Leisure-Time Physical Activity and the Metabolic Syndrome in the Finnish Diabetes Prevention Study

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OBJECTIVE — To assess the effects of leisure-time physical activity (LTPA) and resistance training on metabolic syndrome (MetS) and its components in a post hoc analysis of the Finnish Diabetes Prevention Study, a randomized controlled lifestyle counseling trial.

RESEARCH DESIGN AND METHODS — A cohort of 486 middle-aged overweight men and women with impaired glucose tolerance were followed for an average of 4.1 years. The intervention and control groups were combined in the analyses. LTPA was assessed by questionnaires, dietary intake by food records, and features of the MetS by anthropometric and biochemical measures annually. Resistance training sessions were documented for 137 participants.

RESULTS — Increased moderate-to-vigorous LTPA, even after adjustments for changes in dietary intakes of total and saturated fat, fiber, and energy, and change in BMI was associated with a greater likelihood for resolution (29.7 vs. 19.1%; P = 0.004 in the upper versus lower third of change) and a lesser likelihood for development (23.5 vs. 44.7%; P = 0.041) of the MetS. Of the components of the MetS, the increase in moderate-to-vigorous LTPA was associated most strongly with improvement of glycemia. Among the 137 participants who participated in resistance training, MetS components were favorable in individuals who were in the upper third of participation rate (median 51 times/year) compared with individuals in the lowest third (median 8.5 times/year).

CONCLUSIONS — Increased moderate-to-vigorous LTPA was associated with a decreased likelihood of developing the MetS and an increased likelihood of its resolution in individuals at high risk for type 2 diabetes.

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Research Design and Methods — A detailed description of the design, subjects, and methods applied in the DPS has been reported previously (14). In brief, the DPS was a randomized lifestyle intervention study in 522 middle-aged overweight participants with impaired glucose tolerance, aimed at

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the prevention of type 2 diabetes. In the present study, we included those 486 participants (249 in the intervention and 237 in the control group) who had completed a questionnaire quantifying LTPA at baseline and during yearly follow-up visits (11). A subgroup of 137 participants was taking part in supervised resistance training sessions. The study protocol was approved by the ethics committee of the National Public Health Institute in Helsinki, and all subjects gave written informed consent.

**Intervention**

The aim of the intervention was to encourage people to make healthy lifestyle choices. The participants in the intervention group were given detailed and individualized dietary and exercise counseling as described elsewhere (15). Endurance exercise was recommended to increase aerobic capacity and cardiorespiratory fitness. Session for supervised and individually tailored progressive circuit-type resistance training with moderate intensity were recommended twice a week and offered free of charge in three of the five study centers.

The participants in the control group were given general information about healthy food choices, physical activity, and weight loss at baseline, but no individualized counseling was offered.

**Assessment of physical activity**

The validated Kuopio Ischemic Heart Disease risk factor study questionnaire (11,12) was used for the assessment of physical activity. The participants estimated the frequency, average duration, and intensity of different forms of exercise for individual months during the past 12 months. Based on the reported intensity of different activities and their corresponding metabolic equivalent (MET) values, the total LTPA was divided to low-intensity and to moderate-to-vigorous intensity LTPA (13). Low-intensity LTPA (<3.5 METs) included activities such as gardening, picking berries, casual walking, and bicycling at recreational intensity. Moderate-to-vigorous LTPA (≥3.5 METs) included activities such as brisk walking, jogging, skiing, swimming, rowing, forest work, gymnastics, resistance training, ball games, snow shoveling, and heavy housework.

The duration of total LTPA and its components were calculated as hours/week from the baseline to the end of the follow-up. The changes were calculated by subtracting averaged follow-up value from the corresponding baseline value (11). The participation in resistance training was recorded electronically when the participants visited the resistance training facilities and was analyzed as sessions/year.

**Other measurements**

Medical history and 3-day food records were collected at baseline and at each annual visit. Average intakes of energy (kcal/day), carbohydrates (E%), total fat (E%), saturated fat (E%), and dietary fiber (g/1,000 kcal) were calculated. The average values from years 1–3 were used to measure dietary intake during follow-up (11).

Anthropometry and blood pressure were assessed as described previously. Plasma glucose was determined locally according to standard guidelines. Serum total and HDL cholesterol and triglyceride levels were determined by enzymatic methods (Boehringer Mannheim, Germany).

For the definition of the MetS, we used the National Cholesterol Education Program 2005 criteria (6).

**Statistical analysis**

The data were analyzed using SPSS statistical software (version 11.5; SPSS, Chicago, IL). The baseline values are given as mean ± SD, as median with 0.25–0.75 interquartile range, or as percentages. The Student two-tailed t test, Mann-Whitney U test (fasting and 2-h serum insulin, triglycerides, and LTPA), and χ² test were applied to compare the differences at baseline and during the follow-up. For participants who dropped out or developed diabetes during the study, the measurements at the last observation year was used as the end value.

The primary outcome measure was the change in the MetS status in the combined intervention and control group from baseline to the end, i.e., resolution of the MetS from baseline, development of MetS, or no change with LTPA changes as explanatory variables. Secondary outcome measures were the changes of the MetS components. The change of different LTPA was categorized into thirds. The association with the change in MetS status and its components was analyzed with multinominal regression. The models were adjusted for age, sex, intervention group, and DPS study years (model 1) with further adjustments for changes in diet (intake of total fat, saturated fat, fiber, and energy) (model 2) and BMI (model 3). The change in low-intensity LTPA was also adjusted for the change in moderate-to-vigorous LTPA and vice versa. P values <0.05 were considered statistically significant.

**RESULTS**

**Baseline clinical and metabolic characteristics**

In the combined study cohort, 74.3% had the MetS at baseline. The participants with the MetS at baseline had significantly higher BMI, waist circumference, blood pressure, fasting and 2-h glucose, fasting and 2-h insulin, and serum triglyceride levels and lower serum HDL cholesterol levels (Table 1).

In general, men exercised more than women. Women without the MetS reported significantly more hours per week spent on total and low-intensity LTPA during the previous 12 months than women with the MetS.

**Changes in LTPA during the follow-up**

The median for total LTPA increased from 7.2 (3.6–10.8) at baseline to an average of 7.7 (4.8–11.7) hours per week (P = 0.061) in men and from 5.3 (2.8–8.6) to 5.8 (3.2–9.0) hours per week (P = 0.016) in women during the follow-up. The median for moderate to vigorous LTPA increased from 2.3 (0.9–4.8) to 3.1 (1.8–4.9) (P ≤ 0.001) hours per week in men and from 1.4 (0.3–3.5) to 2.5 (1.1–4.1) (P ≤ 0.001) hours per week in women. There was no significant change in low-intensity LTPA.

**LTPA changes and the incidence for resolution and development of the MetS**

Of the 361 participants meeting the MetS criteria at baseline, 20.8% (n = 75; 26.6% in the intervention and 14.7% in the control group; P = 0.005) showed resolution during the follow-up. Of the 126 participants not meeting the MetS criteria at baseline, 31.2% (n = 39; 30.8% in the intervention and 31.7% in the control group; P = 0.95) developed MetS during the follow-up. The development of the MetS was associated with weight gain and less LTPA in both groups.

The change in total LTPA was associated with the change in MetS status (resolution, no change, development) after adjustment for age, sex, intervention...
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Table 1—Baseline characteristics of the participants according to the absence (MetS⁻) or presence (MetS⁺) of the MetS

|                      | All          | MetS⁻         | MetS⁺         | P       |
|----------------------|--------------|---------------|---------------|---------|
| n                    | 486          | 125           | 361           | 0.843   |
| Group allocation     |              |               |               |         |
| Intervention         | 249          | 65            | 184           |         |
| Control              | 237          | 60            | 177           |         |
| Sex                  |              |               |               | 0.003   |
| Male [n (%)]         | 162 (33.3)   | 55 (34.0)     | 107 (66.0)    |         |
| Female [n (%)]       | 324 (66.7)   | 70 (21.6)     | 254 (78.4)    |         |
| Age (years)          | 55.4 ± 7.0   | 55.8 ± 7.1    | 55.3 ± 7.0    | 0.476   |
| ≤40 (%)              | 27.0         | 27.2          | 26.9          |         |
| 40–49 (%)            | 33.1         | 28.8          | 34.6          |         |
| ≥50 (%)              | 39.9         | 44.0          | 38.0          |         |
| Weight (kg)          | 86.3 ± 14.3  | 80.3 ± 10.0   | 88.4 ± 14.9   | <0.001  |
| BMI (kg/m²)          | 31.2 ± 4.5   | 28.8 ± 3.4    | 32.1 ± 4.6    | <0.001  |
| Waist (cm) (all)     | 101.2 ± 11.0 | 94.7 ± 8.1    | 103.5 ± 11.0  | <0.001  |
| Men                  | 104.2 ± 9.7  | 97.3 ± 6.0    | 107.7 ± 9.4   |         |
| Women                | 99.8 ± 11.4  | 92.7 ± 9.0    | 101.7 ± 11.2  |         |
| Fasting glucose (mmol/l) | 6.1 ± 0.7  | 5.8 ± 0.7     | 6.3 ± 0.7     | <0.001  |
| 2-h glucose (mmol/l) | 8.9 ± 1.5    | 8.6 ± 1.4     | 9.0 ± 1.5     | 0.014   |
| Fasting insulin (mU/l) | 13 (10–18)  | 10 (8–13)     | 11 (11–19)    | <0.001  |
| 2-h insulin (mU/l)   | 79 (54–120)  | 60 (38–77)    | 89 (63–134)   | <0.001  |
| Serum total cholesterol (mmol/l) | 5.6 ± 0.9 | 5.7 ± 0.8     | 5.6 ± 0.9     | 0.064   |
| Serum HDL cholesterol (mmol/l) | 1.21 ± 0.29 | 1.39 ± 0.24   | 1.15 ± 0.28   | <0.001  |
| Serum triglycerides (mmol/l) | 1.56 (1.18–2.09) | 1.20 (0.96–1.43) | 1.72 (1.34–2.29) | <0.001  |
| Lipid-lowering medication (%) | 5.4 | 3.2 | 6.2 | 0.576 |
| Systolic blood pressure (mmHg) | 138 ± 18 | 133 ± 20 | 140 ± 16 | <0.001 |
| Diastolic blood pressure (mmHg) | 86 ± 10 | 82 ± 11 | 87 ± 9 | <0.001 |
| Antihypertensive medication (%) | 35.3 | 16.8 | 41.7 | <0.001 |
| Total LTPA (all) (h/week) | 5.7 (3.1–9.3) | 6.9 (4.3–10.1) | 5.1 (2.8–9.1) | 0.001 |
| Men                  | 7.2 (3.6–10.8) | 7.5 (3.8–10.4) | 6.9 (3.4–10.9) | 0.503 |
| Women                | 5.3 (2.8–8.6)  | 6.7 (4.3–9.8) | 4.9 (2.6–8.2) | 0.002 |
| Moderate-to-vigorous LTPA (all) | 1.7 (0.5–4.0) | 1.9 (0.6–4.4) | 1.6 (0.4–3.8) | 0.165 |
| Men                  | 2.3 (0.9–4.8)  | 2.1 (1.1–4.7) | 2.4 (0.7–4.9) | 0.725 |
| Women                | 1.4 (0.3–3.5)  | 1.7 (0.4–4.2) | 1.3 (0.3–3.5) | 0.481 |
| Low-intensity LTPA   | 3.0 (1.2–5.9)  | 4.1 (1.9–7.2) | 2.9 (1.1–5.3) | 0.004 |
| Men                  | 3.2 (1.4–6.9)  | 3.7 (1.9–7.2) | 3.0 (1.2–6.9) | 0.268 |
| Women                | 2.9 (1.2–5.6)  | 4.4 (1.5–7.2) | 2.8 (1.1–4.6) | 0.011 |

Data are means ± SD for normally distributed or medians (interquartile ranges) for skewed parameters or percentages.

LTPA changes and the components of the MetS

The increase in total LTPA was associated with a decrease in the prevalence of hyperglycemia (P = 0.020–0.053), low HDL cholesterol (P = 0.018–0.057), and hypertriglyceridemia (P = 0.002–0.003) (Table 2). Increased moderate-to-vigorous LTPA decreased the prevalence of elevated fasting glucose (P = 0.003–0.018), but no association with abdominal obesity (P = 0.098–0.181), low HDL cholesterol (P = 0.098–0.232), and high blood pressure (P = 0.068–0.151) was found. In contrast, an increase in low-intensity LTPA was associated with an improvement in hypertriglyceridemia (P = 0.006–0.004), but not any of the other components of the MetS.

Resistance training and the components of the MetS

In the subgroup of 137 individuals taking part in supervised resistance training, the median attendance rate was 27.0 (13.4–42.9) sessions/year during the entire study. Of the MetS status components, the resistance training attendance rate was associated, even after adjustment for dietary and BMI changes, with improvements in hyperglycemia (P = 0.127–0.029), hypertriglyceridemia (P = 0.046–0.081), and low HDL cholesterol (P < 0.001–0.002), but not with elevated blood pressure or abdominal obesity (Table 3).

CONCLUSIONS — Increased moderate-to-vigorous LTPA during the 4.1-
year follow-up increased the likelihood for the MetS to resolve and decreased the likelihood for the MetS to develop, independently of changes in diet and body weight. Moreover, increased moderate-to-vigorous LTPA decreased the prevalence of hyperglycemia. Improvements in fasting plasma glucose, serum triglycerides, and HDL cholesterol, independently of changes in diet, lifestyle LTPA, and other types of LTPA, were associated with participation in resistance training.

Overall, strong and mostly linear dose-response associations of the change in total LTPA with the development and resolution of the MetS were seen. When breaking down physical activity into moderate-to-vigorous LTPA and low-intensity LTPA, it seems evident that most of the benefit was from moderate-to-vigorous-intensity LTPA. Changes in moderate-to-vigorous LTPA were associated with the change in metabolic status, even independently of the changes in BMI, but the association was not linear across categories. Changes in low-intensity LTPA were not associated with the development or resolution of the MetS. Why the dose-response association was not apparent for moderate-to-vigorous LTPA is unclear, but it may be related to the difficulty in the precise assessment of LTPA. Overall, however, our findings support efforts to increase or at least maintain LTPA, especially moderate-to-vigorous LTPA, in the prevention and treatment of the MetS.

In this analysis of the DPS, the intervention and control groups were combined. In separate analysis, there was a significant difference between the groups in the resolution of the MetS. However, there was no difference in the development of MetS between groups; ~30% of those without MetS at baseline developed MetS in both groups during the follow-up. This may be due to the selection of the participants. They were individuals at high risk for type 2 diabetes and for the MetS. During the follow-up, 22% developed type 2 diabetes (11). While the development of MetS was associated with weight gain and less LTPA, those subjects who developed the MetS appeared to not adhere with our intervention. The apparent favorable effects of moderate-to-vigorous LTPA on resolution and development of the MetS are consistent with the results of the uncontrolled Heritage Family Study (16) and some prospective cohort studies showing that increased moder-
In intervention trials, low-intensity LTPA has less consistently improved metabolic outcomes than more intense LTPA (8). However, we have previously reported that increased low-intensity and moderate-to-vigorous LTPA were similarly associated with a lower risk of type 2 diabetes in the Finnish DPS, suggesting that total energy expenditure on LTPA was more important than intensity (11). In line with that finding, the accumulated daily physical activity as measured with an accelerometer was a major determinant of insulin sensitivity, and time spent on moderate-to-vigorous physical activity did not affect insulin sensitivity independently of total activity in the European Relationship between Insulin Sensitivity and Cardiovascular Risk Study (20). The differences may be explained by differences in study populations and specific metabolic outcomes. More information on the long-term metabolic benefits of low-intensity LTPA in different age groups and risk groups is nonetheless needed.

Regular participation in resistance training predicted favorable changes in MetS components. We found that a higher participation rate in resistance training was associated with benefits on impaired fasting glucose, hypertriglyceridemia, and low HDL cholesterol, but not abdominal obesity or blood pressure. In 3- to 6-month trials, resistance training has variably increased muscle mass, decreased fat mass and abdominal obesity, and improved insulin sensitivity in obese adults, hypertensive patients, older men, and older type 2 diabetic patients (8,21,22). In individuals with type 2 diabetes, resistance training resulted in similar improvements of glycemic control as aerobic exercise (23), although the effect on glucose tolerance in impaired glucose tolerance has been less clear (8). Improvements in insulin sensitivity and metabolic risk factors may be mediated in part by changes in body composition, but strength training may also independently affect steps in insulin signaling and glucose transport (24). Based on meta-analyses of trials, resistance training may decrease blood pressure (25), but effects on dyslipidemia have been variable (8).

Our findings suggest that there is a graded benefit in the frequency of resistance training in the prevention or treatment of the MetS components, with rather substantial benefits for individuals engaging in resistance training on median once a week compared with individuals engaging in resistance training on median less than once a month. In the above-mentioned studies showing an improvement in insulin sensitivity in individuals...
at risk for type 2 diabetes and in glycemic control in patients with type 2 diabetes, training frequency was generally two to three times per week. The metabolic benefits of resistance training at a lower frequency may become apparent only after much longer periods of training than in previously published trials, which have usually lasted 3–6 months. However, longer-term trials are needed to test this hypothesis.

Strengths of the DPS include its repeated assessments of LTPA and dietary intake. However, the present analyses are post hoc. Furthermore, the intervention had several components. Detailed assessment of the individual lifestyle components allows statistical disentanglement of their individual effects, but residual confounding is possible. Moreover, we did not objectively measure physical activity. Decreases in LTPA may have been related to factors that themselves may be related to the development of the MetS. Adherence to resistance training was on average poor. When this study was conducted in the early 1990s, it was uncommon for middle-aged and overweight individuals to attend resistance training facilities, where most of the clientele were young and fit. Some also encountered difficulties with transportation and time schedules.

In conclusion, increased participa-

Table 2—Continued

| Tertiles for low LTPA change median (0.25–0.75 interquartile range) (h/week) | Tertiles for moderate-to-vigorous LTPA change median (0.25–0.75 interquartile range) (h/week) |
|---|---|
| Lower | Middle | Upper | P for trend | Lower | Middle | Upper | P for trend |
| −3.2 (−5.6 to −1.7) | 0.1 (−0.4 to 0.5) | 3.1 (1.8 to 5.1) | | −1.5 (−3.1 to −0.5) | 0.5 (0.2 to 0.8) | 2.6 (1.8 to 3.8) | |
| 4.9 | 4.9 | 3.0 | 0.718* | 6.2 | 2.5 | 4.3 | 0.065* |
| 12.3 | 10.5 | 10.5 | 0.753† | 9.3 | 6.8 | 4.3 | 0.083† |
| 11.8 | 12.3 | 13.0 | 0.941* | 19.1 | 11.7 | 6.2 | 0.181‡ |
| 7.5 | 9.3 | 9.9 | 0.928‡ | 8.6 | 8.0 | 9.9 | 0.03* |
| 9.9 | 6.2 | 11.7 | 0.984‡ | 12.3 | 8.0 | 7.4 | 0.11† |
| 8.0 | 19.3 | 16.0 | 0.006* | 14.9 | 12.4 | 16.0 | 0.018‡ |
| 7.4 | 9.3 | 6.8 | 0.005† | 11.7 | 6.2 | 5.6 | 0.491* |
| 16.7 | 14.2 | 18.5 | 0.668‡ | 14.8 | 13.6 | 21.3 | 0.526† |
| 4.9 | 4.3 | 5.0 | 0.807‡ | 7.4 | 4.3 | 2.5 | 0.672‡ |
| 9.9 | 11.1 | 8.1 | 0.824‡ | 6.8 | 8.0 | 14.3 | 0.068* |

Table 3—The average resistance training attendance rate per year and the change (development and resolution) in the MetS components among a subgroup of 137 participants

| Tertiles for average yearly attendance rate for resistance training median (0.25–0.75 interquartile range) |
|---|
| Incidence (%) (n = 137) | Lower | Middle | Upper | P |
| Abdominal obesity | 0.0 | 8.5 (5.5–13.4) | 27.0 (21.9–32.7) | 50.7 (42.3–67.2) | 0.494* |
| Development | 10.2 | 13.0 | 10.9 | 0.537‡ |
| Resolution | 4.4 | 6.5 | 6.5 | 0.549‡ |
| Elevated fasting glucose | 16.8 | 13.3 | 26.1 | 10.9 | 0.127* |
| Development | 5.1 | 6.7 | 2.2 | 0.157‡ |
| Resolution | 11.1 | 17.4 | 2.2 | 0.029‡ |
| Elevated triglycerides | 10.2 | 2.2 | 28.3 | 0.046* |
| Development | 20.4 | 11.1 | 21.7 | 0.067† |
| Resolution | 11.1 | 17.4 | 2.2 | 0.081‡ |
| Low HDL cholesterol | 10.9 | 26.1 | 21.7 | 0.000* |
| Development | 18.2 | 15.6 | 26.1 | 0.01† |
| Resolution | 11.1 | 21.7 | 2.2 | 0.002‡ |
| Elevated blood pressure | 3.6 | 4.4 | 2.2 | 0.982‡ |
| Development | 10.2 | 8.9 | 10.9 | 0.967† |
| Resolution | 10.9 | 10.9 | 10.9 | 0.957‡ |

*Model 1: adjustments for age, sex, group, DPS study years, averaged low-intensity LTPA, and LTPA other than gymnastics and calisthenics. †Model 2: model 1 and adjustments for change in dietary intakes of total fat, saturated fat, fiber, and energy. ‡Model 3: adjustment for model 2 and change in BMI.
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ution in moderate-to-vigorous physical activity and regular long-term participation in resistance training improved the MetS status among men and women with impaired glucose tolerance in the Finnish DPS. Physical activity and resistance training also more specifically had benefits with respect to hyperglycemia and dyslipidemia, but improvements in abdominal obesity were not clearly seen. Resolution or prevention of the MetS and related features might contribute to the protective effect of physical activity on type 2 diabetes.

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P-I-P. designed the study, researched the data, and wrote the manuscript. D.E.L. designed the study, researched the data, and contributed to writing the manuscript. J.G.E. and T.A.L. contributed to data collection and coordination and reviewed the manuscript. M.U. and J.T. are the principal investigators of the DPS study and participated in reviewing/editing the manuscript.

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