Individual responses to combined endurance and strength training in older adults

Running title: Individual responses to physical training

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Disclosure of funding: Ministry of Education, Finland; Juho Vainio Foundation, Finland.

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Abstract

Purpose. A combination of endurance and strength training is generally used to seek further health benefits or enhanced physical performance in older adults compared to either of the training modes alone. The mean change within a training group, however, may conceal a wide range of individual differences in the responses. The purpose was, therefore, to examine the individual trainability of aerobic capacity and maximal strength, when endurance and strength training are performed separately or concurrently.

Methods. 175 previously untrained volunteers, 89 men and 86 women between the ages of 40 and 67, completed a 21-week period of either strength training (S) twice a week, endurance training (E) twice a week, combined training (ES) four times per week, or served as controls. Training adaptations were quantified as peak oxygen uptake (VO_{2peak}) in a bicycle ergometer test to exhaustion and maximal isometric bilateral leg extension force (MVC) in a dynamometer.

Results. A large range in training responses, similar to endurance or strength training alone, was also observed with combined endurance and strength training in both ΔVO_{2peak} (from -8 to 42%) and ΔMVC (from -12 to 87 %). There were no significant correlations between the training responses in VO_{2peak} and MVC in the E, S, or especially in the ES group, suggesting that the same subjects did not systematically increase both aerobic capacity and maximal strength.

Conclusion. The goal of combined endurance and strength training – increasing both aerobic capacity and maximal strength simultaneously – was only achieved by some of the present older subjects. New means are needed to personalize endurance, strength and especially combined endurance and strength training programs for optimal individual adaptations.

Keywords: trainability, training adaptation, aerobic capacity, maximal strength

Introduction

Paragraph Number 1 A considerable number of studies have evidenced the beneficial effects of physical training in older adults. The mean change within a training group, however, may conceal a wide range of individual differences in trainability ranging from high responders to low and no responders, and even negative responders (5). Since training is used, for example, for prevention of various diseases and age-related decreases in physical performance, attention should be aimed at individual differences in training adaptations (24). Therefore, information that is valuable for optimizing training programs may be lost when drawing conclusions based on average training responses alone (5).

Paragraph Number 2 Individual differences in the adaptation to physical training have caught only minor research attention considering the large number of studies investigating training effects. The average change in aerobic capacity with regular endurance training may even conceal a range of responses between a negative change up to a doubling of aerobic capacity (4). Similar to endurance training adaptations, strength training-induced changes in muscle strength have shown large variations, ranging between a negative change to as much as a 250 % increase in young adults (21). It has also been suggested that the variation in strength adaptations may be even larger in older compared to young adults (32).

Paragraph Number 3 A combination of endurance and strength training modalities is generally used to seek further health benefits or enhanced physical performance in older adults compared to either of the training modes alone (9,13,23,37). However, depending on the training volume, mode, or duration of the combined training period, a number of studies have reported interference in the development of maximal strength (3,19) or aerobic capacity (31). Therefore, the ability to improve both characteristics may be limited and individually determined. On the other hand, strength training may also, to some extent, increase aerobic capacity (12,17), while endurance training may lead to some gains in strength (16), suggesting that some synergistic benefits of concurrent endurance and strength training may also occur. Due to the individual responses to both endurance and strength training, it is not known, whether the existing guidelines of concurrent endurance and strength training (33) produce the optimal training responses for each individual.

Paragraph Number 4 The purpose of this study was to examine individual differences in the training response to endurance, strength and combined endurance and strength training in older men and women. The change in aerobic capacity was also examined in relation to the change in maximal strength, to observe whether the same subjects had a high or low response to both training modalities when endurance and strength training programs were performed separately or concurrently.

Methods

Paragraph Number 5 Subjects. Healthy untrained 40 to 67 year old men and women were recruited for the intervention by advertising in newspapers and through e-mail lists. The participants were informed about the design of the study and possible risks and discomforts related to the measurements, and all participants signed a written informed consent. Subjects underwent an examination of general health and a resting electrocardiogram (ECG), administered by a physician. Subjects without cardiovascular or musculoskeletal disorders, diabetes, or medications known to influence cardiovascular or neuromuscular performance continued in the study. The subjects who passed the medical examination performed a maximal exercise test to voluntary exhaustion with ECG monitoring under the supervision of a physician. Subjects showing signs of cardiovascular or musculoskeletal problems were excluded from the study.

Paragraph Number 6 207 subjects continued participation in the intervention. Nine men and six women dropped out for different reasons, such as musculoskeletal injuries, cardiac problems, delayed post measurements due to a respiratory tract infection, or personal reasons. Due to technical or musculoskeletal problems, 17 subjects were discarded from further analysis. Finally, 175 subjects, 89 men and 86 women [mean age 53 (SD 8) years)], completed the intervention. The characteristics of the final subject groups at baseline are presented in table 1. The study plan was approved by the Ethics Committee of the University of Jyväskylä.

Paragraph Number 7 Experimental design. The subjects were randomized into an endurance training, strength training, combined endurance and strength training group or a control group. The measurements were performed once (aerobic capacity) or twice (maximal strength) before the training, representing a control period of two weeks (-2), and after the 21-week training period. This study was part of a larger project, and the data on body composition (36), muscle hypertrophy (25), heart rate variability (26), antioxidant enzyme gene expression (11), androgen receptor mRNA (1), and serum hormones and nutrition (35) have previously been published.

Paragraph Number 8 Aerobic performance test. A graded maximal aerobic cycling test to volitional exhaustion was performed on a mechanically braked bicycle ergometer (Ergomedic 839E, Monark Exercise AB, Sweden) with simultaneous ECG and blood pressure monitoring. The test was supervised by a physician. The exercise intensity was increased by 20 W every

2nd minute starting with 50 W, and pedalling frequency was sustained at 60 rpm throughout the test. Oxygen uptake (VO_2), carbon dioxide production (VCO_2), ventilation (VE), breathing frequency (Fr) and other standard respiratory parameters were measured continuously breath by breath (SensorMedics® Vmax229, SensorMedics Corporation, Yorba Linda, CA, USA). VO_{2peak} was determined as the highest minute average of VO_2 during the test (30).

Paragraph Number 9 Strength measurement. Isometric bilateral leg extension force, i.e. an isometric leg press, (MVC) was measured on a dynamometer (15) in a seated position with a knee angle of 107° and a hip angle of 110°. Subjects were instructed to generate maximum force as rapidly as possible against the force plate for a duration of 2–4 s. Subjects performed a minimum of three trials, and the trial with the highest peak force was selected for further analysis. The force signal was low-pass filtered (20 Hz) and analyzed (Signal software Version 2.15, Cambridge Electronic Design Ltd., Cambridge, UK).

Paragraph Number 10 Strength training. Strength training was carried out twice a week. All strength training sessions were supervised, and training intensity and volume were monitored using training diaries. The strength training program included 7–10 exercises that activated all of the main muscle groups. Every training session included two exercises for the leg extensors (leg press and knee extension), one exercise for the knee flexors (leg curl), and one to two other exercises for the lower extremities (seated calf raise, hip abduction or adduction). For the upper body, each session included three to four exercises (bench press, biceps curl, triceps pull-down, lateral pull-down), and one to two exercises for the trunk (abdominal crunch, seated back extension). The overall intensity and amount of training increased progressively throughout the 21-week training period (15).

Paragraph Number 11 The training period was divided into three 7 week cycles to optimise strength gains and muscle hypertrophy. The focus of the first cycle was to accustom the subjects to high intensity training and to improve muscle endurance and strength using light loads (40 – 60 % of 1RM) and a high number (12 – 20) of repetitions, and by performing 3 sets. The second cycle (weeks 8 – 14) was designed to produce muscle hypertrophy to further increase the total muscle mass/fat ratio by increasing the loads progressively up to 60-80 % of the maximum, with 5 – 12 repetitions and 2 – 4 sets. To optimise maximal strength development and to further produce hypertrophy during weeks 15 – 21, higher loads of 70 – 85 % of 1RM together with 5 – 8 repetitions and 2 – 4 sets were used. In addition, approximately 20 % of the leg press, knee extension and bench press exercises were performed with light loads of 40 to 50 % of 1RM and 5 – 8 repetitions, to meet the requirements of a typical explosive strength training protocol. With the light loads, each repetition was executed as rapidly as possible (15).

Paragraph Number 12 Endurance training. Endurance training was carried out twice a week. The heart rate levels for endurance training were determined based on respiratory parameters and blood lactate concentrations, as described in detail previously (2). During the first 7 week period, the subjects trained on a bicycle ergometer for 30 min below the level of the aerobic threshold. Weeks 5 – 7 during the first period also included three training sessions during which the subjects were accustomed to the intensity above the aerobic threshold by a 10 minute interval in the middle of the sessions. During weeks 8 – 14, one weekly session of 45 min included a 10-min interval between the aerobic-anaerobic thresholds and a 5-min interval above the anaerobic threshold, in addition to a 15-min warm-up and a 15-min cool down below the aerobic threshold. The other weekly training session involved 60 min of cycling below the aerobic threshold. The focus of training during weeks 15 – 21 was to improve maximal endurance. One of the weekly sessions lasted for 60-min, which included two 10-min intervals between the aerobic-anaerobic thresholds, two 5-min intervals above the anaerobic threshold, and 30 min below the aerobic threshold. The other weekly session included 90 min cycling at a steady pace below the aerobic threshold. All training sessions were supervised, and monitoring and constant supervision of heart rate were used. To further confirm the required training intensity and duration of the high intensity intervals average heart rate values from each individual interval in each training session were written down and controlled.

Paragraph Number 13 Combined endurance and strength training. The subjects in the combined endurance and strength training group performed endurance training twice a week and strength training twice a week, performing a total of 4 training sessions per week on alternating days as described in the preceding paragraphs (14).

Paragraph Number 14 Statistical analyses. The results are expressed as individual values and/or means and 95 % confidence intervals (95 % CI). The upper 95 % CI of the control group was also used as the lower limit for a significant individual training-induced change in the training groups. Variability in the training response was calculated as the coefficient of variation, and Levene's test was used to assess the equality of variances between the training groups. Differences in the mean responses between the groups were studied with multifactor analysis of variance (ANOVA for training group, gender, and time interactions) followed by one-way ANOVA and Bonferroni post-hoc analysis. Differences in the training mode-specific responses between men and women were studied using analysis of variance (ANOVA) with repeated measures. The assumptions for repeated measures ANOVA (homogeneity of variance, sphericity, and normal distribution) were tested. Pearson's product-moment correlation coefficient was used to evaluate the relations between variables, and Spearman's rank-order correlation coefficient was used to study the relation between the training responses in aerobic capacity and maximal strength within the training groups. The critical level of significance was set at $P = 0.05$. Statistical analyses were carried out using SPSS 14.0 software for Windows (SPSS Inc., Chicago, IL).

Results

Paragraph Number 15 The average training adherence was 99 (3) % in endurance and 99 (2) % in strength training sessions. All subjects completed a minimum of 90 % of the total training volume. Furthermore, there were five or less subjects in each group who performed <95 % of the total training volume when strength and endurance training programs were analyzed separately in the ES group. There were no differences between groups in the training adherence. The multifactor ANOVA showed a significant gender x time ($P = 0.048$) and training group x time ($P < 0.001$) interactions. On average, VO_{2peak} increased more in ES and E than in S or C (between groups $P < 0.001$), and the mean increase of MVC was larger in ES and S compared to C and E ($P < 0.05$). VO_{2peak} increased similarly in the ES and E groups (between groups $P = 1.00$). Furthermore, similar mean changes in MVC were observed in ES and S (between groups $P = 0.37$). Training and gender-specific changes in VO_{2peak} and MVC are presented in Fig.1. A significant difference between genders in the training response was only observed in ΔVO_{2peak} in ES, whereby women showed a larger mean response than men (Fig.1).

Paragraph Number 16 Large individual differences in trainability were observed in all training groups (Fig.1). Coefficient of variation (CV) of ΔVO_{2peak} was similar in E (0.92) and

ES (0.90), and CV of ΔMVC was similar in S (0.85) and ES (0.82). Large interindividual variation was also observed in ΔVO_{2peak} after strength training and in ΔMVC after endurance training (Fig.1). In S, 27 % of the subjects increased their VO_{2peak} more than the upper 95 % CI of the control group (4.5 %). In E, 33 % increased their MVC more than the upper 95 % CI of the control group (10.1 %).

Paragraph Number 17 There were no significant correlations between the training responses in VO_{2peak} and MVC in E (r = 0.097, P = 0.54), S (r = 0.059, P = 0.69), or ES (r = 0.078, P = 0.58). Fig.2 shows that even though a few subjects in the ES group showed a negative training response in VO_{2peak} or MVC, none of the subjects showed a negative change in both. In addition, none of the subjects reached the highest quintile in both ΔVO_{2peak} and ΔMVC (Fig.2), and only two subjects reached the highest quartile and seven subjects the highest tertile in both ΔVO_{2peak} and ΔMVC. Furthermore, only 55 % of the subjects increased both their VO_{2peak} and MVC more than the upper 95 % CI of the control group.

Paragraph Number 18 The correlations between baseline VO_{2peak} and ΔVO_{2peak} were significant in all training groups (r = -0.53 – -0.43, P < 0.01). When genders were analyzed separately, however, the same correlations were only significant in women in E (r = -0.72, P < 0.001), S (r = -0.44, P = 0.027), and ES (r = -0.56, P = 0.005), but not in any of the groups in men. No significant correlations were found between baseline MVC and ΔMVC in any of the training groups. Across the whole ES group, age correlated significantly with ΔVO_{2peak} (r = -0.34, P = 0.012), but not in men or women separately.

Discussion

Paragraph Number 19 This study examined individual differences in the responses to a controlled endurance, strength or combined endurance and strength training program in previously untrained older men and women. Training-induced adaptations commonly reported after endurance and strength training were also observed with the present 21-week training program, whereby endurance training led to a significant increase in aerobic capacity, and strength training led to significant increase in maximal strength. A new finding was the large individual variation in VO_{2peak} and MVC responses to combined endurance and strength training in older adults, which was similar to endurance or strength training alone, respectively. Moreover, the combined training group did not show a significant correlation between the individual changes in VO_{2peak} and MVC. This finding suggests that the same subjects were not systematically low or high responders to both endurance and strength training when these training modes were performed concurrently for a prolonged period.

Paragraph Number 20 Training responses to the present combined endurance and strength training varied from -8 to 42 % in VO_{2peak} and from -12 to 87 % in MVC. This finding in older adults further confirms the wide range in individual training adaptations that has been previously reported in younger subjects separately with endurance (5,6,29) or strength training (21,32). The range in training responses seems to be similar in the present E and ES groups in terms of VO_{2peak} as well as in S and ES in terms of MVC. Furthermore, the similar mean change in VO_{2peak} in E and ES and in MVC in S and ES suggests that at the group level, no interference due to the present combined training program was observed in the development of VO_{2peak} or MVC. Individual values reveal, however, that only a few of the subjects showed large increases in both VO_{2peak} and MVC.

Paragraph Number 21 In the present study, the intensity of training was individualized based on baseline and midpoint measurements, and yet, a few subjects in the ES group showed a negative response in VO_{2peak} or MVC. However, none of the subjects in ES had a negative response to both aerobic capacity and maximal strength (Fig.2). Correspondingly, none of the subjects in the upper quintile in terms of ΔVO_{2peak}, i.e. very high responders, had a very high response in MVC as well. Furthermore, only a few subjects fell into the upper tertile in both ΔVO_{2peak} and ΔMVC. An individual's ability to improve both characteristics with combined endurance and strength training may, therefore, be limited, which may not have been observed from the comparisons between the group mean values. Previous studies investigating combined endurance and strength training have suggested that the specific exercises involved in both endurance and strength training (28), training volume or frequency (14,22), and duration of the training period (14,19) may determine whether the development of strength or aerobic capacity is inhibited. However, the problem seems to be more complex since there may be an individual optimum for the combination of training design variables as well as proportions of endurance and strength training to enhance the training outcomes in both VO_{2peak} and MVC.

Paragraph Number 22 Some synergistic effects may also be masked in the group mean values. Based on earlier findings, endurance training may produce some stimulus for maximal strength development in older adults through muscle hypertrophy (8,16) and remodelling of contractile properties of the muscle fibres (16). Increases in muscle strength were demonstrated in one third of the present subjects in the E group. Correspondingly, approximately one fourth of the subjects in the strength training group were able to improve their VO_{2peak}. Previous studies suggest that strength training may lead to peripheral changes that improve the capacity of muscle to use oxygen (12) through increased capillarization

(10,18) and conversion of IIX muscle fibers to IIA and IIAX (20). In addition, the increase in lower extremity strength may increase the time to exhaustion in incremental cycling exercise, and as a result, increase VO_{2peak}. A previous investigation about the effects of a short-term endurance or strength training program on VO_{2peak} showed that a subgroup of subjects did not respond to endurance training but increased their VO_{2peak} with strength training (17).

Paragraph Number 23 As the examination of possible determinants of trainability was beyond the scope of the present study, the possibility to discuss the factors contributing to the training response is limited. Previous studies have shown that age and gender only have minor if any effects on the endurance training response (5,17,27). In addition, VO_{2peak} at baseline may be an insignificant (27) or a small contributor (17) to the training response. In our study, the gains in VO_{2peak} were correlated with baseline values in all training groups in women but not in men. A similar kind of trend has been found previously in a study investigating both men and women, but the correlations were not significant in either men ($r = 0.04$) or women ($r = -0.27$) (27). The effect of age on ΔVO_{2peak} seemed to be minor in this study, and was only significant in the ES group. Age, gender and baseline MVC were not correlated with ΔMVC in the present subjects. Based on earlier studies, genotype may explain as much as half of the interindividual variation in the training response after both endurance (6) and strength training (37). However, a question remains regarding how this information can be used to effectively individualize endurance and strength training programs.

Paragraph Number 24 The most recent guidelines for exercise prescription by ACSM suggest three or more aerobic training sessions per week with intensities equal to or over 60 % of maximal heart rate for older adults (7) combined with two to three resistance training sessions per week with fatiguing or near fatiguing intensity (34). Although there are several potential benefits in combining endurance and strength training modalities the present results imply that over a prolonged training period, a large part of older adults may require individualized training prescription for optimal adaptations. A possibility for optimization and a potential branch for further studies could be a careful periodization of endurance and strength training alternating training sessions not only within a week, as in the present study, but also over longer training cycles.

Paragraph Number 25 The present results support the existence of large individual differences in the responses to both endurance and strength training. The new approach was to evaluate the trainability of older men and women after a controlled and progressive combined endurance and strength training program. We conclude that a large range in training adaptations was also observed with combined endurance and strength training. Furthermore, during combined training, high responders in terms of aerobic capacity do not seem to be high responders in maximal strength as well, and vice versa. Examination of individual responses was required to reveal that the apparent goal of combined endurance and strength training – increasing both aerobic capacity and maximal strength simultaneously – was only achieved by approximately half of the present older subjects. New means are needed to personalize endurance, strength and especially combined endurance and strength training programs for optimal individual adaptations.

Acknowledgments

Paragraph Number 26 The results of the present study do not constitute endorsement by ACSM.

Grants

Paragraph Number 27 This study was supported by the Ministry of Education, Finland, and the Juho Vainio Foundation, Finland.

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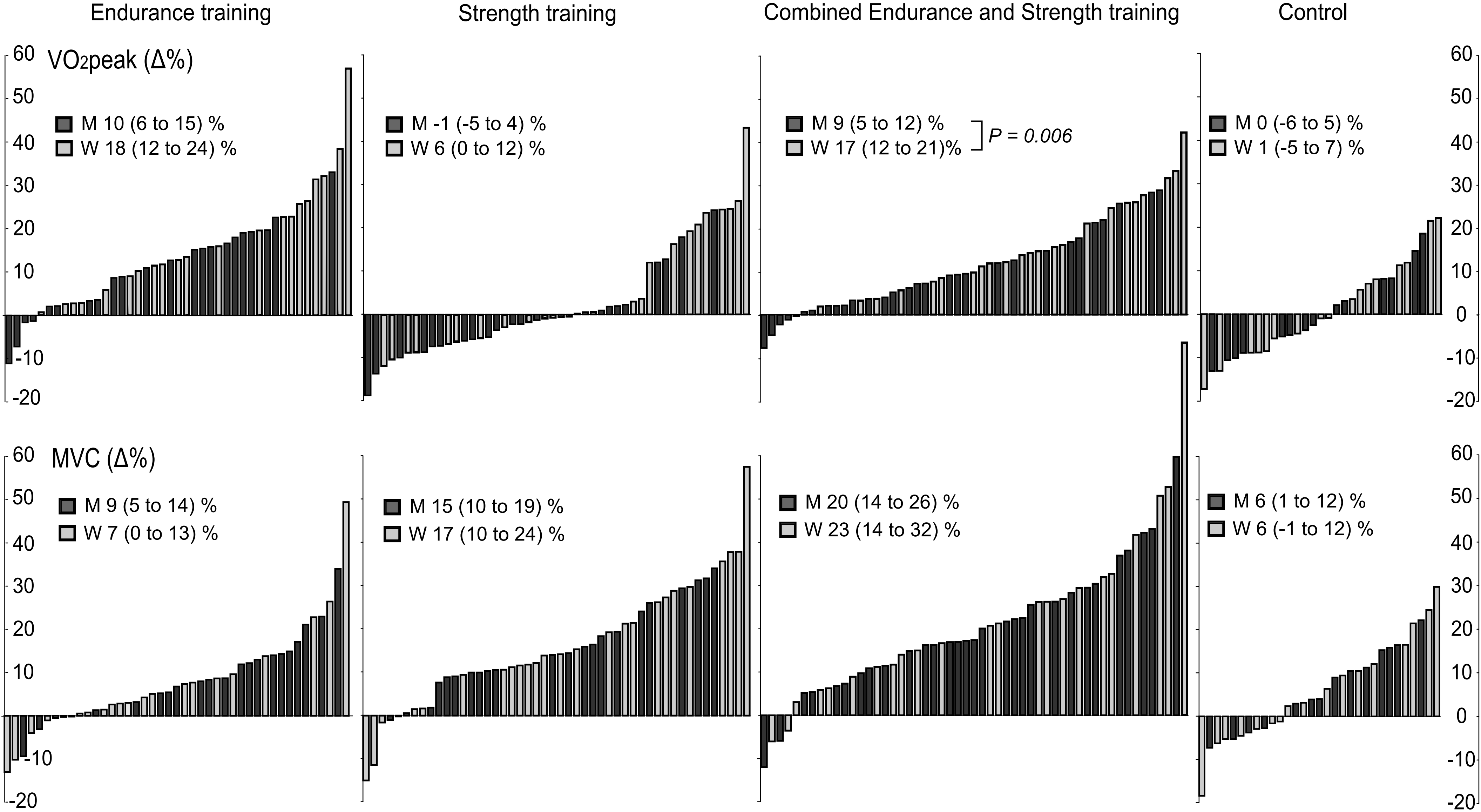
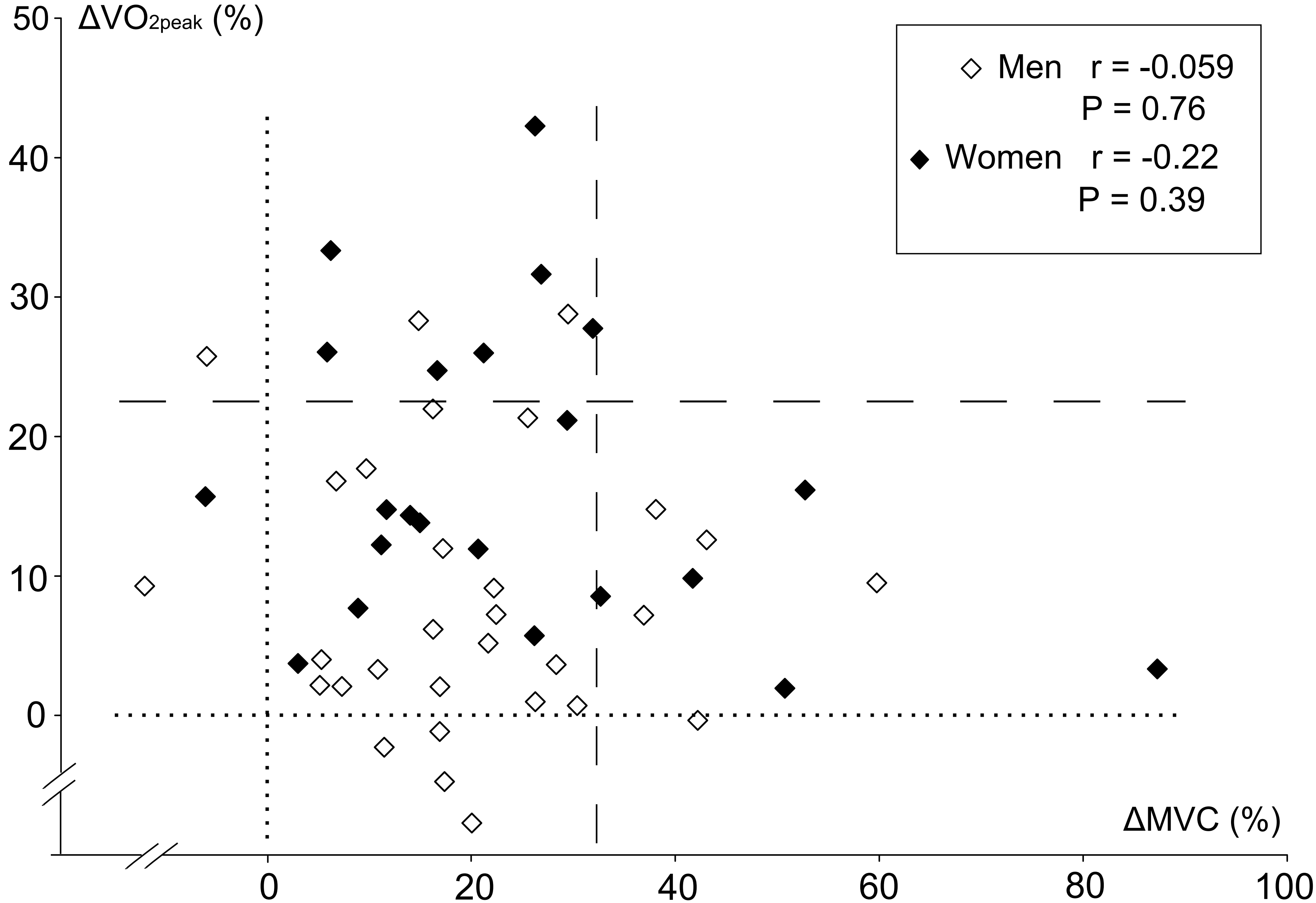
Figure captions

Fig.1. Individual (bars) and mean (95 % CI) responses to endurance, strength, and combined endurance and strength training, as well as in the control group in men (M) and women (W).

Fig.2. Correlations between changes in maximal isometric force (MVC) and peak oxygen uptake (VO_{2peak}) in the combined endurance and strength training group in men (◇) and women (◆). Dashed lines represent the highest quintile (‒ ‒ ‒), and dotted lines represent a negative response (..............) in both VO_{2peak} and MVC.


Endurance training
Strength training
Combined Endurance and Strength training
Control
VO2peak (Δ%)
M 10 (6 to 15) %
W 18 (12 to 24) %
M -1 (-5 to 4) %
W 6 (0 to 12) %
M 9 (5 to 12) %
W 17 (12 to 21)%
P = 0.006
M 0 (-6 to 5) %
W 1 (-5 to 7) %
MVC (Δ%)
M 9 (5 to 14) %
W 7 (0 to 13) %
M 15 (10 to 19) %
W 17 (10 to 24) %
M 20 (14 to 26) %
W 23 (14 to 32) %
M 6 (1 to 12) %
W 6 (-1 to 12) %
60
50
40
30
20
10
0
-10
-20



ΔVO2peak (%)
50
40
30
20
10
0
Men r = -0.059
P = 0.76
Women r = -0.22
P = 0.39
ΔMVC (%)
0
20
40
60
80
100

Table 1. Mean (SD) age, body mass index (BMI), peak oxygen uptake (VO_{2peak}) and maximal strength (MVC) during isometric bilateral leg extension in the strength training (S), endurance training (E), combined training (ES), and control (C) groups before the training period.

	Men				*Between groups*
	E (n = 22)	S (n = 23)	ES (n = 30)	C (n = 14)	*P*
Age (yr)	54 (8)	57 (6)	56 (7)	54 (9)	0.39
BMI ($kg \cdot m^{-2}$)	24.8 (2.9)	26.3 (2.8)	26.2 (3.2)	25.3 (1.6)	0.22
VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$)	32.9 (7.3)	33.4 (6.4)	32.5 (4.2)	34.6 (5.6)	0.75
MVC (N)	2705 (693)	2693 (528)	2776 (668)	2592 (377)	0.82
	Women				*Between groups*
	E (n = 21)	S (n = 25)	ES (n = 23)	C (n = 17)	*P*
Age (yr)	51 (7)	53 (8)	50 (6)	51 (8)	0.56
BMI ($kg \cdot m^{-2}$)	25.7 (2.4)	24.5 (3.0)	24.7 (3.2)	24.2 (2.4)	0.37
VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$)	25.3 (5.2)	26.0 (5.3)	27.1 (4.8)	26.6 (6.3)	0.71
MVC (N)	1992 (431)	1965 (431)	1977 (498)	1882 (278)	0.87