Time Course of Changes in Endurance Capacity: A 1-yr Training Study

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ABSTRACT

SCHARHAG-ROSENBERGER, F., T. MEYER, S. WALITZEK, and W. KINDERMANN. Time Course of Changes in Endurance Capacity: A 1-yr Training Study. *Med. Sci. Sports Exerc.*, Vol. 41, No. 5, pp. 1130–1137, 2009. **Purpose**: To investigate the magnitude and the time course of changes in endurance capacity during the first year of an aerobic endurance training program with constant HR prescription. **Methods**: Eighteen previously untrained subjects (7 males and 11 females, 42 ± 5 yr, BMI of 24.3 ± 2.5 kg·m^{-2}, and maximal oxygen uptake ($\dot{V}O_{2max}$) of 37.7 ± 4.6 mL·min^{-1}·kg^{-1}) completed a 12-month jogging/walking program on 3 d·wk^{-1} 45 min per session with a constant HR prescription of 60% HR reserve. Exhaustive treadmill tests were conducted before the intervention and after 3, 6, 9, and 12 months of training. In addition, submaximal tests on an indoor running track were performed every 4 wk. **Results**: After 12 months, $\dot{V}O_{2max}$ had increased by 0.36 ± 0.33 L·min^{-1} (median [interquartile range]: 16% [9%–20%], $P < 0.001$). After 3, 6, and 9 months, 52%, 65%, and 79% of this increase were reached, respectively. Resting HR decreased by a total of 9 ± 6 min^{-1} ($P < 0.001$). Of this change, 47% and 102% had occurred after 3 and 6 months, respectively. Submaximal exercise HR during the treadmill tests decreased by 11 ± 7 min^{-1} ($P < 0.001$) on average. After 3 and 6 months of training, 93% and 101% of this change were observed, respectively. The running track tests revealed that submaximal exercise HR did not change significantly after the ninth week of training. **Conclusions**: Beginners in recreational endurance exercise are advised to increase their training stimulus after 6 months of training to maintain training effectiveness because no further significant changes in endurance capacity were observed thereafter. When planning future endurance training studies in untrained subjects, it should be taken into account that submaximal exercise HR might reflect endurance changes during the first week only, whereas $\dot{V}O_{2max}$ remains responsive after several months. **Key Words:** ENDURANCE TRAINING, ACSM RECOMMENDATIONS, HR RESERVE, $\dot{V}O_{2max}$, TRAINING STIMULUS

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The American College of Sports Medicine (ACSM) regularly publishes recommendations how endurance training should be designed to improve cardiorespiratory fitness and promote health (1,2). Although many recreational athletes train according to these prescriptions, the magnitude and the time course of long-term changes in endurance capacity during such a training program have hardly been surveyed. The lack of information about typical characteristics of the adaptive responses during the first year of a recreational endurance training program makes it difficult to monitor recreational athletes and appropriately plan future endurance training studies. For instance, beginners in endurance exercise do not know which magnitude of changes in endurance capacity they can expect during their first year of training and whether these changes occur uniformly over time. Furthermore, detailed knowledge about the characteristics of different training adaptations would enable estimation of the required length, sensitive parameters, and appropriate sample sizes for future endurance training studies in untrained subjects.

At least since Åstrand and Rodahl (3) published their first textbook in 1970, the idea of large adaptations to endurance exercise in the beginning of a training program and smaller adaptations with growing endurance capacity is well known. However, so far, most of the endurance training studies were conducted during short periods. Previous long-term investigations have some limitations with respect to the reported magnitude and time course of endurance changes (4,9,10,15,27). Atomi and Miyashita (4), Iwasaki et al. (15), and Weltman et al. (27) conducted endurance training studies for 11 and 12 months, respectively, but the training stimulus increased markedly over time. Hence, the magnitude and the time course of the training adaptations cannot be attributed to one defined training prescription. In addition, at the end of these studies, the exercise intensities and/or volumes were above those recommended by the ACSM (2). Furthermore, the studies were conducted with 7 to 11 subjects in each group only. In a 10-month training study, Denis et al. (9) investigated only

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five subjects who were not completely untrained. Duncan et al. (10) included a total of 342 subjects in a 2-yr training study. However, depending on the group they were assigned to, the subjects performed only between 58% and 66% of their prescribed exercise during the first 6 months of the training program. After the sixth month, adherence was not assessed furthermore.

Altogether, the most obvious shortcomings of previous long-term endurance training studies are small sample sizes and subjects who are not representative for beginners in recreational endurance exercise about their initial fitness level and age. The training stimuli have often been increased over time and were not suitable for recreational athletes. Moreover, most authors do not provide any information about the adherence of the subjects to the training prescriptions. Other studies report insufficient adherence. It therefore seemed warranted to carefully investigate the magnitude and the time course of changes in endurance capacity during the first year of an aerobic endurance training program with a constant training stimulus according to the ACSM recommendations in untrained subjects. To overcome previous methodical problems, an appropriate sample size was estimated *a priori* and representative subjects were chosen. The training program was controlled thoroughly by recording and evaluating every single training session during the whole 1-yr period. That way of controlling the subject's adherence to the training prescriptions has not been reported before in long-term endurance training studies. Maximal oxygen uptake, maximal running velocity (V_{max}), resting HR, and submaximal exercise HR were chosen as indicators for endurance capacity.

METHODS

Subjects and screening evaluation. Twenty-five subjects were recruited for participation in the study. They underwent a screening evaluation including a medical check (medical history and physical examination), a resting ECG, and an exhaustive treadmill test with ECG recordings and gas exchange measurements. The test served to habituate the subjects to the testing procedure, to ensure the absence of health risks, and to verify that they were untrained. Only individuals who were not involved in regular (defined as $\geq$1 wk^{-1}) physical activity for at least 6 months before the study, who had never performed competitive endurance exercise before, and whose $\dot{V}O_{2max}$ values were <50 and <45 $mL \cdot min^{-1} \cdot kg^{-1}$ for males and females, respectively, were included. All subjects gave written informed consent after the study was approved by the local ethics committee. During the training period, seven subjects dropped out of the study. Reasons for dropout were illnesses and injuries not related to the study (N = 4, excluded after 9, 12, 33, and 40 wk), ligamental strain during training (N = 1, dropped out after 30 wk), lack of adherence to the training prescriptions (N = 1, excluded after 47 wk), and moving house (N = 1, dropped out after 13 wk). When the seven subjects dropped out of the study, the magnitude of their training adaptations was not different from that of the subjects who continued participation. A total of 18 subjects (7 males and 11 females) completed the study. Age, weight, BMI, and pretraining $\dot{V}O_{2max}$ of the analyzed subjects were 42 ± 5 yr, 73 ± 13 kg, 24.3 ± 2.5 $kg \cdot m^{-2}$, and 37.7 ± 4.6 $mL \cdot min^{-1} \cdot kg^{-1}$, respectively ($N$ = 18).

General design. The subjects performed 12 months of aerobic endurance training. Maximal incremental treadmill tests were conducted before the training period and after 3, 6, 9, and 12 months of training. In addition, submaximal tests on an indoor running track were performed every 4 wk. The treadmill tests included resting HR measurement, weighing, and the maximal treadmill protocol with HR, lactate, and gas exchange measurements. The submaximal indoor track tests were conducted with HR measurements only to receive a higher temporal resolution of changes in submaximal exercise HR. All treadmill and indoor track tests took place at the same time of day for a given subject. The subjects did not train for at least 24 h before the treadmill tests, and they kept their nutritional intake similar on the day before all treadmill tests. This was controlled with a written protocol.

Laboratory testing. Resting HR was measured by a telemetric system (Polar F6; Polar Electro, Kempele, Finland) in a supine position at the end of a 10-min resting period. For the exhaustive treadmill tests, a Woodway treadmill (ELG 70; Woodway GmbH, Weil am Rhein, Germany) with a constant inclination of 0.5% was used. The exercise protocol started with 4, 5, or 6 $km \cdot h^{-1}$ depending on the subject's fitness level. Running velocity was increased stepwise by 1 $km \cdot h^{-1}$ every 3 min with 30-s breaks for capillary blood sampling until four to five stages were completed. Once more, running velocity was increased by 1 $km \cdot h^{-1}$ for 3 min and then, without any further interruptions, it was increased rampwise by 0.8 $km \cdot h^{-1}$ every minute until voluntary exhaustion. The rampwise part of the test was designed not to exceed the optimal test duration of approximately 10 min for an accurate determination of $\dot{V}O_{2max}$ (7). Gas exchange measurements were conducted continuously using the Meta Max II metabolic test system (Cortex Biophysik GmbH, Leipzig, Germany; mixing chamber; sampling frequency: 10 s). Its accuracy has recently been documented for workloads between 100 and 250 W (17). Maximal oxygen uptake and maximal respiratory exchange ratio (RER_{max}) were assessed. HR was recorded continuously using a telemetric system (Polar F6; Polar Electro). Maximal HR (HR_{max}) was analyzed, and HR at the end of the five initial exercise stages was recorded to obtain submaximal exercise HR. To quantify changes in submaximal exercise HR, the mean HR of the five initial exercise stages was calculated. Capillary blood samples to determine blood lactate concentration (La, enzymatic–amperometric method; Greiner, Flacht, Germany) were taken from the hyperemized earlobe at rest, during the 30-s breaks between the workloads, immediately after cessation of exercise, and at the first and third minutes after exercise. Blood lactate threshold (LT) was determined as "baseline La + 1 mmol" according to Hagberg and Coyle (12), and the maximal blood lactate concentration (La_{max}) was assessed. Maximal parameters were only analyzed if at least one of the following criteria was fulfilled: (i) Leveling-off defined as an increase in $\dot{V}O_2$ during the last 60 s of the test of <100 $mL \cdot min^{-1}$ (5), (ii) $HR_{max} \geq (220 - age) - 10\%$, (iii) $La_{max} \geq 8\ mmol \cdot L^{-1}$, (iv) $RER_{max} \geq 1.1$ (21). One subject did not meet these criteria and was excluded from statistical analyses of maximal parameters. Intraindividually, exercise protocols were identical over time, and the moment of transition from walking to running was held constant.

Field testing. The indoor track tests were conducted in groups of up to eight subjects on a 200-m indoor running track. The incremental exercise protocol started with 5, 6, or 7 $km \cdot h^{-1}$, and running velocity was increased every 3 min by 1 $km \cdot h^{-1}$ with 20-s breaks between the exercise stages. Every subject performed four stages that, in each individual, resulted in an HR ≥160 min^{-1} on the last stage of the first test. Exercise protocols were identical for a given subject. Running velocity was precisely given by a flashing light system next to the track (Gümbel, Ludwigshafen, Germany). HR were recorded using telemetric systems (Polar F6; Polar Electro) and were analyzed at the end of each stage.

Training program. The training program was designed to be within the current ACSM recommendations (2). It consisted of 1 yr of walking or jogging on 3 $d \cdot wk^{-1}$ for 45 min per session with a constant HR prescription. Training HR was calculated from the data obtained during the pretraining treadmill test as follows:

1. The ACSM recommends exercise intensities of 40% or 50% to 85% HR reserve (HRR) (2). The lower intensity values, namely 40% to 49% HRR, result in health benefits but not necessarily in changes in cardiorespiratory fitness. To ensure improvements in endurance capacity, 60% HRR was chosen as the training prescription.
2. Fixed percentages of maximal values often lead to interindividually inhomogeneous metabolic responses (19). A metabolic criterion should therefore be added. For this purpose, the LT according to Hagberg and Coyle (12) was determined because it was validated for race walking and, therefore, seemed to be applicable for walking and jogging velocities (12). The HR at the LT was linearly interpolated.

To ensure fitness changes, the higher training prescription of either 60% HRR or HR at the LT was chosen. Indeed, the two training prescriptions differed by 2 ± 11 min^{-1} only, and the prescribed training intensity was 62 ± 4% HRR. All subjects were given telemetric systems (Polar F6; Polar Electro) that were individually programmed to alarm >5 min^{-1} below or above their prescribed HR. To assess adherence to the training prescriptions, each training session was logged in the telemetric systems and evaluated by one of the investigators. The subjects participated in a supervised training session once a week and trained on their own twice a week. In the 3rd and 12th months of the training program, capillary blood samples were drawn during a training session to determine La and thereby assess the metabolic demand of training.

Statistics. Data are given as means ± SD, median [interquartile range], or individual courses. They were checked for normal distribution by using the Shapiro–Wilk *W*-test. As this was present throughout dependent variables, parametric tests were chosen. One-factorial ANOVA for repeated measures (factor: duration of the endurance training program) were used to compare resting HR and maximal parameters among the five treadmill tests and to compare adherence of the subjects during the four periods among the treadmill tests. This test was also used to detect changes in running velocity during the training sessions over time, which was estimated from the results of the five treadmill tests. Submaximal exercise HR during the treadmill and the indoor track tests were compared by using a two-factorial ANOVA (factor 1: duration of the endurance training program; factor 2: exercise stage of the test). For *post hoc* comparisons, the Scheffé test was used. The number of subjects showing a leveling-off was compared among the five treadmill tests using the McNemar test. A Student's *t*-test for paired samples served to compare the blood lactate concentrations during the training sessions in the 3rd and 12th months of the training program. Finally, the changes in endurance parameters for 1 yr were correlated with the number of training sessions per week by using the Pearson product–moment correlation. $P < 0.05$ for the α error was considered significant.

An appropriate sample size was *a priori* estimated according to Hopkins (personal Web site: http://sportsci.org/resource/stats/). The smallest worthwhile pre–post difference in $\dot{V}O_{2max}$ to detect was chosen to be 6%, which is slightly above the intraindividual variability of $\dot{V}O_{2max}$ measurements reported by Katch et al. (16). For a two-tailed $\alpha = 0.05$, a power of 0.8, the smallest worthwhile pre–post difference of 6%, and a within-subject variation for $\dot{V}O_{2max}$ measurements of 5.6%, the calculation resulted in a sample size of $N = 14$ (16). It was assumed that approximately 40% of the subjects would drop out, and therefore, the study was started with $N = 25$ (22).

RESULTS

Compliance and Training Characteristics

The subjects trained on 2.8 ± 0.2 $d \cdot wk^{-1}$ for 48 ± 2 min per session on average, and their mean exercise HR was 1 ± 1 min^{-1} above the prescribed HR ($N = 18$). Compliance was similar during the four periods among the treadmill tests (frequency of the training sessions: 2.8 ± 0.2 vs 2.7 ± 0.3 vs 2.7 ± 0.3 vs 2.7 ± 0.2 sessions per wk, $P > 0.20$, and duration of the training sessions: 48 ± 3 vs 48 ± 3 vs

TABLE 1. Magnitude of the adaptive responses.

	Total 1-yr Change	
	Mean ± SD	*P*
Body weight (kg)	−1.3 ± 2.6	NS
Resting HR (min^{-1})	−9 ± 6	<0.001
Submax. exerc. HR (min^{-1})	−11 ± 7	<0.001
V_{max} ($km \cdot h^{-1}$)	+1.5 ± 0.8	<0.001
$\dot{V}O_{2max}$		
($L \cdot min^{-1}$)	+0.36 ± 0.33	<0.001
($mL \cdot min^{-1} \cdot kg^{-1}$)	+5.7 ± 4.1	<0.001
($mL \cdot min^{-1} \cdot kg^{-2/3}$)	+23 ± 17	<0.001
Degree of effort		
Leveling-off (*N*)	0	>0.20
HR_{max} (min^{-1})	−2 ± 6	>0.20
La_{max} ($mmol \cdot L^{-1}$)	−0.1 ± 1.3	>0.20
RER_{max}	−0.06 ± 0.04	<0.001

HR_{max}, maximal HR; La_{max}, maximal blood lactate concentration; RER_{max}, maximal respiratory exchange ratio ($N = 18$ for body weight, resting HR, and submax. exerc. HR; $N = 17$ for V_{max}, $\dot{V}O_{2max}$, leveling-off, HR_{max}, and La_{max}; $N = 16$ for RER_{max}); Submax. exerc. HR, submaximal exercise HR; $\dot{V}O_{2max}$, maximal oxygen uptake; V_{max}, maximal running velocity; NS, not significant.

48 ± 4 vs 47 ± 3 min, $P > 0.20$, $N = 18$). The prescribed training intensity corresponded to 62 ± 8% $\dot{V}O_{2max}$ and 77 ± 3% HR_{max} on average. Running velocity during the training sessions increased significantly from 7.3 ± 0.7 to 8.0 ± 1.0 $km \cdot h^{-1}$ on average during the 1-yr training period ($P < 0.001$, $N = 18$). However, mean blood lactate concentration during the training sessions decreased slightly but significantly from 1.4 ± 0.2 $mmol \cdot L^{-1}$ in the 3rd month to 1.2 ± 0.2 $mmol \cdot L^{-1}$ in the 12th month ($P < 0.01$, $N = 10$).

Training Adaptations

The magnitude and the time course of the adaptive responses to the 1-yr training program are given in Tables 1 and 2, respectively. In Figure 1, the time courses of different parameters of endurance fitness are compared.

Maximal parameters. Changes in $\dot{V}O_{2max}$ are presented in Figure 2. Maximal oxygen uptake ($L \cdot min^{-1}$) had increased by a total of 16% [9%–20%] (median [interquartile range]) after 12 months of training. After 3, 6, and 9 months of training, 52%, 65%, and 79% of the total 1-yr change had occurred, respectively. As related to body weight, the total increase in $\dot{V}O_{2max}$ after 12 months of training amounted to 14% [8%–23%] (median [interquartile range]). The changes in $\dot{V}O_{2max}$ expressed in liters per minute and milliliters per minute per kilogram were not significant anymore after the third month of training. However, allometrically scaled data ($mL \cdot min^{-1} \cdot kg^{-2/3}$) showed a significant change from the 3rd to the 12th month of training. Maximal running velocity reached 53%, 87%, and 87% of its total 1-yr change after 3, 6, and 9 months of training, respectively. After the sixth month of training, increases in V_{max} were not significant anymore. In addition to the maximal parameters associated with aerobic performance, parameters of effort are provided in Table 2. Although two of them indicated similar effort during the five treadmill tests, two others showed significantly higher effort in the first test.

Submaximal parameters. Resting HR was observed to reach 47%, 102%, and 83% of its total 1-yr change after 3, 6, and 9 months of training, respectively. The decrease in resting HR was significant from pretraining to the sixth month of training, and no further significant changes were observed thereafter. Changes in submaximal exercise HR during the treadmill tests are shown in Figure 3. Submaximal exercise HR demonstrated 93%, 101%, and 76% of its total 1-yr change after 3, 6, and 9 months of training. Figure 4 provides the changes in submaximal exercise HR measured during the indoor track tests. The higher temporal resolution revealed that there was no further significant change in submaximal exercise HR after the ninth week of training.

Changes in endurance capacity and adherence to the training prescriptions. There was no significant correlation between the changes in the examined endurance parameters for 1 yr and the number of training sessions per week: $\dot{V}O_{2max}$ ($L \cdot min^{-1}$): $P = 0.92$, $r = -0.03$, $N = 17$; V_{max}: ($km \cdot h^{-1}$): $P = 0.61$, $r = 0.14$, $N = 17$; resting HR

TABLE 2. Time course of the adaptive responses.

	Months of Training				
	0	3	6	9	12
Body weight (kg)	73.0 ± 13.0+,Δ	72.0 ± 12.6	71.2 ± 11.7*	71.3 ± 11.3*	71.7 ± 11.6
Resting HR (min^{-1})	71 ± 7+++,ΔΔ,§§§	67 ± 7	62 ± 5***	64 ± 8**	62 ± 8***
Submax. exerc. HR (min^{-1})	127 ± 11###,+++,ΔΔΔ,§§§	117 ± 10***	116 ± 9***	118 ± 11***	116 ± 9***
V_{max} ($km \cdot h^{-1}$)	11.6 ± 1.5###,+++,ΔΔΔ,§§§	12.4 ± 1.5***,+,ΔΔ,§§§	12.9 ± 1.5***,#	12.9 ± 1.6***,##	13.1 ± 1.6***,###
$\dot{V}O_{2max}$					
($L \cdot min^{-1}$)	2.77 ± 0.61#,++,ΔΔΔ,§§§	2.96 ± 0.58*	3.00 ± 0.64**	3.05 ± 0.69***	3.13 ± 0.63***
($mL \cdot min^{-1} \cdot kg^{-1}$)	37.7 ± 4.6##,+++,ΔΔΔ,§§§	41.0 ± 5.2**	42.0 ± 5.8***	42.5 ± 5.8***	43.4 ± 5.5***
($mL \cdot min^{-1} \cdot kg^{-2/3}$)	157 ± 21##,+++,ΔΔΔ,§§§	170 ± 22**,§	174 ± 25***	176 ± 27***	180 ± 24***,#
Degree of effort					
Leveling-off (*N*)	9	7	7	10	9
HR_{max} (min^{-1})	183 ± 8##	177 ± 7**	179 ± 10	181 ± 10	180 ± 10
La_{max} ($mmol \cdot L^{-1}$)	8.6 ± 2.6	8.2 ± 3.4	8.0 ± 2.9	7.9 ± 2.6	8.5 ± 2.1
RER_{max}	1.11 ± 0.05###,+++,ΔΔΔ,§§§	1.05 ± 0.05***	1.05 ± 0.04***	1.03 ± 0.04***	1.04 ± 0.03***

Data are presented as means ± SD.

HR_{max}, maximal HR; La_{max}, maximal blood lactate concentration; RER_{max}, maximal respiratory exchange ratio ($N = 18$ for body weight, resting HR, and submax. exerc. HR; $N = 17$ for V_{max}, $\dot{V}O_{2max}$, leveling-off, HR_{max}, and La_{max}; $N = 16$ for RER_{max}); Submax. exerc. HR, submaximal exercise HR; $\dot{V}O_{2max}$, maximal oxygen uptake; V_{max}, maximal running velocity.
Significant differences: * from pretraining, # from the 3rd month, + from the 6th month, Δfrom the 9th month, and § from the 12th month of training; one symbol: $P < 0.05$, two symbols: $P < 0.01$, three symbols: $P < 0.001$.

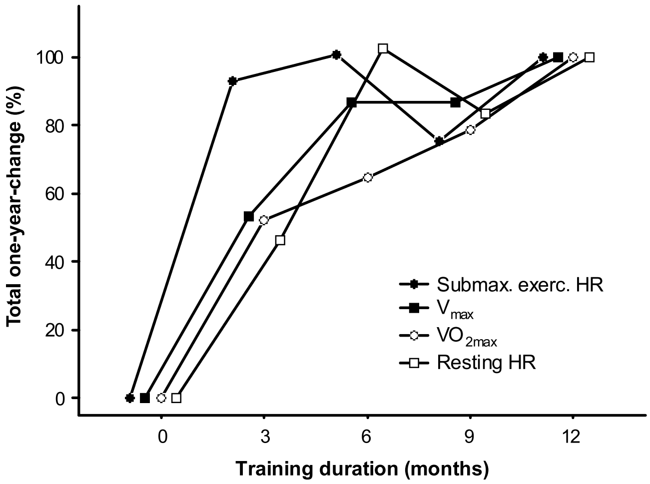

FIGURE 1—Time courses of different adaptations to the 1-yr training program. The total 1-yr change of each parameter is set 100% (for the change in submaximal exercise HR, the mean of five exercise stages is used). Data are presented as means. Submax. exerc. HR, submaximal exercise HR; $\dot{V}O_{2max}$, maximal oxygen uptake (L·min^{-1}); V_{max}, maximal running velocity (N = 18 for submax. exerc. HR and resting HR; N = 17 for $\dot{V}O_{2max}$ and V_{max}).

(min^{-1}): P = 0.40, r = 0.21, N = 18; and submaximal exercise HR (min^{-1}): P = 0.88, r = −0.04, N = 18.

DISCUSSION

This study demonstrates that 1 yr of jogging or walking on 3 d·wk^{-1} for 45 min per session with a constant HR prescription of 60% HRR leads to increases in $\dot{V}O_{2max}$ and V_{max} by approximately 0.4 ± 0.3 L·min^{-1} (median [interquartile range]: 16% [9%–20%]) and 1.5 ± 0.8 km·h^{-1}, respectively, and to decreases in resting and submaximal exercise HR by approximately 10 ± 7 min^{-1} on average in initially untrained subjects. The time course of changes in endurance capacity has seemed to be asymptotic with most of the improvements occurring during the first 3 to 6 months of training.

The adherence of the subjects to the training prescription was thoroughly controlled in the present study and was not associated with the magnitude of endurance changes. In view of the relatively long study duration, the level of adherence can be deemed well. Furthermore, adherence was similar during the four periods among the treadmill tests. This is an important requirement for the interpretation of the time course of the training adaptations. About the changes in $\dot{V}O_{2max}$ and V_{max}, the degree of effort during the treadmill tests must also be considered. Two of four parameters indicated higher effort during the pretraining test compared with the test after 3 months of training and all other tests, respectively. Therefore, during the first 3 months of training, that is, when the larger part of changes in endurance capacity was observed, the adaptations might even have been slightly underestimated. Subjects of endurance training studies usually tend toward spending higher maximal effort after training. Initially untrained subjects get habituated to physical effort and, because neither the intervention nor the tests are perfectly blinded, improvements are expected by the subjects and the investigator (20). However, an overestimation of endurance training adaptations because of higher effort spent in the posttraining test can be excluded in the present study.

For monitoring recreational endurance athletes, it is important that no further significant improvements in endurance capacity were observed after the sixth month of training. At that time, all parameters had reached at least approximately two thirds of their total 1-yr change. Therefore, beginners in recreational endurance exercise should be advised to increase the training stimulus after 6 months of training to maintain training effectiveness. So far, the ACSM recommendations do not address the question whether a constant training stimulus is still effective after a longer period (2). It is only described that individuals with higher fitness levels require a higher training stimulus to achieve increases in endurance capacity than untrained individuals. Changes in the training stimulus over time are not explicitly recommended, probably because an automatic adaptation is assumed when constant target HR are used. The present

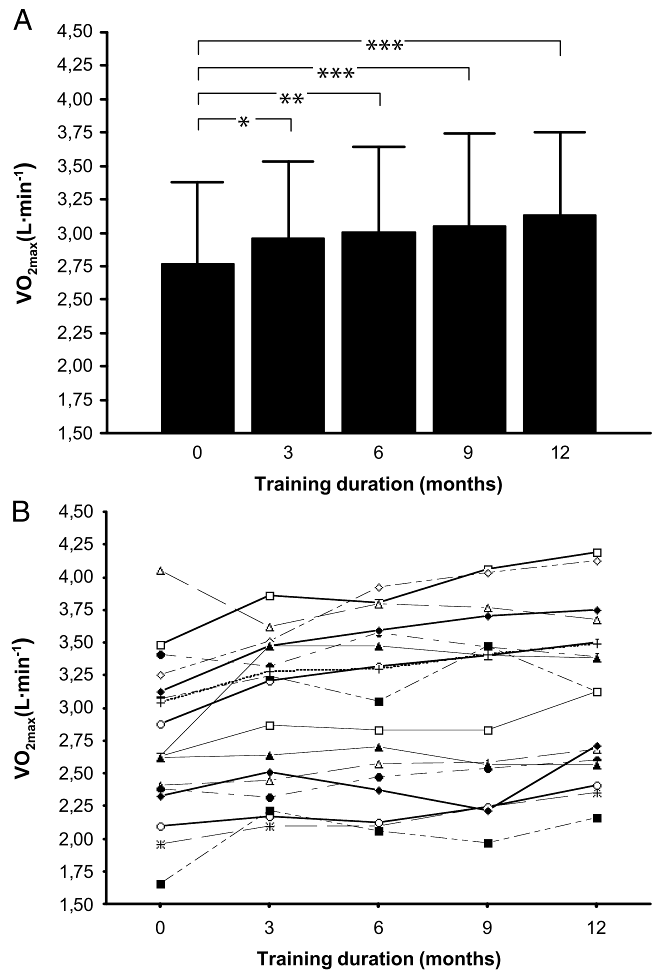

FIGURE 2—Time course of the maximal oxygen uptake ($\dot{V}O_{2max}$). A. Means ± SD. B. Individual courses (N = 17).

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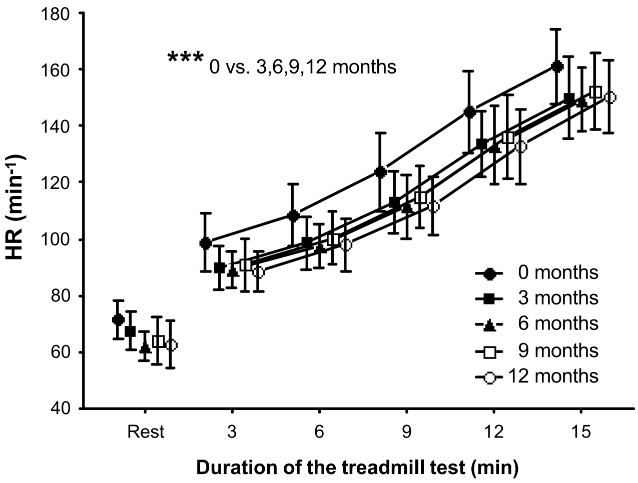

FIGURE 3—Time course of the submaximal exercise HR during the treadmill tests (means ± SD, *N* = 18).

data suggest that this issue should be included in future training recommendations for recreational endurance athletes more clearly. It cannot be derived from the present data whether an elevation of exercise intensity or exercise duration is preferable. Further endurance training studies are necessary to answer that question.

The four observed parameters of endurance capacity showed different time courses during the 1-yr training period, which should be considered when planning future endurance training studies in untrained subjects. Submaximal exercise HR stopped changing significantly after the ninth week of training and, therefore, does not seem to be an appropriate parameter to indicate fitness changes in long-term training studies of several months. Resting HR decreased continuously during the first 6 months of training and remained constant thereafter. In contrast, changes in $\dot{V}O_{2max}$ did not level off during the 1-yr training period. If the whole magnitude of possible changes in $\dot{V}O_{2max}$ due to a constant training stimulus is to be surveyed, it might be necessary to conduct a study that lasts much longer than 1 yr.

The longest training study that investigated the time course of changes in endurance capacity with a constant training stimulus over time was conducted by Gaesser and Rich and lasted 18 wk (11). Two groups of seven and nine subjects performed either high-intensity or low-intensity endurance exercise on a cycle ergometer at the upper limit and just below the ACSM recommendations, respectively (2). Training workload was adjusted to the current $\dot{V}O_{2max}$ every 3 wk, which led to an increase in exercise HR by 6 to 10 min^{-1}. The highest $\dot{V}O_{2max}$ values were observed in the 15th and the 12th wk of endurance training in the high- and low-intensity groups, respectively. Thus, the increase in $\dot{V}O_{2max}$ plateaued within 4.5 months of training, which is in contrast to the outcome of the present study. The low-intensity training program surveyed by Gaesser and Rich (11) might have been insufficient to cause continuous improvements in $\dot{V}O_{2max}$, but this does not apply to the high-intensity program. The stagnation of changes in $\dot{V}O_{2max}$ observed in the high-intensity group occurred from the 15th to the 18th wk of training, and no further tests were conducted thereafter. Possibly, a time slot of 3 wk is too short to measure endurance changes within an advanced training phase. Therefore, besides the low number of subjects tested, the short duration of the study of Gaesser and Rich (11) might represent a limitation.

Hickson et al. (13) published another frequently cited study describing the time course of endurance changes. Ten subjects conducted interval training on a cycle ergometer on 3 d·wk^{-1} and continuous running or cycling on the alternate days. They trained for 4 wk with a constant intensity prescription and then another 5 wk with a higher constant intensity prescription. Weekly maximal cycle ergometer tests revealed no significant changes in $\dot{V}O_{2max}$ from the third to the fourth week of the first training period, and a similar pattern was observed during the second training period. The authors conclude that, unless the training stimulus is increased, endurance exercise does not lead to further improvements in $\dot{V}O_{2max}$ after the third week of training (13). It must be mentioned that $\dot{V}O_{2max}$ did not change significantly from the first to the second week of the first training cycle and neither did it change from the second to the third week of the second training cycle. Apparently, missing improvements from 1 wk to the next week can hardly be interpreted as permanent stagnations in $\dot{V}O_{2max}$ changes. Considering the very short study duration and the fact that Hickson et al. (13) surveyed only 10 young subjects with different initial fitness levels, the reported early leveling-off in endurance changes might be questioned.

In the present study, endurance capacity did not change significantly after the sixth month of training, and it is therefore not surprising that the magnitude of the observed training adaptations is similar to that reported in former endurance training studies of shorter durations. For example, in studies that lasted 4 to 8 months and surveyed endurance training programs that were suitable for recreational

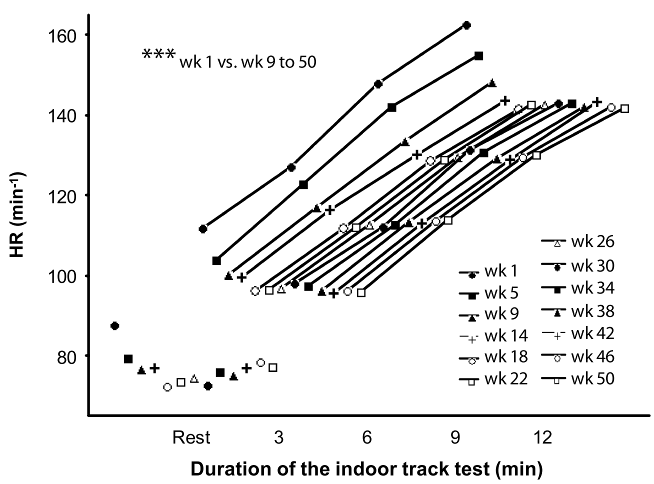

FIGURE 4—Time course of the submaximal exercise HR during the indoor track tests (means, *error bars* have been omitted to aid clarity, tests are arranged from left [week 1] to right [week 50], *N* = 18).

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athletes, maximal oxygen uptake was observed to increase by 3.7 to 12.3 mL·min^{-1}·kg^{-1} compared with 5.7 mL·min^{-1}·kg^{-1} in the present study (8,11,18,25,28). These investigations report changes in resting HR between 0 and −9 min^{-1}, whereas resting HR decreased by 9 min^{-1} in the present study (25,26,28). Submaximal exercise HR was found to decrease by 10 to 21 min^{-1} in the mentioned studies versus 11 min^{-1} in the present investigation (25,26,28). Reasons for the wide range of study outcomes might be differences in the exact study durations and differences in the training stimuli (23). Changes in resting HR can furthermore depend on whether it was measured in a supine position under resting conditions or before the start of an exercise test. Information about this is not provided in some papers (25,26).

The large SD and the individual courses of changes in $\dot{V}O_{2max}$ demonstrate considerable individual differences in the response to endurance training. This has been described before, particularly by Bouchard and Rankinen (6) who analyzed the data of the HERITAGE Family Study (a 20-wk endurance training study with approximately 400 to 1000 subjects). Changes in $\dot{V}O_{2max}$ were found to range from about zero gain to an increase of 1.00 L·min^{-1}. According to Bouchard et al. (5), the main cause of this variability has to do with genetic characteristics. Analytic procedures revealed a maximal heritability of the $\dot{V}O_{2max}$ response to endurance training of 47% (5). Large individual differences should therefore be considered when monitoring recreational endurance athletes.

Training intensity was prescribed by a constant HR throughout the training program. As endurance capacity of the subjects improved, this prescription led to an increase in running velocity during the training sessions. The cardiocirculatory strain of the training program remained constant over time. However, a decrease in blood lactate concentration and the metabolic strain of training, respectively, was observed. To reduce or avoid this effect, some investigators regularly adjusted the training prescription to the current endurance capacity (11,14,24,26,27). In practice, recreational endurance athletes do not regularly conduct endurance tests after short periods. Therefore, we chose a constant HR prescription as a more realistic approach.

CONCLUSION

One year of recreational endurance training on 3 d·wk^{-1} for 45 min per session with a constant HR prescription of 60% HRR elicits increases in $\dot{V}O_{2max}$ and V_{max} by approximately 0.4 ± 0.3 L·min^{-1} (median [interquartile range]: 16% [9%–20%]) and 1.5 ± 0.8 km·h^{-1}, respectively, and decreases in resting and submaximal exercise HR by approximately 10 ± 7 min^{-1} on average in initially untrained individuals. Beginners in recreational endurance exercise are advised to increase their training stimulus after 6 months of training to maintain training effectiveness because no further significant changes in endurance capacity were observed thereafter. When planning future endurance training studies in untrained subjects, it should be taken into account that submaximal exercise HR might reflect endurance changes during the first week of training only, whereas $\dot{V}O_{2max}$ still seems to be responsive after months.

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