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ORIGINAL ARTICLE

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Individual differences in the responses to endurance and resistance training

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Abstract Large individual differences in the responsiveness of cardiorespiratory fitness (VO_{2peak}) to endurance training have been observed in healthy subjects. We tested the hypothesis that subjects with a poor responsiveness to endurance training might benefit from resistance training in terms of aerobic fitness. The study population consisted of sedentary healthy male and female subjects ($n=91$, 42 ± 5 year) assigned to either a training ($n=73$) or a control group ($n=18$). The randomized cross-over study design included a 2-week laboratory-controlled endurance or resistance training period with a 2-month detraining period between the interventions. Large individual differences were observed in the changes of VO_{2peak} (ΔVO_{2peak}) after both the endurance (average 8 ± 6 %, $P<0.001$, range −5 to +22%) and resistance training (average 4 ± 5%, $P<0.001$, range −8 to +16%). The average increase in ΔVO_{2peak} between genders was similar after both the endurance (8 ± 6% for both genders, $P=$ns) and resistance training (3 ± 5% for males and 5 ± 6% for females, $P=$ns). There was no linear relationship between the changes in VO_{2peak} after each training intervention ($r=-.09$, $P=$ns). On the contrary, when the study group was divided into quartiles according to the endurance training response (1 ± 3, 6 ± 1, 9 ± 1, and 16 ± 3% increase in VO_{2peak}), the group with the lowest response to endurance training increased VO_{2peak} after the resistance training intervention (ΔVO_{2peak} 7 ± 5%, $P<0.001$). The individual responsiveness of VO_{2peak} to exercise training is related to the mode of training. The healthy males and females whose training response is low after endurance training seem to result in a marked improvement in their cardiorespiratory fitness by resistance training.

Keywords Individual training response · Controlled · Randomized cross-over study design

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Introduction

Low level of cardiorespiratory fitness (VO_{2peak}) is associated with an increased risk of cardiovascular morbidity and mortality (Blair et al. 1989; Ekelund et al. 1988; Myers et al. 2002; Sandvik et al. 1993). Even small improvements in VO_{2peak} are associated with a reduced risk of death (Erikssen et al. 1998). Improvement in VO_{2peak} occurs after a few weeks of physical exercise training (Hickson et al. 1981; Lee et al. 2003; Mier et al. 1997). However, enormous heterogeneity in the responsiveness to aerobic training has been observed even in highly standardized training programs (Bouchard and Rankinen 2001; Hautala et al. 2003). Mean improvements in VO_{2peak} have been about 10–15% of the baseline values, but the training-induced changes have ranged even from negative response to 40% increase (Bouchard and Rankinen 2001).

Resistance training has the potential to improve VO_{2peak} and decrease the risk for cardiovascular diseases (Kelley and Kelley 2000). Neural adaptation plays a significant role in the strength increase observed in the early stages of adaptation to training (Moritani and deVries 1979) concurrently with muscular hypertrophy (Phillips 2000; Staron et al. 1994). The effect of resistance training on muscular strength, hypertrophy, power, local muscular endurance, and motor performance is evident (Kraemer et al. 2002). Resistance training results also in small to moderate increases in mean VO_{2peak} (Stone et al. 1991). To date, according to our knowledge there are no data available on the effect of resistance training on VO_{2peak} at the individual level.

Since low VO_{2peak} is a remarkable risk factor for untoward cardiovascular events, the procedures how to improve VO_{2peak} for those individuals whose responsiveness to endurance training is low are warranted. Therefore, the purpose of this study was to test the hypothesis that resistance training may increase VO_{2peak} in individuals whose responsiveness to endurance training is low. We assessed the effects of standardized endurance and resistance exercise training interventions on VO_{2peak} using a controlled, randomized cross-over study design (OULUXO Study). Training procedures were standardized according to the current guidelines of American College of Sports Medicine (ACSM 1998; Kraemer et al. 2002).

Methods

Subjects

The subjects were recruited by advertising in a newspaper, which attracted 355 replies. All smokers, subjects with a high body mass index (BMI > 32), subjects who did regular physical training more than twice a week, and subjects with diabetes mellitus, asthma, or cardiovascular disorders were excluded. We invited 108 subjects to our laboratory (Department of Exercise and Medical Physiology, Merikoski Rehabilitation and Research Centre, Oulu, Finland) for more specific assessment. The number of subjects was selected, based on a priori power analysis, to give 90% power to the responsiveness of VO_{2peak}. The subjects were randomized into a training group ($n = 90$) and a control group ($n = 18$). Fourteen subjects dropped out due to personal or health-related problems. Finally, 35 male and 38 female subjects (mean age: 42 ± 1 year) performed both the endurance and the resistance-training programs (Table 1). The control group consisted of 9 male and 9 female subjects (mean age: 41 ± 1 year). The Ethical Committee of the Northern Ostrobothnia Hospital District, Oulu, Finland, approved the protocol.

Experimental design

Sequence of tests

The subjects were first assigned to either exercise training or a control group via stratified random selection. Based on the same criterion, the subjects assigned to the training group were divided to start their exercise with either endurance or resistance exercise training. The selection was done before the initial visit to our laboratory in an attempt to minimize any baseline group difference in physical status. On their first visit to the laboratory, the subjects completed a health status questionnaire, gave written informed consent, and were assessed for body mass index (BMI). Resting electrocardiogram (ECG) was recorded to assess their cardiac health status, and leg strength was measured for the assessment of peak isometric strength. On the next day, resting blood pressure was measured following a graded maximal exercise test on a bicycle for the assessment of maximal aerobic power (VO_{2peak}). Use of alcohol or strenuous physical activity was not allowed during the test days or the two preceding days.

After the initial assessment, 37 subjects in the exercise group underwent highly controlled endurance training, while 36 of them underwent controlled resistance training in our laboratory. The control group was asked to maintain their previous level of physical activity. The training period was 2 weeks, including five consecutive sessions a week (Monday–Friday). On the Monday immediately following the training period, all subjects underwent a 2-day testing session in the same order as before the training period. After these measurements, the subjects were asked not to do any more physical exercise training than they had done before participating in this study for 2 months. The detraining period of 2 months was selected based on previous studies (Mujika and Padilla 2001a, b). Subsequent to detraining for 2 months, the subjects underwent the same pre- and post-training measurements and a second training period of 2 weeks using the training mode other than they had started with (a controlled, randomized cross-over study design). The control group was measured in analogy before and after training periods.

Assessment of peak isometric strength

At the beginning of the strength measurement session, a 5-min warm-up was performed on a bicycle ergometer (workload, 50 W for women and 75 W for men). The peak isometric strength ($Strength_{peak}$) of the leg extensors was measured with a standard leg press dynamometer (Newtest Oy, Oulu, Finland). The subjects sat on the dynamometer chair with their knees at 120° and ankles at 90° flexion while pressing maximally against strain gauges to assess the peak strength of their legs. Familiarization with strength measurements included three submaximal contractions for legs (approximately 70–80% of maximal contraction) with resting periods of 1 min. Isometric strength was recorded for three maximal efforts, each lasting for 3–5 s. The resting period between the maximal efforts was 2 min. The highest value (in kilograms, kg) of the three trials was accepted as the result. If the measured maximal values deviated from each other by more than 10%, an extra maximal effort was performed.

Table 1 The realization of the training

	Endurance training ($n=73$)		Resistance training ($n=73$)		Control ($n=18$)	
	Pre	Post	Pre	Post	Pre	Post
Age (year)	42 ± 5				41 ± 4	
Height (m)	1.70 ± 0.09				1.73 ± 0.08	
Weight (kg)	73 ± 14	72 ± 14	72 ± 14	73 ± 14	75 ± 9	75 ± 9
BMI (kg m^2)	25 ± 3	25 ± 3	25 ± 3	25 ± 3	25 ± 2	25 ± 2
Training						
Duration (min)		40 ± 2		39 ± 7		
Intensity, %HR$_{max}$		74 ± 3		62 ± 6**		
RPE%		70 ± 8		72 ± 8		
Recovery%		81 ± 10		77 ± 7*		

Values are means ± SD. *HR* heart rate; *RPE%*, average of session ratings of perceived maximal (100%) exertion; *Recovery%*, average of session ratings of complete (100%) recovery

*$P < 0.01$

**$P < 0.001$ endurance versus resistance training

Assessment of peak oxygen consumption and heart rate

The subjects performed a graded maximal exercise test on an 839E Monark cycle ergometer (Stockholm, Sweden), starting at 25 W and followed by a work rate increase at 25 W increments every 2 min until exhaustion. Pedaling rate was started from 50 rpm and increased by 5 rpm after every load up to 90 rpm, to achieve maximal effort. The subject was encouraged to continue cycling until he or she could no longer maintain the required pace, at which time the test was terminated. Ventilation (VE), gas exchange (M909 Ergospirometer, Medikro, Kuopio, Finland), and heart rate (Cardiolife TEC-7721K, Nihon Kohden, Tokyo, Japan) were monitored continuously during the protocol. The highest value of oxygen uptake measured during the test (1-min collection) was taken as the peak oxygen uptake ($\dot{V}O_{2peak}$). All subjects fulfilled the criteria for $\dot{V}O_{2peak}$ given in the literature (i.e., respiratory exchange ratio >1.1 or maximum heart rate (HR$_{max}$) within ±10 beats of the age-appropriate reference value) (Howley et al. 1995). Heart rate (HR) was recorded during the exercise test with a Polar R-R Recorder (Polar Electro Oy, Kempele, Finland) at an accuracy of 1 ms and saved in a computer for further analysis of HR$_{max}$ (mean of 10 s) with the HEARTS software (Heart Signal Co, Kempele, Finland).

Exercise training

Endurance exercise training consisted of cycling on an 818E Monark cycle ergometer for 40 min (Stockholm, Sweden). Each exercise session consisted of a 5-min warm-up period (cycling at 50 and 75 W resistance for females and males, respectively), followed by 30 min of cycling at a resistance that elicited a HR of 70–80% HR$_{max}$, and ended with a 5-min cool-down period (cycling at 50 and 75 W resistance for females and males, respectively). Exercise intensity was closely monitored using a Polar Electro heart rate monitor A1 (Polar Electro Oy, Kempele, Finland), and the mean HR of each exercise was recorded. The individual HR$_{max}$ was established based on the HR$_{max}$ achieved during the $\dot{V}O_{2peak}$ test. Endurance exercise training was planned on the basis of the recommendations of American College of Sports Medicine (ACSM 1998). A professional instructor supervised each training session.

Resistance exercise training was established based on the recommendations of ACSM (Kraemer et al. 2002). Resistance training consisted of 15 exercises involving the major muscle groups performed with one set of 8–12 repetitions to near fatigue (8–12 RM). Each exercise session consisted of a 5-min warm-up period (cycling at 50 and 75 W resistance for females and males, respectively), followed by resistance training every 2 days specifically focusing on either leg or arm strength. The exercise session ended with a 5-min cool-down period (cycling at 50 and 75 W resistance for females and males, respectively). The first ten exercises included all the major muscle groups, and the second half round of exercises (5) mainly consisted of leg or arm exercises. The velocity of muscle contraction was moderate, and the resting period between the exercises was 1 min. At the first two training sessions, the subjects were instructed to use HUR strength training devices (HUR Oy, Kokkola, Finland) and to find the correct resistance. The subjects performed a single exercise set to near fatigue even when the resistance was too low or high. If the number of repetitions was under 8 or over 12 in a single exercise, resistance was decreased or increased in the next exercise session in order to reach 8–12 repetitions. Exercise intensity was closely monitored using a Polar Electro heart rate monitor A1 (Polar Electro Oy, Kempele, Finland), and the mean HR of each exercise was recorded. A professional instructor supervised each training session.

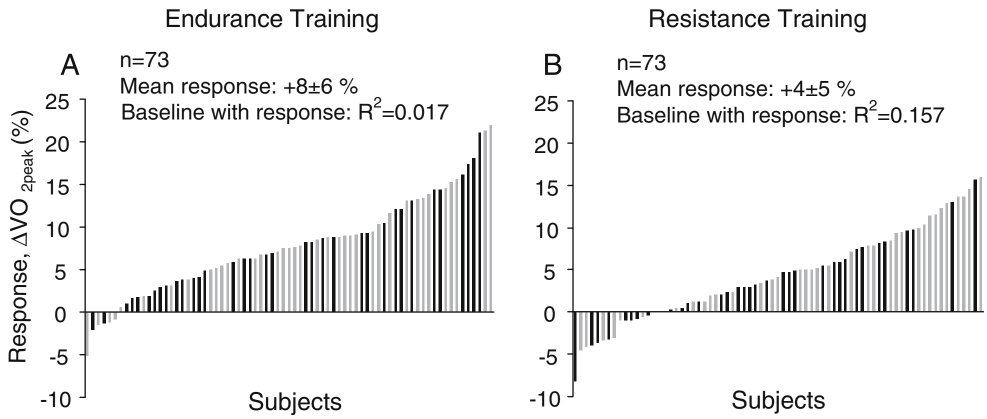

Fig. 1 Heterogeneity of VO_{2peak} training responses after 2 weeks of controlled endurance (**a**) and resistance (**b**) training among healthy female (*gray bars*) and male (*black bars*) subjects

Perceived exertion and subjective recovery

Immediately after each exercise session, the subjects were asked to give a perceived exertion score (RPE) on the Borg scale of 6–20 (Borg 1973). Maximal perceived exertion (20) was determined as 100%. In addition, just before the next training session, the subjects were asked about their subjective feeling of recovery from the preceding exercise on a scale of 6–20. A subjective feeling of complete recovery (20) was recorded as 100%.

Statistical methods

The results are expressed as mean ± SD. The normal Gaussian distribution of the data was verified by the Kolmogorov–Smirnov goodness-of-fit test. The differences within the groups after training were analyzed by a two-factor analysis of variance (ANOVA) for repeated measures with time and interventions followed by post hoc analysis (Student's paired t test). A linear (enter) regression analysis procedure was used to study the contribution of the baseline status of age, BMI, VO_{2peak}, strength and changes (Δ) in these parameters after both training interventions. ANOVA was used to study the contribution of starting training mode to the training responses of VO_{2peak}. Pearson's bivariate correlation analysis was performed to study the differences in the changes of fitness, training, and anthropometrics after 2 weeks of exercise training in the male and female groups. Pearson's bivariate correlation analysis was also used to study the differences in ΔVO_{2peak} after endurance and resistance training. When the training group was divided into quartiles according to ΔVO_{2peak}, ANOVA was used, followed by a post hoc analysis of Bonferroni's t test, to compare the differences between the groups. The data were analyzed using the SPSS software (SPSS 12.0, SPSS inc., Chicago, USA). $P < 0.05$ was considered statistically significant.

Results

Training responses

The realization of training is presented in Table 1. The individual training responses in VO_{2peak} (%) are shown in Fig. 1. The average increase in VO_{2peak} was $8 \pm 6\%$ ($P < 0.001$, range -5 to $+22\%$) after endurance training and $4 \pm 5\%$ ($P < 0.001$, range -8 to $+16\%$) after resistance training. The absolute values are presented in Table 2. The training responses did not differ between the males and females e.g. the average increase in ΔVO_{2peak} between genders was similar after both the endurance ($8 \pm 6\%$ for both genders, P = ns) and resistance training ($3 \pm 5\%$ for males and $5 \pm 6\%$ for females, P = ns). None of the measured variables changed within the control group. The change of the VO_{2peak} in the control group was $-0.4 \pm 6.4\%$ (95%

Table 2 Effects of training

	Endurance training ($n = 73$)		Resistance training ($n = 73$)		Control ($n = 18$)	
	Pre	Post	Pre	Post	Pre	Post
VO_{2peak} (l min^{-1})	2.5 ± 0.7	2.7 ± 0.8*	2.5 ± 0.8	2.6 ± 0.8*	2.8 ± 0.7	2.8 ± 0.7
VO_{2peak} (ml kg^{-1} min^{-1})	34 ± 7	37 ± 7*	34 ± 7	36 ± 7*	36 ± 7	36 ± 7
Strength$_{peak}$ of legs (kg kg^{-1})	4.31 ± 1.10	4.51 ± 1.12*	4.23 ± 1.09	4.82 ± 1.15*	4.25 ± 0.94	4.20 ± 0.81
HR_{max} (bpm)	181 ± 10	181 ± 9	180 ± 10	180 ± 10	180 ± 10	180 ± 11
RER_{max}	1.25 ± 0.07	1.25 ± 0.07	1.24 ± 0.07	1.25 ± 0.07	1.24 ± 0.07	1.25 ± 0.07

Values are means ± SD. VO_2, oxygen consumption; *Strength* isometric strength; *HR* heart rate; *RER* respiratory exchange ratio
*$P < 0.001$ pre- versus post-exercise training

confidence intervals $\pm 2.9\%$). 62 (85%) and 55 (71%) of the subjects in the endurance and resistance training group, respectively, improved their VO_{2peak} more than the upper 95% confidence interval of the control group.

Resistance training effects on VO_{2peak}

There was no linear association between the responses in VO_{2peak} (ΔVO_{2peak}) after endurance and those after resistance training ($r = -.09$, $P = $ ns, Fig. 2). The study group was divided into quartiles according to the endurance training response (1 ± 3, 6 ± 1, 9 ± 1, and $16 \pm 3\%$ increase in VO_{2peak}). Thereafter, the resistance training effects on VO_{2peak} were analyzed in these subgroups and separately for males and females (Fig. 3). Resistance training resulted in $7 \pm 5\%$ VO_{2peak} increase ($P < 0.001$) among the subjects with the lowest endurance training response ($1 \pm 3\%$, $P = $ ns). The low-response group did not differ from the other groups after either endurance or resistance training in terms of the realization of training or the changes in BMI. There were no differences between the subgroups in the baseline level of age, BMI, VO_{2peak}, Strength$_{peak}$, respiratory exchange ratio, or HR_{max}.

Effects of baseline on training response

The association between baseline VO_{2peak} and ΔVO_{2peak} was statistically significant after both endurance ($r = -.26$, $P < 0.05$) and resistance training ($r = -.32$, $P < 0.01$). The contribution of age to the ΔVO_{2peak} was not statistically significant after endurance or resistance ($r = .10$ and $r = -.10$, respectively). Baseline BMI associated with ΔVO_{2peak} after endurance training ($r = .37$, $P < 0.01$), but not after resistance training ($r = -.10$, $P = $ ns). There was no association between baseline strength$_{peak}$ and ΔVO_{2peak} after both endurance ($r = -.01$, $P = $ ns) and resistance training ($r = -.04$, $P = $ ns).

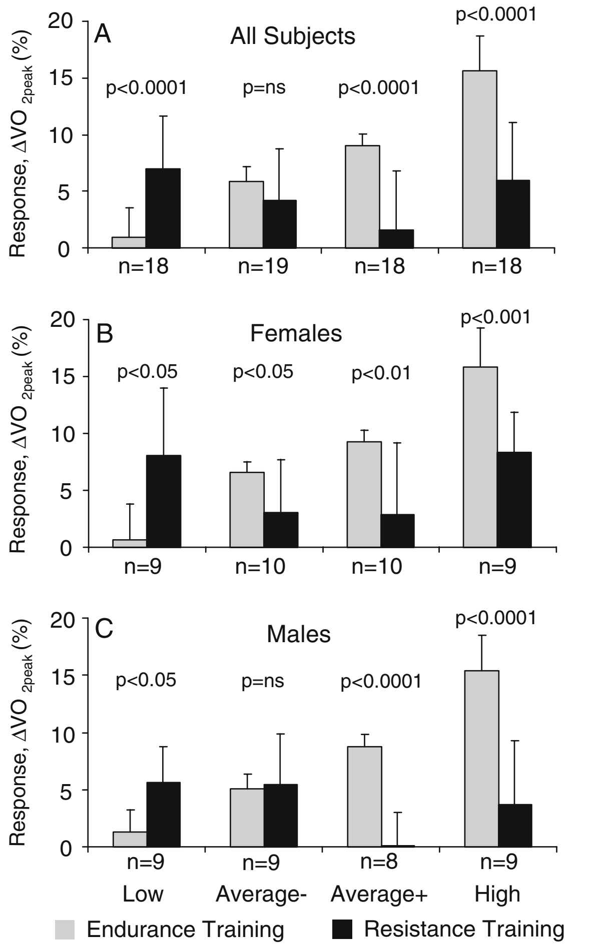

Fig. 3 Exercise training responses after endurance and resistance training for all the subjects (**a**) and separately for females (**b**), and males (**c**). The subjects were divided into quartiles according to their endurance training response as follows: 1 ± 3 (Low), 6 ± 1 (Average $-$), 9 ± 1 (Average $+$), and 16 ± 3 (High) % increase VO_{2peak}

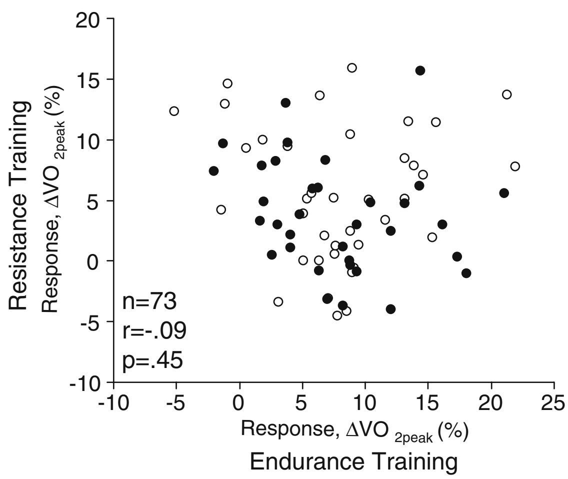

Fig. 2 The association between endurance and resistance training responses in VO_{2peak} (ΔVO_{2peak}, %). *White circles* represent female and *black circles* male subjects

Effects of initial training mode on training response

The training effect on VO_{2peak} was similar whether initial training mode was endurance or resistance training (e.g., ΔVO_{2peak} after endurance training was $9 \pm 4\%$ in subjects who performed endurance period first and $7 \pm 7\%$ in subjects who performed endurance period last, $P = $ ns). The training effect on VO_{2peak} was also similar when analyzed separately in the subgroups (e.g., ΔVO_{2peak} after endurance training for low responders was $1 \pm 3\%$ in subjects who performed endurance period first and $2 \pm 2\%$ in subjects who performed endurance period last, $P = $ ns).

Discussion

The main finding of this study is that if the training response is low after endurance training, cardiorespiratory fitness may be improved effectively by the resistance training among the healthy male and female subjects. There was no linear relationship between the responses in VO_{2peak} after endurance and resistance training, suggesting that there are individual differences in the training responses, which are highly dependent on the training mode itself. Some individuals who are not able to improve their fitness by endurance training seem to obtain a marked benefit in their aerobic fitness by resistance training. On the other hand, all individuals who improve significantly their fitness by endurance training do not necessarily benefit from resistance training.

Individual responses to training

Several studies have documented that about ~10 % of individuals achieve no or only a poor improvement in their cardiorespiratory fitness after highly controlled endurance training (Bouchard and Rankinen 2001; Hautala et al. 2003; Lortie et al. 1984; Skinner et al. 2000, 2001). There has been less information on the effects of resistance training on individual responses. We observed here that resistance training, performed according to the current guidelines of American College of Sports Medicine (Kraemer et al. 2002), might also serve as an effective method to improve the cardiorespiratory fitness. An evident training response was observed in more than two-thirds of the subjects after short-term resistance training when compared to a change in aerobic fitness of the control group. However, similar heterogeneity was observed in the responses to resistance training as that observed after endurance training.

Baseline characteristics as a determinant of training response

Previous studies have shown that the baseline characteristics may have an impact on responsiveness to endurance training (Bouchard and Rankinen 2001; Skinner et al. 2001). According to the previous studies, we also found similar relationship between baseline fitness and responsiveness after both training modes in the present study. Subjects with lower level of VO_{2peak} at baseline improved their cardiorespiratory fitness more compared to subjects with higher baseline level of VO_{2peak}. However, the baseline strength was not related to the changes in VO_{2peak} after the both training modes.

Low cardiorespiratory fitness is associated with high level of total and abdominal fat independent of BMI (Janssen et al. 2004; Wong et al. 2004). In the present study, the baseline BMI associated positively with the improvement in VO_{2peak} after endurance training. It may be possible that those individuals with higher BMI at baseline had higher proportion of lean muscle tissue and therefore improved their fitness more compared to those with lower proportion of lean muscle tissue. However, this hypothesis must be tested in future studies. It is also notable that the predictive value of BMI is less representative when the average values are below 30 kg m^2 (Garn et al. 1986), which is the case in the present study.

Individual training adaptation

The association between the endurance and resistance training responses in the VO_{2peak} shows that there are individuals who are resistant to endurance training, but gain markedly from resistance training (Figs. 2, 3). On the other hand, the individuals with the highest response to endurance training also have a high response to resistance training. Furthermore, some of the individuals respond only to endurance training but not at all to resistance training. These observations suggest that there are some intrinsic features that predispose the individuals to favorable influences of either the endurance or resistance training mode.

One of the potential factors explaining the heterogeneity in the individual responses is genetic feature. It is well known that genetic background causes considerable variation in both the baseline cardiorespiratory fitness and the changes in fitness after exercise training interventions (Bouchard et al. 1999; Bouchard and Rankinen 2001; Perusse et al. 2003; Rankinen et al. 2004). The present study showed that cardiorespiratory fitness could be improved effectively by resistance training in a subgroup of subjects if the response to VO_{2peak} was low after the endurance training. It can be hypothesized that the subjects of this specific subgroup may be genetically predisposed to a poor endurance training response. The present findings support the notion that the role of genetic inheritance may be a major determinant of the responsiveness of fitness to both endurance and resistance training.

Study limitations

The short-term training period of the present study may be an obvious limitation. However, despite the short-term exercise training interventions, the magnitude of the average training effect is the same as that reported also in previous short-term exercise training studies (Hickson et al. 1981; Lee et al. 2003; Mier et al. 1997; Moritani and deVries 1979), and the heterogeneity of individual training responses in VO_{2peak} is similar than reported in HERITAGE family study among 720 healthy individuals after 20 weeks of endurance training (Bouchard and Rankinen 2001). Secondly, sufficient number of subjects and cross-over study design diminish training protocol-related biases. Furthermore, we also included a control group to estimate the amount of spontaneous temporal changes in the cardiorespiratory fitness.

Conclusion

The present observations provide novel information on the individual differences in responses to endurance and resistance training. In particular, healthy subjects with a low endurance training response may improve their cardiorespiratory fitness after resistance training. These data suggest that training modes could be tailored individually by assessing first the responses to short-term exercise. Those who are not able to improve their cardiorespiratory fitness by short-term endurance training should be advised to start resistance-training programs in attempts to improve their cardiorespiratory fitness. However, further studies on the methods of how to predict individual changes in fitness are warranted.

The polygenic nature of performance and health-related fitness phenotypes challenge the future studies in the field of molecular and cellular adaptation to exercise training. It is also highly possible that genetic factors may be major modifiers of training-induced changes in the specific subgroups observed in the present study.

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