

EFFECTS OF SUPERVISED VS NON-SUPERVISED COMBINED AEROBIC AND RESISTANCE EXERCISE PROGRAMME ON CARDIOMETABOLIC RISK FACTORS

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SUMMARY

Objective: We examined the effect of a 6-month combined aerobic and resistance training programme on cardiometabolic risk factors in non-diabetic subjects and compared its effectiveness when executed under strict professional supervision or without direct supervision.

Methods: Eighty-five sedentary, non-diabetic subjects (27 men and 58 women), mean age 47.5 ± 0.6 years, mean body mass index (BMI, 33.8 ± 0.6 kg/m²) participated in a combined exercise programme assigned to supervised (S, n=31), non-supervised (NS, n=24) or control group (C, n=30). Cardiometabolic risk parameters were assessed at baseline and after the 6-month training.

Results: In both the S and NS group there was a significant decrease in BMI (-1.6 ± 0.3 , $p < 0.001$ and -1.0 ± 0.3 kg/m², $p = 0.004$), waist circumference (-10.1 ± 1.1 cm, $p < 0.001$ and -7.8 ± 0.8 cm, $p < 0.001$), fat mass ($-1.8 \pm 0.4\%$, $p < 0.001$ and $-2.1 \pm 0.6\%$, $p = 0.003$), and a significant increase in fat-free mass ($+1.7 \pm 0.4\%$, $p < 0.001$ and $+2.0 \pm 0.7\%$, $p = 0.008$), and aerobic capacity ($+6.9 \pm 1.1$, $p < 0.001$ and $+6.9 \pm 0.8$ ml/kg per min, $p = 0.008$). Fasting glucose did not change in S and NS, but increased in C ($p = 0.048$). In the S group a significant decrease in fasting insulin ($p < 0.001$), homeostasis model assessment of insulin resistance ($p < 0.001$), highly sensitive C-reactive protein ($p = 0.004$), leucocytes count ($p = 0.04$), systolic high ($p < 0.001$) and diastolic ($p = 0.009$) blood pressure was found. Comparable significant decreases in total and low-density lipoprotein cholesterol were observed in all study groups.

Conclusions: A 6-month combined exercise programme led to substantial improvement of various cardiometabolic risk factors. This programme was effective even when executed without direct supervision, although the effects were more pronounced in the supervised group. Our findings suggest that non-supervised exercise programmes may be a valuable, cost-effective tool to translate the current physical activity guidelines in a real-life setting.

Key words: overweight, obesity, metabolic disease, cardiovascular disease, physical activity

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INTRODUCTION

The prevalence of obesity has dramatically increased in the last few decades due to rapid changes in lifestyle and their interaction with genetic factors. Epidemiological studies indicate further growing tendency for the future (1–4). Obesity is associated with numerous metabolic derangements and is among the major causes for the development of insulin resistance, metabolic syndrome, type 2 diabetes mellitus (T2DM), and cardiovascular disease (5–7).

Sedentary lifestyle is a pathogenic factor of obesity development and obesity-related cardiometabolic complications (8–15). Increased physical activity and exercise training are well-established strategies for the treatment and prevention of obesity and its related diseases (16–19). Therefore, public health organizations recommend engagement in at least 150 min of moderate intensity aerobic physical activity (PA) in combination with 2 strength training sessions per week for all adults (20, 21). These

recommendations are, however, based predominantly on evidence from studies evaluating the effect of both exercise modalities independently. To date, few trials have tested the impact of a combined aerobic and resistance training on cardiometabolic risk factors among overweight and obese individuals without history of T2DM (22–24).

Large-scale lifestyle and physical activity interventions were found to be effective in the treatment and prevention of obesity, metabolic syndrome, and T2DM among high-risk populations (25–29). These interventions have included regular counseling and high level of professional exercise supervision, thus being expensive and hard to implement on a population level. Recently, several studies demonstrated that the expensive lifestyle modifications and/or physical activity programmes could be successfully translated into a “real-world” setting. With this respect, the low-resource interventions used in the Ballarat Diabetes Prevention Pilot Initiative (BDPPI) (30), the Good Aging in Lahti Region (GOAL) (31), the Greater Green Triangle Study

(GGTS) (32), and the Diabetes Education & Prevention with a Lifestyle Intervention offered in the YMCA (DEPLOY) pilot study (33) substantially reduced diabetes risk and even 10-year coronary heart disease risk (34) among individuals predisposed to develop T2DM. Considering the rapidly growing prevalence of physical inactivity and the associated health care burden, more easily affordable exercise strategies are also needed. Programmes comprising an initial supervised exercise course and provision of regular exercise advice thereafter might represent a valuable, cost-effective tool to translate the physical activity guidelines on community level.

Thus, in the present study we aimed to: 1) test the effect of a 6-month training programme combining aerobic and resistance type exercises in accordance with the current physical activity guidelines on cardiometabolic risk factors and 2) compare the effectiveness of a supervised vs. non-supervised combined exercise programme among sedentary, middle-aged, overweight/obese, non-diabetic individuals.

MATERIALS AND METHODS

Study Design and Subjects

Combating the Metabolic Syndrome through Physical Activity (COMPACT) is a 6-month study designed to: 1) test the feasibility of an exercise programme combining aerobic and resistance type exercises in accordance with the current PA guidelines and its effect on various cardiometabolic risk factors, 2) compare the effectiveness of a supervised vs. non-supervised combined exercise programme in accordance with the current PA guidelines among sedentary middle-aged, overweight and obese individuals without T2DM. The COMPACT study was conducted at the International Scientific Institute, National Sports Academy, Sofia, Bulgaria (Fig. 1).

Through postings at the University campus and announcements on the web page of the University, on the Internet, and in the local newspapers, 141 individuals admitted to initial interview were 40–60 years old, had body mass index (BMI) ≥ 25 kg/m² and were physically inactive at the time of enrolment (a lack of engagement in structured PA of moderate to high intensity for more than 30 min 2 times per week).

Involvement in the study was not permitted if any of the following exclusion criteria was met: medical history of T2DM; presence of a cardiovascular disorder or abnormality: arrhythmias, congenital heart defects, ischaemic heart disease; myocardial infarction or stroke in the last 6 months; poorly controlled hypertension ($\geq 160/110$ mmHg); presence of neurological, thyroid, hepatic, renal or musculoskeletal disease; presence of acute or chronic inflammatory disease; adherence to a weight-loss diet or body weight change of more than ± 3 kg in the last 3 months; use of medications or nutritional supplements that may affect energy expenditure and body weight, lipid and carbohydrate metabolism; drug or alcohol abuse. Based on these criteria 94 subjects out of the initially interviewed 141 were included in the baseline examination. Of them, 9 individuals turned out to have a so far undiagnosed T2DM with fasting blood glucose ≥ 7.0 mmol/l and were excluded from further participation. The remaining 85 subjects were enrolled in three study groups matched for age, sex

and BMI: the supervised PA group (S, n=31), the non-supervised PA group (NS, n=24), or the control group (C, n=30). Two subjects dropped out from S and NS, respectively, and two subjects from the C group were lost to follow-up. Thus, 29 subjects from S, 22 from NS, and 28 from the C group completed the study and were included in the final analyses (Fig. 1).

The study conforms to the principles outlined in the Declaration of Helsinki. All subjects were provided with a detailed explanation of the study aims and gave their written informed consent prior to the baseline medical examination.

Exercise Programme

All participants were provided healthy lifestyle counselling emphasizing the health benefits of regular PA and balanced nutrition at a specially designed lecture at the start of the study. In addition, every subject had a scheduled 1-hour personal meeting with a dietician at which he/she was given individually tailored advice and was provided with a standardized low calorie diet (1,400 kcal and 1,800 kcal per day, for women and men, respectively) consisting of 55% of total energy intake from carbohydrates, 30% from fat, and 15% from protein. Thereafter, subjects allocated to the C group were not contacted for the next 6 months until the final study visit.

Subjects in the S and NS physical activity group participated in an intensive 6-month physical exercise programme in accordance with the current PA guidelines promoting engagement in at least 150 min of aerobic exercises in combination with 2 sessions of resistance exercises per week.

All training sessions incorporated endurance exercises (e.g. brisk walking, low-intensity running, aerobics, taekwondo, dancing), resistance exercise (e.g. free weight exercises, own body weight exercises, resistance bands exercises, abdominal crunches), and flexibility exercises (e.g. stretching of the major muscle groups).

Since subjects were physically inactive prior to enrolment, they participated in a 1-week exercise course consisting of 2 lectures and 3 practical sessions during which they got acquainted with the basic principles of sports training and the execution of different exercises. Subsequently, during the initial 10 weeks of the study, participants were encouraged to perform 2 exercise sessions per week with low to moderate intensity (aerobic exercises at 50–60% of the maximum heart rate; resistance exercise for the major muscle groups in 2 sets of 8–14 repetitions) and duration of 30–35 min. For 10 consecutive weeks, the number of sessions was raised to 3/week and their intensity (aerobic exercises at 60–75% of maximum heart rate; resistance exercises in 3 sets of 8–14 repetitions) and duration (45–60 min) was also increased. During the last 4 weeks of the study the goal was participation in 4 training sessions per week (45–60 min). The overall aim was participation in 66 exercise sessions for the whole study duration.

The supervised and the non-supervised programmes differed with respect to PA advice regularity and degree of professional supervision. In the S group all training sessions were conducted and supervised by a trained physical therapist. Subjects in the NS group were encouraged to achieve the study aim without direct supervision. However, personal meetings with a physical therapist were scheduled once in 3 weeks in order to evaluate the progress and set up new activity goals.

Exercise participation was verified by direct supervision in the supervised group and by exercise diary and telephone interviews in the non-supervised group.

Measurements

All measurements were performed at baseline and after the 6-month exercise programme between 8:00 a.m. and 10:00 a.m. after a 10-hour overnight fast. Subjects were asked to refrain from strenuous exercise as well as from food excess or deprivation 3 days prior to both study visits.

Anthropometry and Blood Pressure Assessment

Anthropometric measurements were performed according to standard techniques with subjects wearing light clothing. Blood pressure was examined in a sitting position after a rest of at least 5 minutes. Two consecutive measurements were performed within 3 minutes and the second one was taken into consideration.

Body Composition Analysis

Body composition analysis was performed using the bio impedance technique on a TANITA BC 418 MA analyser (TANITA Corporation, Tokyo, Japan).

Sub-maximal Aerobic Capacity Assessment

Sub-maximal aerobic capacity was assessed on a treadmill (Quasar Med 4.0, HP Cosmos, Nussdorf-Traunstein, Germany) using the Modified Bruce protocol (35). Maximal aerobic capacity (VO_2max) was then estimated using the equation of Foster (36).

Other Measurements

At baseline and after the 6-month exercise programme medical history was taken and physical examination was performed. In addition, participants completed the short version of the International Physical Activity Questionnaire (IPAQ) and a questionnaire concerning their motivation for participation in the study as well as their self-perception of current psychological and health status. At baseline, 12-lead resting ECG was performed in order to exclude the presence of any acquired or congenital heart disease. At the end of the study subjects underwent a detailed interview concerning the factors that have stimulated or limited their participation in the exercise programme.

Blood Sample Analyses

Venous blood samples were obtained by venipuncture. EDTA plasma and serum were separated by centrifugation (4000 rpm for 8 minutes at 4°C). Aliquots of plasma and serum were immediately stored at -40°C until further analyses. Fasting glucose, lipid profile, and leucocytes count were determined using fresh material.

Leucocytes count was determined photometrically on a Diagon D5 Cell analyser (Diagon Ltd., Budapest, Hungary). Fasting glucose was measured in serum by the glucose-hexokinase method on an Integra 400 Plus analyser (Roche Diagnostics GmbH, Mannheim, Germany). Fasting serum total cholesterol, high-density lipoprotein (HDL) cholesterol, and triglyceride concentrations were measured enzymatically on an Integra 400 Plus analyser (Roche Diagnostics GmbH). Serum low-density lipoprotein (LDL) cholesterol concentration was calculated using

Friedewald equation. Fasting insulin concentration was measured in serum by ELISA (Mecordia, Uppsala, Sweden; inter-assay variability: 2.9%; intra-assay variability: 3.4%), which shows no cross-reactivity with proinsulin. Insulin resistance was calculated from fasting serum glucose and fasting serum insulin using the homeostasis model assessment for insulin resistance (HOMA-IR). Serum high sensitive C-reactive protein (hs-CRP) concentration was measured by ELISA (ap Dianv, Turnhout, Belgium; inter-assay variability: 6.1%; intra-assay variability: 5.1%).

Statistical Methods

Data are presented as n, mean \pm SEM, or percentage (%) as respectively indicated. The distribution of variables was assessed by the Kolmogorov-Smirnov test for homogeneity of variance and non-normally distributed variables were logarithmically transformed to approximate normal distribution. One-way ANOVA was used for between-group comparisons at baseline and at the end of the intervention. Within-group changes were analysed using paired sample Student's t test. Multiple linear regression analyses were performed to determine the predictors of changes in BMI, waist circumference and insulin resistance (HOMA-IR). Differences were considered statistically significant at $P < 0.05$. All statistical analyses were executed using SPSS for Windows, version 17.0 (SPSS Inc., Chicago, IL).

RESULTS

Baseline demographic, anthropometric, and metabolic characteristics of the study participants are presented in Table 1. No significant between-group differences were observed except for LDL-cholesterol, which was significantly higher in the non-supervised vs. the supervised PA group ($p = 0.02$).

As a result of the 6-month combined exercise programme body weight and BMI decreased significantly in the S ($p < 0.001$ for both) and the NS group ($p = 0.005$ and $p = 0.004$, respectively), and slightly increased in the C group ($p > 0.05$ for both) (Fig. 2a, 2b and 2c). Waist circumference decreased significantly from baseline in all three study groups (Fig. 2d). Statistically significant favourable changes in fat mass and fat-free mass were found in the S ($p < 0.001$ for both) and the NS group ($p = 0.003$ and $p = 0.008$, respectively), whereas in the C group a tendency towards an increase in fat mass and a decrease in fat-free mass was present (Fig. 2e and 2f). The magnitude of changes in body weight, BMI, waist circumference, and body composition was comparable between the S and the NS group ($p > 0.05$ for all variables), and was significantly greater in both PA groups when compared to the group C ($p < 0.01$ for all variables) (Fig. 2).

After the exercise programme a comparable increase in maximal aerobic capacity (VO_2max) was observed within the S and the NS group ($p < 0.001$ for the change in both groups), while it remained unchanged in the group C ($p > 0.05$) (Fig. 3).

Changes in lipid profile, glucose homeostasis, inflammation, and blood pressure (BP) as a result of the combined exercise programme are depicted in Table 2. Total and LDL cholesterol concentrations decreased significantly from baseline in all three groups, while HDL cholesterol and triglyceride levels remained unchanged. Fasting glucose concentration increased within the

Table 1: Baseline characteristics of study participants

Characteristic	Supervised group	Non-supervised group	Control group
n (men/women)	29(10/19)	22(8/14)	28(9/19)
Age (years)	47.8±1	47.8±1.3	46.8±1.2
Body weight (kg)	94.7±4.8	93.7±4.2	98.7±3
Body mass index (kg/m ²)	33.7±1.2	33.4±1.4	34.0±1
Waist circumference (cm)	107.4±3	104.6±2.9	107.7±2.3
Fat mass (%)	38.5±6.8	38.9±1.7	38.8±1.4
Fat-free mass (%)	61.3±1.3	61.0±1.7	61.0±1.4
VO ₂ max (ml/kg per min)	32.1±2.4	32.5±2.9	33.5±2.1
Total cholesterol (mmol/l)	5.50±0.2	6.14±0.2	5.97±0.2
LDL cholesterol (mmol/l)	3.33±0.2*	3.95±0.2	3.73±0.1
HDL cholesterol (mmol/l)	1.47±0.1	1.46±0.1	1.42±0.1
Triglycerides (mmol/l)	1.54±0.2	1.60±0.2	1.63±0.2
Fasting glucose (mmol/l)	5.66±0.1	5.41±0.1	5.44±0.1
Fasting insulin (pmol/l)	11.35±1.1	9.06±1.3	11.04±1.5
HOMA-IR	2.88±0.3	2.23±0.4	2.77±0.5
Systolic blood pressure (mmHg)	136±3.1	126±3.3	132±3.1
Diastolic blood pressure (mmHg)	89±1.6	86±2.1	86±1.5
hs-CRP (mg/l)	3.3±0.4	3.2±0.6	3.3±0.6
Leucocytes count (GPT/l)	8.6±0.5	7.6±0.4	8.2±0.4

Data are presented as n, mean±SEM, or % as respectively indicated

* p<0.02 vs. non-supervised group

Table 2: Changes in various cardiometabolic risk factors as a result of the exercise programme

Characteristic	Supervised group	Non-supervised group	Control group
Total cholesterol (mmol/l)	-0.32±0.1*	-0.58±0.2*	-0.35±0.1*
LDL cholesterol (mmol/l)	-0.38±0.1*	-0.57±0.12*	-0.28±0.1*
HDL cholesterol (mmol/l)	0.03±0.05	0.003±0.1	-0.01±0.04
Triglycerides (mmol/l)	0.05±0.1	-0.01±0.2	-0.04±0.1
Fasting glucose (mmol/l)	-0.16±0.1	0.01±0.2	0.15±0.1*
Fasting insulin (pmol/l)	-3.24±0.9*‡	-0.14±0.9	-1.46±1.1
HOMA-IR	-0.88±0.2*‡	-0.01±0.3	-0.36±0.3
Systolic blood pressure (mmHg)	-10.7±2.4*‡	-1.8±2.9	-2.3±1.8
Diastolic blood pressure (mmHg)	-4.8±1.7*†	-2.3±1.9	0.9±1.1
hs-CRP (mg/l)	-0.92±0.3*†	-0.26±0.3	-0.05±0.3
Leucocytes count (GPT/l)	-0.7±0.3*	-0.4±0.3	-0.4±0.2

Data are presented as mean±SEM, or % as respectively indicated

* p<0.05 for within group change from baseline to final visit

† p<0.05 vs. control group

‡ p<0.05 vs. non-supervised group

group C (p=0.048) and remained unchanged in both exercise groups. Fasting insulin and HOMA-IR decreased significantly from baseline only in the group S (p=0.001 for both). Similarly, a significant decrease from baseline in leucocytes count (p=0.04), hs-CRP (p=0.004) as well as in systolic (p<0.001) and diastolic (p=0.009) BP was observed only in the group S (Table 2).

Subjects in the supervised group attended 73.4±6.7% of all exercise sessions or 2±0.2 sessions per week, whereas those in the non-supervised group completed 54.8±5.6% of the prescribed exercise sessions or 1.5 sessions per week. Thus, adherence to the

prescribed exercise was significantly greater in the supervised vs. the non-supervised group (p=0.047).

Multiple linear regression analyses revealed the number of attended training sessions as an independent determinant of change in BMI, change in waist circumference, and change in HOMA-IR (Table 3).

No differences in the effect of the exercise programme on the investigated cardiometabolic risk factors were found between men and women. Similarly, no gender differences in exercise adherence were present (data not shown).

Table 3: Multiple linear regression analyses of changes in various cardiometabolic risk factors and the number of attended training sessions as determinants of changes (Δ) in BMI, waist circumference, and HOMA-IR

Determinants	Dependent variables	
	Δ BMI	
	β coefficient	p-value
Age	0.052	ns
Sex	0.111	ns
BMI at baseline	0.298	0.02
Number of training sessions	0.524	<0.001
	Δ waist circumference	
Age	0.252	ns
Sex	0.107	ns
Waist circumference at baseline	0.030	ns
Number of training sessions	0.647	<0.001
	Δ HOMA-IR	
Age	0.115	ns
Sex	0.018	ns
Δ BMI	-0.170	ns
Δ waist circumference	0.160	ns
Number of training sessions	0.335	0.034
HOMA-IR at baseline	0.604	<0.001
Δ leucocytes count	-0.154	ns
Δ hs-CRP	0.008	ns

ns – not significant

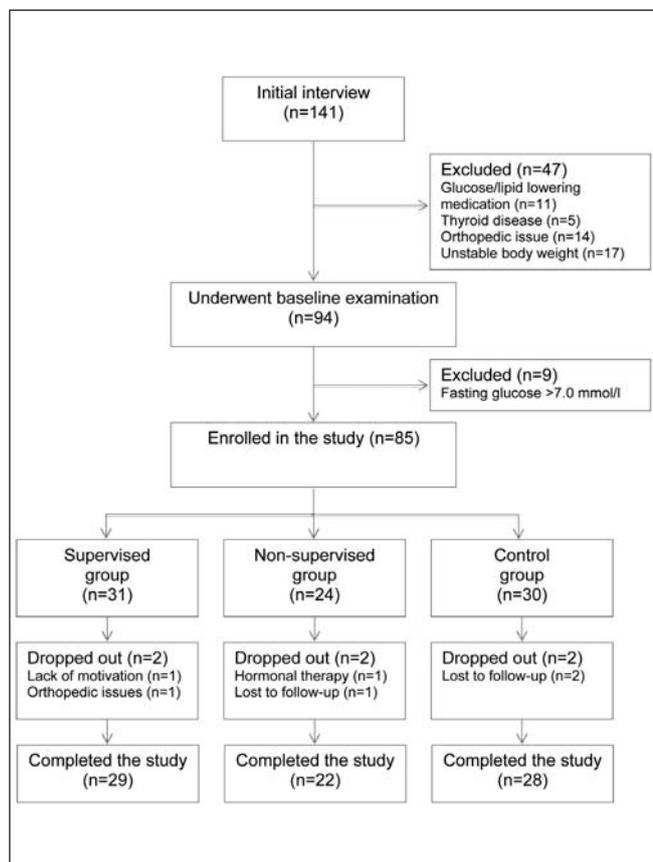


Fig. 1. Study flow chart.

DISCUSSION

The main findings of the COMPACT study were that: 1) training programme combining aerobic and resistance type exercises in accordance with the current PA guidelines led to substantial improvements in various cardiometabolic risk factors among previously inactive, overweight/obese, middle-aged individuals without T2DM and 2) this programme was effective also without direct supervision, although the effect was more strongly expressed when executed under strict professional supervision. These findings confirm and further extend earlier reports on the health effects of combined aerobic and resistance exercise training and suggest that programmes comprising an initial supervised exercise course and provision of regular exercise advice thereafter may be a valuable, cost-effective tool to translate the current PA guidelines in a real-life setting.

In the current work, a significant decrease in body weight, BMI, and waist circumference and substantial beneficial changes in body composition occurred as a result of the exercise training. This is in agreement with some but not all of the reports on the effect of combined exercise on anthropometric risk factors in overweight/obese individuals. Thus, Stensvold et al. (24) observed a decrease in waist girth and no changes in body weight and BMI after 12 weeks of combined exercise training. Recently, Bateman et al. (22) and Slentz et al. (23) found significant changes in body mass and waist circumference after 8 months of training in obese individuals. In contrast, however, others did not find an effect of combined training on these anthropometric variables (37). Data

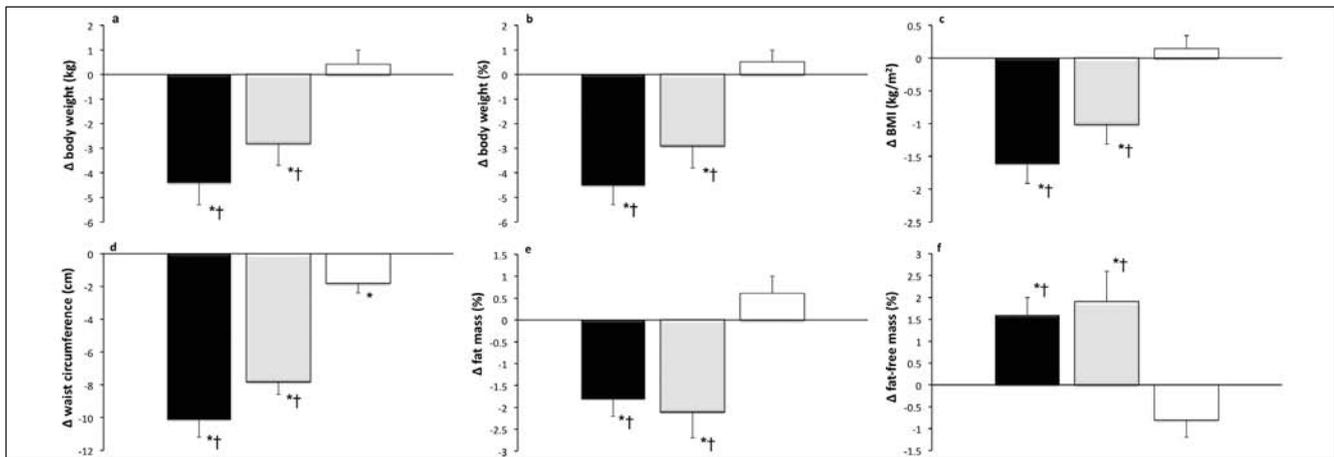


Fig. 2. Representing a) absolute change in body weight, b) % change in body weight, c) change in body mass index, d) change in waist circumference, e) change in % fat mass, and f) change in % fat-free mass as a result of the combined exercise programme; black bars: supervised group; grey bars: non-supervised group; white bars: control group.

* $p < 0.05$ for within group change from baseline to final visit; † $p < 0.05$ vs. control group; values are mean \pm SEM

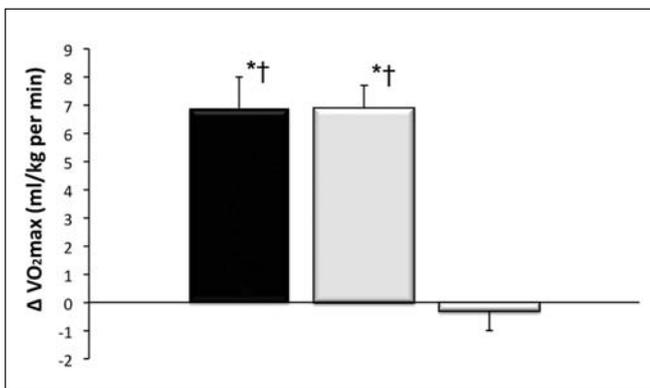


Fig. 3. Changes in maximal aerobic capacity (VO_{2max}) as a result of the combined exercise programme; black bars: supervised group; grey bars: non-supervised group; white bars: control group.

* $p < 0.05$ for within group change from baseline to final visit; † $p < 0.05$ vs. control group; values are mean \pm SEM

concerning the impact of combined training on body composition are more consistent. In line with our findings, a decrease in fat mass and an increase in lean body mass after 12 weeks and 8 months of exercise, respectively, were previously reported (23, 24).

The changes in body weight, waist circumference, and body composition found in the present study were comparable between the S and the NS group, which corroborates previous observations (30–33, 38). Perri et al. (38) for example reported equal decrease in body weight as a result of a group- and a home-based exercise programme in obese women. In addition, Payne et al. (30) found comparable changes in body mass and waist circumference after a gymnasium- and a home-based resistance exercise programme in the BDPPI. Similar findings were observed in response to the low-resource lifestyle and PA interventions used in the GOAL (31), GGTS (32), and the DEPLOY study (33).

Poor cardiorespiratory fitness is an independent predictor of metabolic syndrome, T2DM, and cardiovascular disease, while high aerobic capacity is associated with lower cardiometabolic

disease prevalence (39–41). Substantial improvements in maximal aerobic capacity were previously observed among middle-aged, overweight or obese individuals after 12 (24), 16 weeks (37) and 8 months (22, 23) of combined exercise, respectively. Accordingly, we found a significant increase in VO_{2max} after 6 months of training. The increase in aerobic capacity was equivalent in both physical activity groups, which is in agreement with the observations of others, who reported comparable increases in VO_{2max} after group- and home-based exercise interventions (38, 42). This finding is, however, surprising since the exercise adherence was higher in the supervised group and one might expect significantly higher increase in VO_{2max} in this group compared to the non-supervised. The discrepancy may be explained by different factors such as higher adherence to aerobic exercise despite lower total exercise adherence in the NS group. On the other hand, in the present study aerobic capacity was estimated after performance of sub-maximal aerobic capacity test and not directly measured by spiroergometry. Thus, the method used for aerobic capacity assessment might have not been sensitive enough to detect small changes in VO_{2max} .

As a result of the 6-month combined training significant decreases in total and LDL cholesterol concentrations were observed, but HDL cholesterol and triglyceride levels remained unchanged. In general, physical exercise is associated with beneficial changes in lipid profile, although controversial findings have been reported (43). Data on the influence of combined training on blood lipids is also ambiguous. Thus, Libardi et al. (37) and Bateman et al. (22) found significant decrease in total cholesterol (37) and triglyceride concentration (22, 37) after 16 weeks and 8 months of combined training, respectively, in overweight and obese individuals. In contrast, however, Stensvold et al. (24) did not observe an effect on these parameters after 12 weeks of exercise. In none of these studies an effect of combined exercise on LDL and HDL cholesterol was reported.

In the present study, the S and the NS exercise groups exhibited comparable changes in lipid profile. Accordingly, significant improvements in total and LDL cholesterol have been observed after home-based and cost-effective community-based interventions

(30, 32, 33). In some of these trials beneficial changes in HDL cholesterol and/or triglycerides have also been present, potentially due to the frequent dietary counselling and the emphasis on dietary modification (30, 32).

No changes in fasting glucose concentration occurred as a result of the 6-month exercise programme in the present study, which is in line with previous reports on the effect of combined exercise among overweight or obese individuals (22, 24, 37). Recently, Payne et al. (30) reported comparable significant changes in fasting glucose levels after a gymnasium- and a home-based resistance training programme. Similar findings were also reported in the low-resource GOAL study and GGTS (31, 32). In all these trials, however, subjects were selected to have impaired glucose tolerance and other T2DM risk factors. The COMPACT study participants were sedentary and overweight/obese, but had normal glucose levels at baseline, which may to a certain extent explain the discrepancy.

Noteworthy is the fact that while fasting glucose did not change in the S and in the NS group, a significant increase in glucose level was observed in the group C. Based on this finding it is tempting to suggest that the exercise programme prevented a potential increase in fasting glycemia among subjects in the physical activity groups.

Strong relationship between PA and insulin sensitivity even among healthy individuals has been repeatedly reported (44, 45), but information on the effect of combined exercise on insulin sensitivity is sparse. In agreement with our findings, Slentz et al. (23) recently found significant improvement in insulin resistance (assessed by HOMA-IR) after 8 months on combined training in obese adults. On the contrary, Stensvold et al. (24) did not observe a change in HOMA-IR after 12 weeks of training among obese individuals most likely due to the relatively short duration of the study.

Furthermore, physical exercise has been found to improve insulin sensitivity through changes in body weight, but also through weight-loss independent mechanisms (46). Accordingly, in our study, the number of attended training sessions remained a significant predictor of the change in HOMA-IR after adjustment for changes in BMI (Table 3).

After 6 months of exercise training insulin resistance improved significantly in the S and remained unchanged in the NS group. Subjects in the NS group were somewhat more insulin sensitive at baseline, which may to a certain extent explain the difference. However, it is also very likely that the lack of effect in the NS group is due to lower adherence to exercise prescription, since multiple regression analysis revealed the number of attended training sessions as an independent determinant of the change in HOMA-IR.

In the present study, the combination of aerobic and resistance exercises led to a significant reduction in leucocytes count and hs-CRP concentration. PA has been suggested to decrease cardiometabolic disease risk by reducing subclinical inflammation (47), but reports on the effect of exercise on inflammatory biomarkers remain controversial (48, 49). Hitherto, only one study has tested the effect of combined training on inflammation among overweight subjects, with no effect on CRP concentration (37).

The positive effect of exercise on resting BP is well established (50, 51). Similarly to aerobic or resistance training alone, combined exercise was recently found to decrease BP (22).

In accordance with these findings, we also observed significant reduction in systolic and diastolic BP in response to exercise.

In the current work, significant changes in BP and markers of inflammation were only present in the S group. Similarly, Payne et al. (30) found a more pronounced decrease in systolic blood pressure in the supervised group of the BDPPI. A plausible explanation of the lack of effect on BP and the examined inflammatory biomarkers in the non-supervised group may be the lower exercise adherence.

At the end of the study, significant decreases in waist circumference as well as in total and LDL cholesterol concentrations were also observed in the control group. Subject in this group did not participate in a structured exercise programme, but received healthy lifestyle counselling at baseline and were provided a standard low-calorie diet. Thus, it may be assumed that some of the previously inactive and overweight/obese individuals adopted the provided advice, increased their leisure time PA and modified their dietary habits.

In order to determine whether there were any differences in the effect of the exercise programme on the investigated cardiometabolic risk factors as well as in exercise adherence, we conducted all the analyses separately among men and women. The results in both genders replicated those observed in the whole study population and no between-gender differences were found. Thus, it might be concluded that our results are not only valid for the whole study population in general, but also for both genders.

All subjects included in the present study were provided tailored dietary advice and were given a standard low calorie diet at baseline. During the study no additional dietary counselling was provided and neither the dietary adherence nor the change in dietary habits was evaluated. This may be considered a major limitation of the study, since the potential contribution of a dietary modification to the effect of the exercise on the investigated parameters cannot be distinguished. While providing standardized diets to the subjects in all 3 study groups, we aimed at experimental control for the effect of the diet on the exercise training outcomes. However, a hypothetical effect of the diet on the investigated cardiometabolic risk factors cannot be excluded. Nevertheless, dietary counselling is an integral part of every lifestyle modification programme and thus the design of our study reflects to a great extent a potential real-life situation in which a supervised or a non-supervised exercise programme may be used for metabolic disease prevention.

In summary, a 6-month training programme combining aerobic and resistance type exercises in accordance with the current PA guidelines led to substantial improvements in various cardiometabolic risk factors among previously sedentary, overweight or obese individuals, without T2DM. This programme was effective also in the group without direct supervision, although the effect was more strongly expressed when executed under strict professional supervision. Our findings indicate that combined exercise may improve cardiometabolic risk and suggest that low-resource programmes comprising baseline exercise course and regular PA advice thereafter, may represent an effective tool to translate the current PA guidelines into a “real-world” setting.

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Conflict of Interest

None declared

Ethical Standards

The authors of the current manuscript declare that all the experiments comply with the current laws of the country in which they were performed (Bulgaria). The study conforms to the principles outlined in the Declaration of Helsinki. The study protocol was approved by the Institutional Review Board of the National Sports Academy, Sofia, Bulgaria, and all subjects gave their written informed consent prior to participation.

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