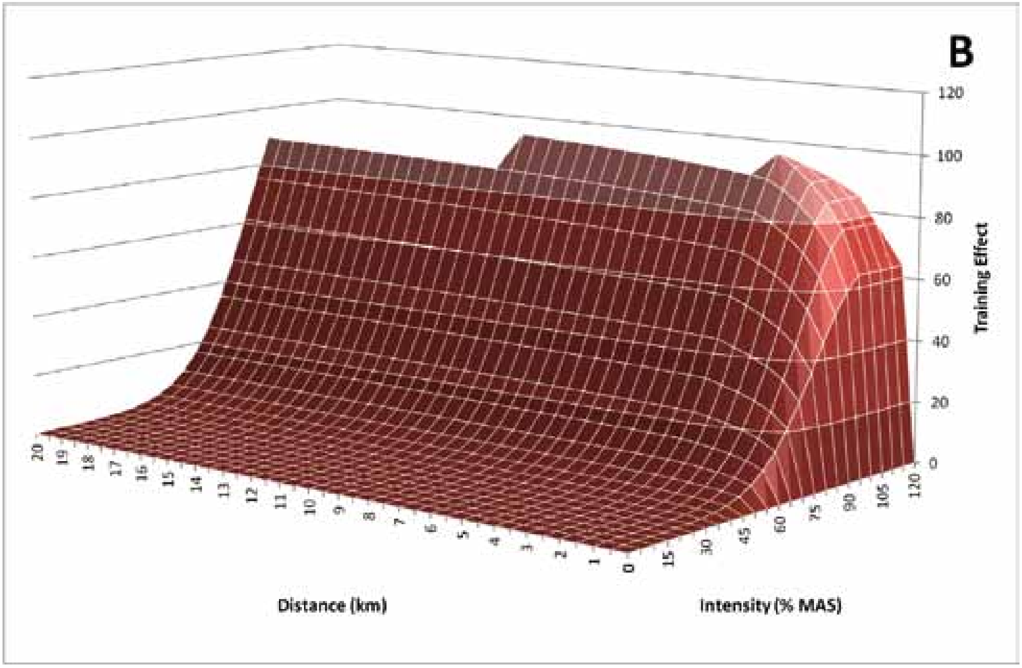


Figure 2: The influence of running intensity and distance on MAS training effect in novice (A) and elite (B) runner

load and the resulting fatigue. The next step in the MAS Training Effect Model is to determine the magnitude of fatigue from a single exercise and the time needed for recovery. The physiological basis for the endurance training load model is the excess of post-exercise oxygen consumption (EPOC), which is measured as the increased oxygen consumption after an exercise (BØRSHEIM & BAHR, 2003). The magnitude of EPOC is related to both the intensity and duration of the exercise. A curvilinear relationship between the magnitude of EPOC and the intensity of the exercise bout has been found, whereas the relationship between exercise duration and EPOC magnitude appears to be more linear. The EPOC based model of the training load of endurance exercise is shown in Figure 3A. If the body is allowed to recover after the exercise, the exercise-induced fatigue disappears over time. The rate of this recovery depends on the training load of the exercise (Figure 3B). The combination of training load and recovery model constitutes the second formula (F2) in the MAS Training Effect Model.

The MAS training effect (F1) and training load (F2) of a single exercise can be described as an antagonist transfer function. A positive influence that synthesises all the positive ef-

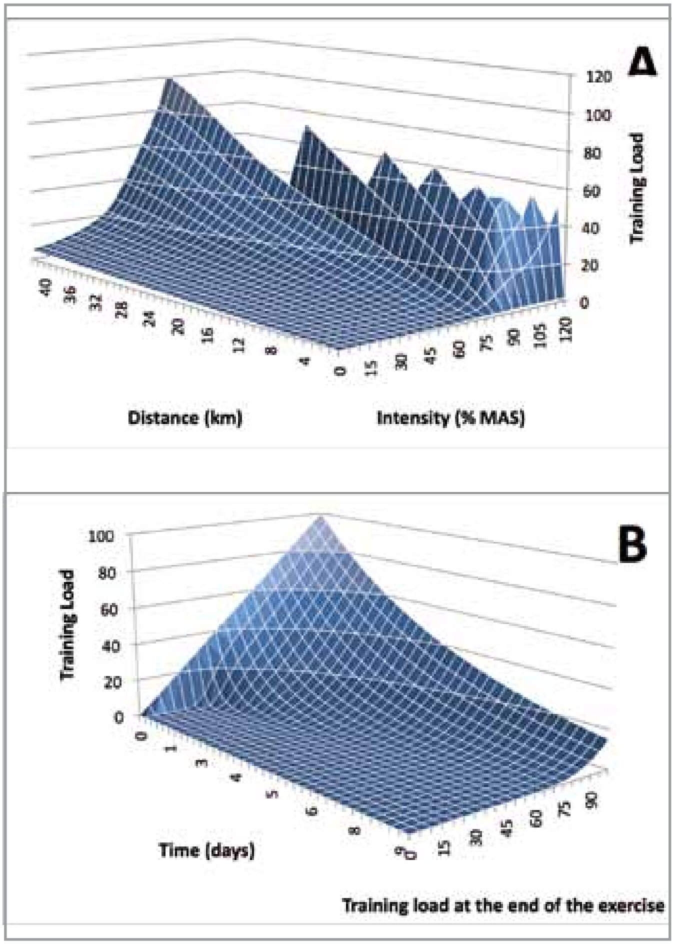


Figure 3: The model for the determination of training load by intensity and distance of running (A) (The rate of recovery depends on the training load of the exercise (B).)

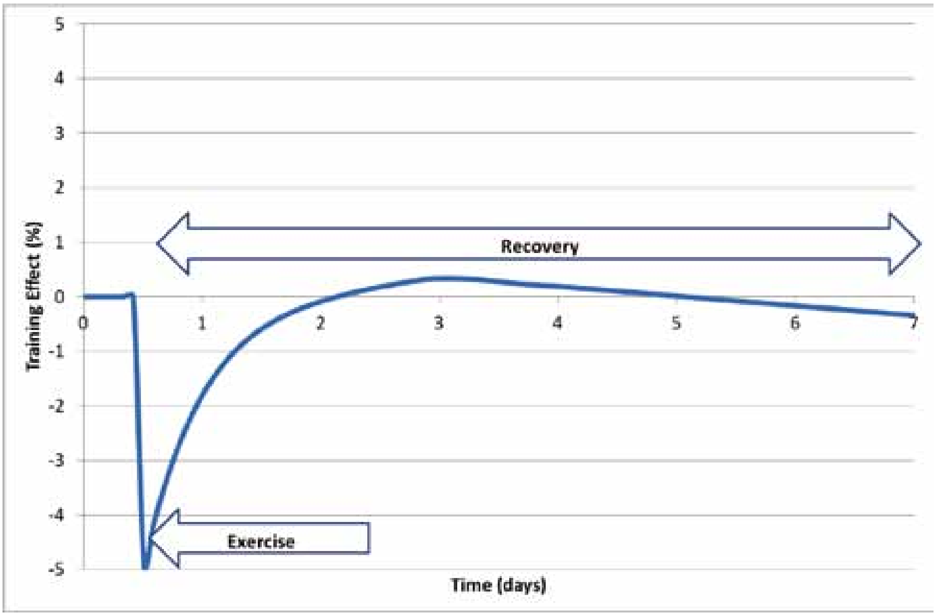


Figure 4: The changes in maximal aerobic speed during exercise and recovery, when the negative effects of fatigue and positive effects of adaptation processes are combined

fects leading to an increase in performance are included in the training effect formula (F1) and a negative function that synthesises all the negative effects leading to short-term or long-term fatigue and having a negative influence on performance are included in the training load formula (F2). Therefore, the integrated changes in MAS can be calculated by F1 – F2 and can be presented as a function of time (Figure 4).

Effect of training status

However, the adaptation to endurance training is not as simple as presented in Figure 4. The model is more complicated when the runner performs several exercises during a period and there is not enough time to fully recover from the previous exercise within the time between two successive exercises. The normal situation for an elite runner is that a single exercise does not cause a substantial training effect, but, instead, a well-planned training programme, in which individual factors and periodisation are taken into consideration, is needed. Moreover, a particular exercise does not induce a similar training effect at different times of the year. The effect of a training stimulus depends on the training status of the runner. When similar exercises are repeated, the body will be more prepared for them, which reduces the effect of the training and levels off the increase in MAS. The ideas of a decreased training effect and a plateau in the improvement of MAS are also included in the third foumula (F3) of the MAS Training Effect Model.

Effect of decreased training and detraining

In practice, a runner can rarely follow an optimal training programme, one in which the training load and effect increase progressively towards the competitive season and then before the main competition there is a tapering period to induce a peak in performance. It is more the rule than the exception that adjustments to the initial plan must be made, for example, whenever a runner is ill or injured, he/she has to stop training for a certain period of time. The adaptations induced by endurance training are both functional (oxidative enzymes, hormones, responses of autonomic nervous system) and structural (heart size, cardiac output, VO_2max). Functional adaptation to training takes place faster than structural adaptation and therefore functional changes disappeared faster than structural changes. The general idea of the decreased training model (F4, Figure 5A) is that the adaptive responses, both functional and structural, disappear as fast as they develop. Although there is a delay in the decrease in MAS when training is decreased or stopped, since recovery and the adaptive processes continue for a certain period (i.e. in tapering before a major competition), in general MAS decreases as a function of time (F5, Figure 5B) but the rate of MAS decrease depends on the training background of the individual: MAS decrease is faster for a novice than for an elite runner but the total decrease is greater for elite runner than the novice.

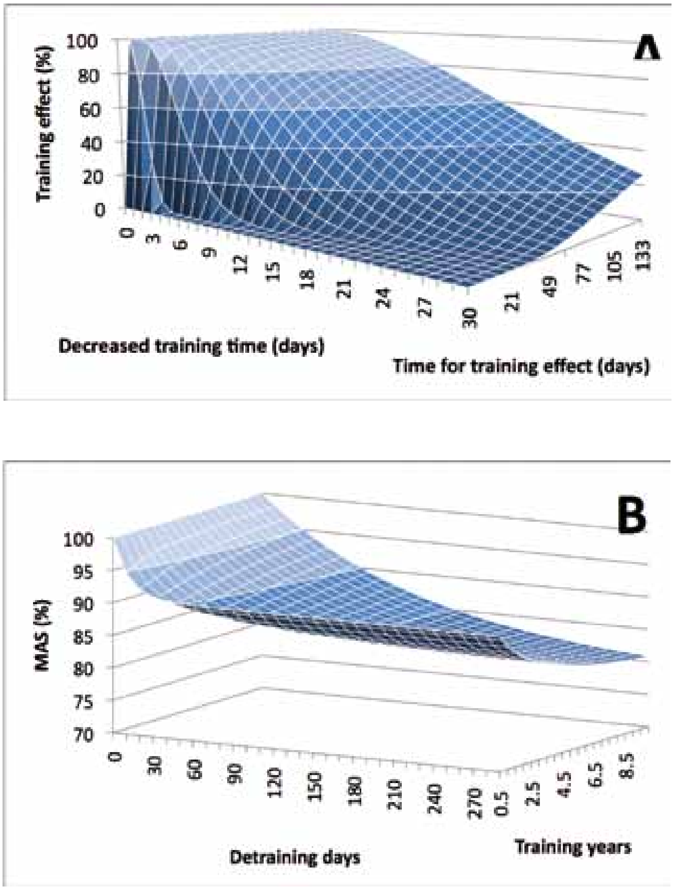


Figure 5: The model for decreased training (A) and detraining (B) effect on maximal aerobic speed (MAS) as a function of time

METHODS

Subjects

Sixty-two healthy male and female recreational runners volunteered to participate in this study. Prior to signing an informed consent document, all the subjects were fully informed about the study design, including information on the possible risks and benefits. The study design was approved by the Ethics Committee of Jyväskylä University.

Nine runners could not complete all of the tests or training during the seven-month training period and they were excluded the final analyses. Fifty-three healthy male (n = 37) and female (n = 16) recreational distance runners were included in the final results. All subjects were healthy, non-smokers, of normal weight (BMI < 30 $kg \cdot m^{-2}$), without diseases or contra-indications to exercise and none were using regular medication. All were required to have run regularly for at least one year and to run at least three times per week during the last month of the study. Descriptive characteristics of the subjects are presented in Table 1.

Experimental design and training

The subjects took part in a 28-week training programme (Table 2), which was designed to prepare them for participation in a marathon or a half marathon. The runners' anthropometry was measured and endurance performance characteristics were determined three times during the programme - in Week 0, Week 14 and Week 28. In addition to body height and mass measures, body composition was measured using bioimpedance (In Body 720 Body Composition Analyzer, Biospace Co. Ltd., Seoul, South Korea). The anthropometry measurements were taken in the mornings between 07:30 and 08:30 after 10 hours of fasting.

The training programme was divided into two 14-week periods: the basic training period (BTP) and the intensive training period (ITP). In the BTP, the subjects were asked to maintain the same training volume they were on before the study (3 – 6 times per week). The intensity of the training was mostly below the aerobic threshold (AerT, avg. 65% MAS), which was individually determined for each subject from the incremental treadmill test (AUNOLA & RUSKO,

Table 1: Descriptive characteristics of the study runners

	Men (n = 37)	Women (n = 16)
Age (yr)	35.7 ± 6.9	33.4 ± 7.3
Height (m)	1.79 ± 0.05	1.66 ± 0.07
Body mass (kg)	78.8 ± 7.3	62.2 ± 8.5
BMI ($kg \cdot m^{-2}$)	24.5 ± 2.1	22.4 ± 2.0
Body fat (%)	17.5 ± 5.4	25.3 ± 5.6
Years running	5.2 ± 4.2	3.4 ± 2.4
Average training times / week	4.5 ± 0.8	4.4 ± 0.6
MAS ($km \cdot h^{-1}$)	14.9 ± 1.2	13.2 ± 1.4
VO_{2max} ($l \cdot min^{-1}$)	3.92 ± 0.38	2.71 ± 0.42
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	49.9 ± 4.5	44.1 ± 5.4
s_{AnT} ($km \cdot h^{-1}$)	12.1 ± 1.3	11.0 ± 1.2
s_{AerT} ($km \cdot h^{-1}$)	9.5 ± 1.1	8.8 ± 1.1

MAS = maximal aerobic speed; s_{AnT} = speed at anaerobic threshold; s_{AerT} = speed at aerobic threshold

Table 2: Description of training week during a 28-week training programme

	Basic training period	**Intensive training period**
Week periodisation (hard:easy)	3:1	2:1
High intensity runs	None	0 – 2 times during intense weeks
Moderate intensity runs	None	0 – 2 times during intense weeks
Long low intensity runs	1 (15 – 20 km)	1 (20 – 30 km)
Basic low intensity runs	2 – 5 (5 – 15 km)	1 – 3 (5 – 15 km)
Strength training sessions	1 – 2	1

1986). The training in the BTP was performed in four-week cycles, in which three weeks of hard training was followed by an easy training week. The training comprised primarily running exercises but occasionally cycling, Nordic walking or cross country skiing were included. Furthermore, the runners were asked to complete strength training exercises one to two times per week.

The ITP included higher running training volume (prolonged duration of the training sessions) and intensity compared to the basic training period. During the ITP, two hard training weeks were followed by an easy training week. During the hard training weeks the runners were programmed to perform two intensive training sessions, in which the intensity was between AerT and anaerobic threshold (AnT) in the beginning of the ITP and thereafter progressively increased above AnT at the end of the ITP. The other endurance training sessions during intense training weeks were performed below AerT. Furthermore, the subjects were asked to complete one strength training session per week throughout the ITP. All training sessions during the easy training week were performed below AerT.

The subjects controlled their training intensity by measuring their heart rate (HR) during all exercises using Suunto t6 heart rate monitors and GPS pod speed/distance sensors (Suunto Ltd., Vantaa, Finland). They kept training diaries throughout the study, recording the training modes used, duration of the training sessions, the average HR and the running distance. In addition, they rated their perceived exertion (RPE) after each training session using a 0 to 10 scale (BORG, 1982). HR data was used for determining the times in three intensity zones; low (below AerT), moderate (between AerT and AnT) and high (above AnT). Training impulse (TRIMP), an index of training load, was calculated by using the following formula (BANISTER, 1991):

$$\text{TRIMP} = t \times \Delta\text{HR ratio} \times y,$$

where t = duration of training (min), ΔHR ratio =

$$(HR_{exercise} - HR_{rest}) \times (HR_{max} - HR_{rest})^{-1},$$

$$y = 0.64\, e^{(1.92 \times \Delta\text{HR ratio})} \text{ (men)}$$

$$\text{and } y = 0.86\, e^{(1.67 \times \Delta\text{HR ratio})} \text{ (women).}$$

Incremental treadmill test

To measure endurance performance characteristics, an incremental treadmill test was performed in the laboratory conditions. Maximal aerobic speed (MAS), maximal oxygen uptake (VO_2max), anaerobic threshold (AnT) and aerobic threshold (AerT) were determined from the test (AUNOLA & RUSKO, 1986). The initial treadmill speed was 7 km·h^{-1} for women and 8 km·h^{-1} for men and increased by 1 km·h^{-1} every third minute until volitional exhaustion. The slope of the treadmill was kept at 0.5° throughout the test.

HR (Suunto t6, Suunto Ltd., Vantaa, Finland) and VO_2 (Oxygen Mobile, Viasys Health Care GmbH, Würzburg, Germany) were measured throughout the test. They were averaged from the last minute of each load for the analyses. Blood samples (20 µl) were taken from fingertip at the end of each 3-min running load to determine blood lactate concentrations (Biosen S_line Lab+ lactate analyzer, EKF Diagnostic, Magdeburg, Germany). MAS was determined as the speed at exhaustion. If the runner could not complete the whole three min load until exhaustion, MAS was calculated as follows: v [km·h^{-1}] + t [sec] x 150^{-1} [sec], where v = speed of the last completed 3-min running load; t = running time at exhaustion during the last run subtracted by 30 sec (= time needed for fingertip blood sample). Corresponding speed at AnT (s_{AnT}) and AerT (s_{AerT}) were calculated accordingly. VO_2max was determined as the highest 60 sec average VO_2 value during the test.

Training effect on MAS

In order to calculate training effect on MAS, the training data (intensity, distance and training mode) of each training session as well as individual factors (training data during the previous month, training years, age, MAS, s_{AnT}) were inserted in the new MAS Training Effect Model. Thereafter, the absolute and relative changes in MAS can be determined and drawn as a function of time (Figure 6).

Statistical analysis

Most statistical comparisons and analysis were done by SPSS Statistics 19.0 program (IBM SPSS Statistics 19.0 Inc, Chicago, IL). Standard statistical methods were used to calculate mean, standard deviation, coefficient of variation and correlation coefficient. The validity of the new MAS Training Effect Model was evaluated by correlation coefficients and

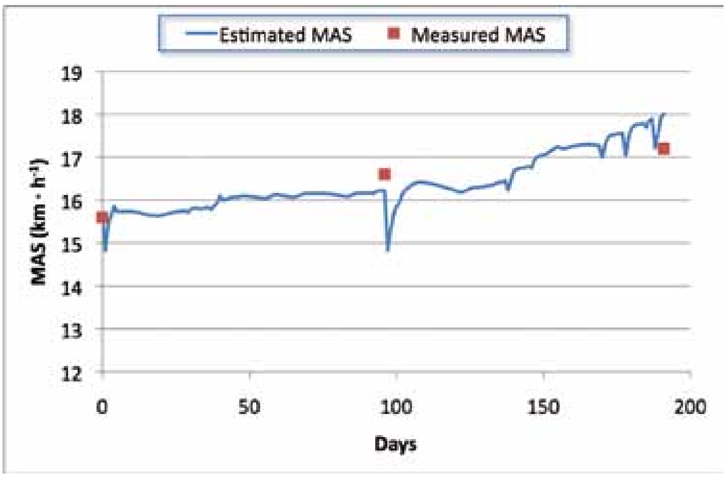


Figure 6: The estimated (curve) and measured (dots) maximum aerobic speed (MAS) of one runner during the 28-week training period

by the test of BLAND & ALTMAN (1986). The significance of the changes between pre- and post-results was tested with ANOVA. The $P < 0.05$ criterion was used for establishing statistical significance.

Results

The average increase in MAS was 7.2 ± 4.7% (varied from -3.7 to 21.9%) during the 28-week training programme. The programme was considered successful since 50 of the total 53 runners improved their MAS. The results of the incremental treadmill test at Week 0, Week 14 and Week 28 are shown in Table 3.

The training variables that describe the volume of training correlated positively with MAS at the end of the 28-week training period, but the variables that describe the intensity of training correlated negatively with MAS at the end of the 28-week training period (Table 4). Furthermore,

Table 3: The results of the incremental treadmill test at week 0, 14 and 28

	Week 0	Week 14	Week 28	PRE – POST
MAS (km · h-1)	14.4 ± 1.5	15.0 ± 1.4	15.4 ± 1.5	P < 0.001
VO2max (ml · kg-1 · min-1)	48.2 ± 5.4	50.0 ± 5.8	50.6 ± 5.9	P < 0.001
HRmax (bpm)	187 ± 8	187 ± 10	186 ± 10	P = 0.017
Peak B-La (mmol · l-1)	10.7 ± 2.5	10.6 ± 2.2	10.5 ± 2.4	P = 0.355
sAnT (km · h-1)	11.8 ± 1.3	12.5 ± 1.4	13.0 ± 1.3	P < 0.001
sAerT (km · h-1)	9.3 ± 1.1	9.9 ± 1.2	10.4 ± 1.1	P < 0.001

MAS = maximal aerobic speed; VO_{2max} = maximal oxygen uptake; HR_{max} = maximal heart rate; Peak B-La = peak blood lactate concentration; s_{AnT} = speed at anaerobic threshold; s_{AerT} = speed at aerobic threshold

Table 4: Correlation coefficients between training data and maximum aerobic speed (MAS) at the end of the 28-week training period or changes in MAS during the 28-week training period

	MAS (km · h^{-1})	Change in MAS (%)
Endurance training volume (h)	0.354**	0.017
Number of endurance training sessions	0.327*	0.051
Running distance (km)	0.398**	0.031
Low intensity runs (h)	0.285*	0.126
Moderate intensity runs (h)	-0.025	0.021
High intensity runs (h)	0.193	-0.078
Average heart rate (bpm)	-0.341*	0.080
RPE (0-10)	-0.016	-0.335*
Average intensity (% MAS)	-0.380**	0.004
Sum TRIMP	-0.059	0.026
Sum of MAS training effect of single exercises	0.125	0.077

* = P < 0.05; ** = P < 0.01; *** = P < 0.001

there were almost no significant correlations between the training data and changes in MAS as shown in Table 4. The only significant but negative correlation was observed between the average RPE and change in MAS (Table 4). When using the new Formula 1, the average MAS training effect of single exercises was 30.9 ± 5.5 and the sum of it in the whole training period was 4010 ± 1064. There was no significant correlation between the sum of MAS training effect and the changes in MAS (Table 4).

The next step of the analysis was to estimate the validity of the complete MAS Training Effect Model. When the complete model was used, the estimated MAS correlated positively with measured MAS ($r = 0.867$, $P < 0.001$) and a positive correlation was observed between the changes in estimated and measured MAS ($r = 0.364$, $P = 0.007$) (Figure 7A and 7B). The estimated MAS was -0.2 ± 0.7 $km \cdot h^{-1}$ lower than the measured MAS after 14-weeks of training and after the whole 28-week training period the new model overestimated the MAS by 0.5 ± 0.9 $km \cdot h^{-1}$ (Figure 8A and 8B). The coefficient of variation for the estimated MAS was 4.8% in the first 14-week period and 6.3 % in the whole 28-week period. The 0.5 $km \cdot h^{-1}$ difference in MAS estimation means that the new model overestimated the 3000m time by 22 sec for a recreational distance runner in the 28-week period.

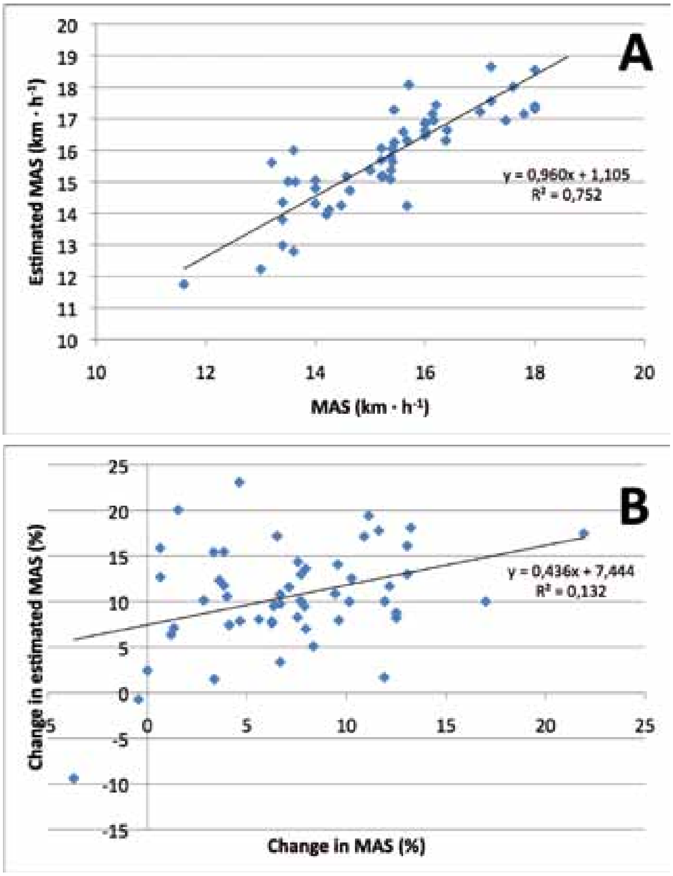


Figure 7: The relationship between the estimated maximum aerobic speed (MAS) and measured MAS (A) and the relationship between the estimated and measured changes in MAS (B)

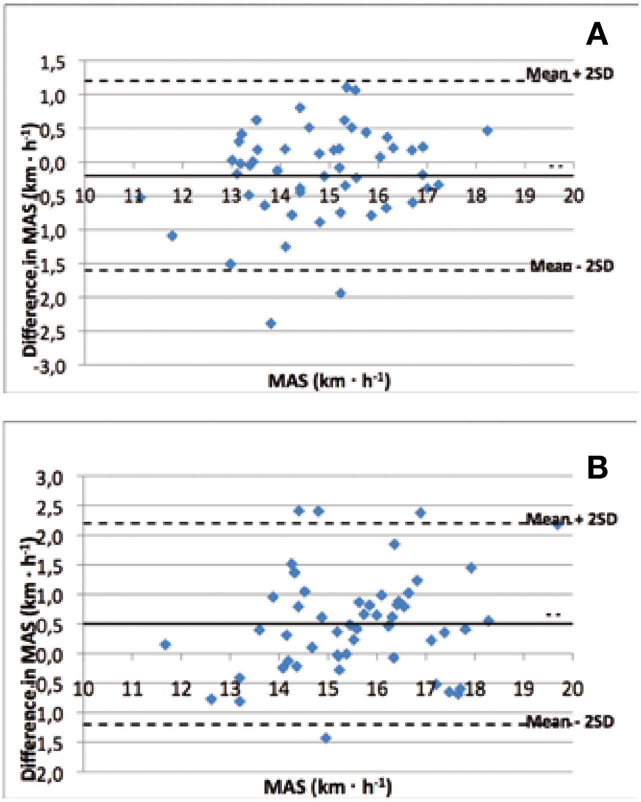


Figure 8: Maximal aerobic speed (MAS) and difference in estimated MAS after 14 weeks (A) and 28 weeks (B) of training

Nineteen of the runners improved their MAS more than 8% (responders) and the improvement of MAS was less than 6% in 19 runners (non-responders). The average improvement in MAS was 12.1 ± 3.1% and 2.4 ± 2.3% in responders and non-responders, respectively ($P < 0.001$). There were no significant differences in the training volume or intensity between the two groups and the estimated improvement in MAS was 12.1 ± 4.8% for the responders and 9.4 ± 7.6% for the non-responders ($P = 0.192$) suggesting that the new model overestimated the MAS especially in non-responders.

Discussion

In the present study, the validity of a new model to monitor changes in MAS over a long-term training period was examined. The results of the present study showed that the average values of training variables, like total volume, intensity or frequency of the exercise, are not related to changes in MAS in recreational distance runners. Even the variables in which the exercise intensity and volume have been combined, like the sum of TRIMP or MAS training effect of single exercises, are not related to changes in MAS. In the new MAS Training Effect Model, not only has the intensity and duration of a single exercise been taken into account but also included are the time for adaptation, exercise induced fatigue, specificity of training, training status, peridodisation of training, decreased training, and detraining affect the changes in MAS. The main result of the present study was that the new MAS Training Effect Model is a valid method to monitor changes in MAS in recreational runners as a function of time over a long-term training period.

The results of the present study show that although it is thought that the volume or intensity of training are important impulses to induce training adaptation in distance running, the absolute volume or average intensity were not related to changes in MAS. One reason for these non-significant relationships is the differences between individuals. The present results are not contradictory to the thoughts of the coaches and published training theory, which hold that distance running performance can be improved by increasing the volume or intensity of training, since this statement may be true within one runner but not in comparison between the runners. Some individual factors were included in Formula 1, in which the MAS training effect was calculated for the exercises with different intensity and distance (Figure 2). In Formula 1, the factor that the same absolute running velocity or intensity does not induce similar adaptation processes is taken into account by determining the intensity as % of MAS. Furthermore, the factor that the lactate steady state velocity is not relatively (% of MAS) at the same level in each individual has been taken into account. In the present subjects, the s_{AnT} varies from 66 to 87%, suggesting that this is an individual factor that should be taken into consideration when building up a model for monitoring MAS. Although both of these factors have been taken into account, the sum of single training effects did not correlate with the changes in MAS. The result was similar when the sum of TRIMP was used in the correlation analyses.

Another reason for the non-significant correlations between training volume or intensity variables is the training status. It is well known among endurance coaches that similar training does not produce similar results each year within one runner, not to mention in different runners. This is because the training status of a runner changes every day, training period and year. The training effect of exactly the same exercise does not produce similar adaptations every time, since exercise induced adaptations prepare the body to perform the same exercise more easily the next time. In the MAS Training Effect Model, it has been taken into account that if similar exercises are repeated several times, the training effect on MAS decreases from one time to the next.

In a normal, real-life training programme, the training is not same each day or week. Coaches periodise training e.g. so that two to three hard weeks are followed by an easy training week. Furthermore each runner has to make changes in running distance, intensity, frequency or all of these during a training period. As a result, training weeks are not similar and therefore the average or sum of the training do not us tell everything about the training effect. This may be one reason why the average or sum of the training data did not correlate with the changes in MAS in the present study. In the training of the distance runners, the periodisation of training ensures adequate recovery and it is therefore an important factor to take into account when modelling the training effect on MAS. Similarly, when a runner has to decrease the training volume, intensity, frequency or all of these, it has an effect on the development of MAS. When training status, periodisation, decrease in training and detraining were included in the MAS Training Effect Model, the correlation was improved from 0.125 to 0.364 suggesting that these factors significantly improved the validity of the model.

For the study subjects MAS improved 0.6 $km \cdot h^{-1}$ during the BTP and 0.4 $km \cdot h^{-1}$ during the ITP. The respective improvements in estimated MAS were 0.4 $km \cdot h^{-1}$ and 1.1 $km \cdot h^{-1}$ suggesting that the new model clearly overestimated the MAS during the ITP. This is also shown in Figure 6. This means that the importance of high-intensity training in improving MAS is not as high as suggested by the new model or by the current knowledge on endurance training. The actual change in MAS was similar in the BTP and ITP, suggesting that low intensity training caused similar adaptations to high-intensity training. However, this is not so simple to evaluate since the training status of runners was different at the beginning of the BTP and at the beginning of the ITP.

An interesting finding in the present study was that MAS estimation worked better for responders than for non-responders. The model clearly overestimated MAS in non-responders suggesting that other factors than the content of training explains why the non-responders gain only a little or no benefit from a similar training programme compared to responders. If this is the case then the new MAS Training Effect Model can be used to determine which runners respond to training or not. If the gap between the estimated and measured MAS increases, then the coach and athlete should change their training programme or alter other factors responsible for the non-responsiveness to training.

The comparison of the changes in MAS in the first 14-week training period and the whole 28-week training period suggest that the estimation of MAS was better during a shorter training period. This is logical since not only training but also other factors cause variation in the estimated MAS and the effect of non-training factors should increase with time. Physical training is not the only stressor to which the body has to respond. The stressors not included in the model are physical environmental factors (temperature, humidity, hypoxia, and change in time zone), psychosocial factors, and basic individual needs (rest, nutrition). The body integrates the effects of all stressors to the total stress of the body. Depending on the individual stress factors and training status the responses to the same exercises are not equal every time. If the total stress of the body is too high, the body enters a state of short or long-term fatigue, MAS decreases and eventually overtraining syndrome may develop.

Conclusion

The present study confirms that not only factors determining the training impulse of a single exercise (i.e. running intensity and distance) but also individual factors and factors related to the periodisation of training are important when modelling training effect in distance running. Furthermore, it shows that a model can estimate MAS changes during a long-term training period. The new model comprises two antagonistic functions describing the exercise induced fatigue and adaptation processes, individual factors and training programming, in which the frequency, periodisation, and recoveries between the exercises are determined. However, individual training responses, which may depend on numerous non-training physiological, psychological, and sociological factors, cannot be fully taken into account. Further investigations with data related to different level runners and more varied training regimens are needed to complete the analysis of the accuracy of the new model and to improve the formulation.

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