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Adaptation to Maximal Effort: Genetics vs. Environment
A Case History

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Abstract. An individual's functional ability in physiological responsiveness is thought to be an interaction between his heredity and his environment. This hypothesis was tested to determine if different extragenetic influences would alter functional adaptability in a set of MZ triplets. After a 3-month aerobic physical fitness training program varying only in frequency, measured values for the triplets' maximum oxygen consumption ($MaxVo_2$) were 59.1, 44.5, and 57.8 ml/min/kg, as compared to pretreatment values of 45.2, 45.1, and 49.1 ml/min/kg respectively. These results clearly indicate intrapair differences in functional adaptability, stemming from difference in the training frequency program. The split-triplet design of this study indicates that environmental factors contribute substantially to the intrapair variance found among MZ siblings. Data extrapolation suggests that environmental stimulation of sufficient magnitude is likely to alter the functional adaptability in the individual set by his genotype.

Key words: Monozygotic triplets, Environment, Training, Oxygen consumption, Adaptation

INTRODUCTION

It is generally recognized that interindividual variability exists in adaptive responses to chronic exercise, that is, an individual's functional adaptability in physiological responsveness in the result of the interaction between his heredity and his environment [5]. However, ignorance still exists as to what degree individual differences are attributable to genetic variation and to what degree to environmental conditions. One solution to elucidate these influences is intrapair comparison of differences between MZ siblings. In

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this manner, genetic variation is controlled for by monozygosity, and phenotypic variability in these individuals would be due solely to environmental factors.

It is well known that oxygen consumption increases with the magnitude of physical exertion. Therefore, as an exercising subject approaches that point of exhaustion, his oxygen consumption will reach a maximum above which it will not increase even with additional work loads. This peak value is referred to as the individual's maximal oxygen consumption (Vo_2max); a fundamental physiological limitation for an individual. At present, Vo_2max is the most widely used and accepted criterion of cardiorespiratory endurance, or status of "physical fitness". To account for individual differences in size, Vo_2max is frequently expressed relative to body weight (ml of oxygen/kg of body weight/min). This allows for a more equitable comparison between individuals of different size and levels of fitness. There is ample evidence to suggest that maximal oxygen consumption is affected by a number of factors such as training, sex, age, and inactivity [7].

The present study was conducted to determine whether extragenetic influences (ie, varying frequencies of physical training) are effective in altering functional adaptability in a set of MZ triplets. The degree to which the genetic factor is operant in different individuals is not known. However, the split-triplet method circumvents this problem, because each trained triplet is accompanied by a genotypically identical control. This all-male set of triplets was exposed to the same home environment throughout the entire investigational period.

The validity of this study depends to a large extent upon the accurate determination of monozygosity and upon reliable assessment of the relative exposure of the triplets to extragenetic influences. According to Klissouras [4], the genetic contribution to the variance of cardiorespiratory variables can be estimated from a simple additive model of heredity plus environment. For MZ triplets there is no genetic variability and the intraindividual difference is attributed solely to extragenetic, or environmental influences, and an error of measurement.

MATERIALS AND METHODS

A set of healthy, 20 yrs old MZ male triplets were used for the present investigation. Their height was 172 cm; their weight 67.5, 67.5, and 63.4 respectively. They were classified as MZ on the basis of morphological traits and a serological examination as well as dermatoglyphic analyses [6]. Discordance for a single antiserum was regarded as sufficient evidence of di- or trizygosity. The probability of monozygosity in using these criteria is 95% in concordant sets of siblings [1,3,8]. The triplets were found be concordant for hemoglobin (Hp A) and haptoglobin (Hp 2-1); for enzyme systems phosphoglucomutase (PGM 1-1), acid phosphate (AP BB), glucose-6-phosphate dehydrogenase (G6PD B) 6-glucophosphodehydrogenase (6GPD N), catalase (CAT N), and lactate dehydrogenase (LDH N); and for the red cell antigens of the various systems (A_1, Se, CDe/CDe, Ms/Ns, kk, Fyb/fyb, Jka+, P+). Also, the total finger ridge counts of the triplets were very close; 196, 202 and 206. In summary, the evidence in favor of monozygosity was overwhelming.

The exercise tests to determine Vo_2max levels were conducted on three consecutive days, the same time of day for each of the subjects. All subjects were tested twice. Oxygen consumption measurements were made before and after the treatment protocols (Table). Environmental conditions were kept uniform throughout the entire investigation. The means and standard deviations of environmental parameters were 755.5 mmHg ± 1.2 mmHg for barometric pressure, $20^\circ \pm 2.0^\circ$ Celsius for ambient temperature, and 54.7 ± 1.9% for relative humidity.

The subjects were given a progressive exercise test on an A.R. Young standard model treadmill. The testing procedures used in this study have been extensively delineated by Wasserman et al [9].

Table: Peak Values for Ventilation Volume (V_E), Oxygen Consumption (Vo_2), Carbon Dioxide Production (VCo_2), MaxVo_2 and Heart Rates Before and After Treatment

Subject		V_F(1/min)STPD	Vo_2(1/min)STPD	VCo_2(1/min)STPD	MaxVo_2(ml/min/kg)	Heart rate(b/min)
01	Before	88.9	3.06	3.88	45.2	204
	After	80.8	3.55	3.83	59.1	200
02	Before	84.6	3.06	3.79	45.1	201
	After	79.2	3.02	3.51	44.5	200
03	Before	80.2	2.94	3.12	49.1	199
	After	82.2	3.47	3.87	57.8	198

Briefly described here, the treadmill was incremented by 1% grade at the end of each minute; the speed was held constant at 7 mph. During the experimental protocol all brothers were present, creating a competitive atmosphere which motivated them to exert themselves to exhaustion at supramaximal efforts, a technique delineated by Klissouras [4]. Prior to the actual data collection, training for the treadmill running session was insituted for all subjects for 5 min.

Open-circuit spirometry methods were used to determine the rate of oxygen consumption every 30 sec. Subjects breathed through a Hans Rudolph valve. The volume of air was measured with a Parkinson-Cowan CD4 dry gas meter which had been calibrated against a 120 Tissot gasometer. A 5 l plexiglass mixing chamber was used for sampling expiratory gases. Fractions of oxygen and carbon dioxide in the expired air were determined with Beckman OM11 and LB2 analyzers, respectively. Both analyzers were calibrated with gases of known concentrations, which were verified by gas chromatography. Oxygen uptake was calculated by a Rockwell microprocessor utilizing Rockwell computational software. Results were based on the volume of the expired air and fractional concentration of expired oxygen and carbon dioxide. The EKG was recorded with a Burdick electrocardiograph model EK/5A, with a CM 5 lead configuration, and was used to determine heart rate, as well as monitor task progress. Standard measures of ventilation volume (V_E), respiratory quotient (RQ), oxygen consumption (Vo_2), carbon dioxide production (VCo_2), anaerobic threshold (AT), and maximum aerobic capacity (Vo_2 max) were determined for each individual and corrected for standard conditions. The anaerobic threshold was determined according to the non-invasive procedures developed by Wasserman et al [9].

At the beginning of September until the end of December 1982, two of three subjects engaged in an aerobic training program, comprised of jogging. This exercise program differed among the subjects only in training frequency. Subject 01 trained for a total of 90 hr, subject 02 for a total of less than 10 hr, and subject 03 for a total of 150 hr. Subject 01 jogged 5 times a week for 80 min, while subject 03 jogged 5 times a week for 120 min. Both subjects ran at the same time each day. During the exercise protocol, heart rate was frequently monitored by both subjects in order to maintain a 50-60% of maximum heart rate intensity.

RESULTS

Values for ventilation volume (V_E), oxygen consumption (Vo_2), carbon dioxide production (VCo_2), respiratory quotient (RQ), anaerobic threshold (AT), and maximal aerobic capacity (Vo_2 max), clearly show a disparity among trained and untrained subjects. Data obtained are given in the Table.

A closer examination of these individual values discloses intrapair differences in functional adaptability as measured by maximal oxygen uptake between MZ triplets (subject 01 = 59.1, 02 = 44.5, 03 = 57.8).

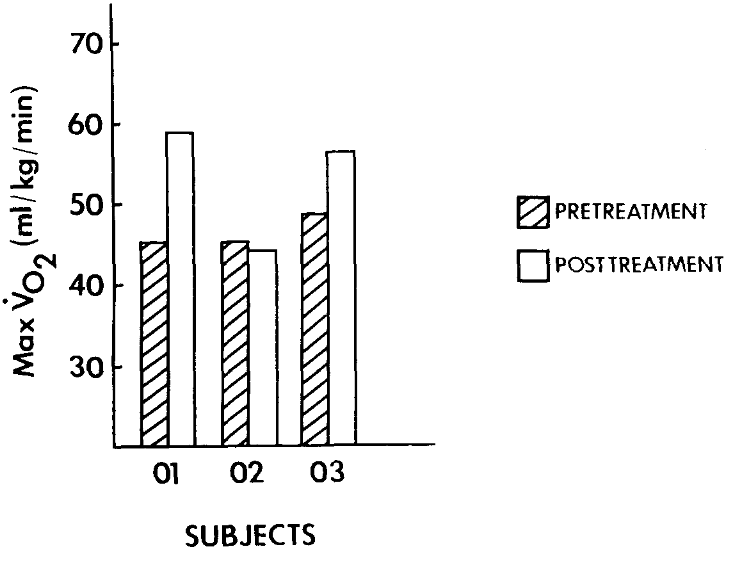
The anaerobic threshold was determined according to the noninvasive procedures by Wasserman et al [9] and occurred at 66%, 54% and 64% of MaxVo_2 for subjects 01, 02 and 03, respectively.

The divergence in functional adaptability as measured by maximal oxygen consumption between our MZ subjects (Figure), suggests that collaboration of environmental factors with the genes is essential for the genotype to reach its full expression [4].

DISCUSSION

Increase in maximal oxygen consumption as a result of training is well documented [2], and there is little doubt that intensive environmental stimulation elicits proportionate changes. In addition, the adaptive value of an individual is decreased with hypokinesis [7]. This observation supports the notion of reversibility of function, that is, environmental stimulation may not have lasting effects. It seems that if there is not a continuous stimulation of sufficient magnitude, the adaptive value of an individual will be set by his genotype.

Previously published findings on identical twins revealed maximal oxygen consumption similarity between 40 year old MZ siblings who had been separated at age 12 and had experienced different lifestyles. One twin had engaged in vigorous training for competitive basketball, whereas his brother was only moderately active during the same period. When tested, their maximal oxygen consumption was closely similar, the absolute values being 37.8 and 41.7 ml/kg/min for the trained and the untrained twin, respectively [5]. In the present investigation all subjects lived at home with their parents and ate the same diet.



Figure

In spite of the divergence of the individual cardiorespiratory variables measured (V_E, Vo_2 and VCo_2), the determination of the anaerobic threshold revealed a striking similarity as to the onset of anaerobiosis among the trained triplets.

Our split-triplet investigation suggests that MZ genotypes respond to varying levels of physical fitness training with concomitant Vo_2 max levels of similar magnitude. The experiment made it possible to separate the observed intrapair variance into its three components: that due to heredity, that due to training, and that due to the interaction between genotype and training did contribute substantially to the total variance of maximal aerobic output. These observations may be extrapolated to all populations and support the notion that the magnitude of improvement in Vo_2 max is commensurate to the relative strenght of the extragenetic influences.

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