Telemonitoring-supported exercise training, metabolic syndrome severity, and work ability in company employees: a randomised controlled trial

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Summary

Background Metabolic syndrome is a predisposing factor for cardiovascular and metabolic disease, but also has socioeconomic relevance by affecting the health and productivity of workers. We tested the effect of regular telemonitoring-supported physical activity on metabolic syndrome severity and work ability in company employees.

Methods This was a prospective, randomised, parallel-group, and assessor-blind study done in workers in the main Volkswagen factory (Wolfsburg, Germany). Volunteers with diagnosed metabolic syndrome according to American Heart Association/National Heart, Lung, and Blood Institute criteria were randomly assigned (1:1) to a 6-month lifestyle intervention focusing on regular exercise (exercise group), or to a waiting-list control group, using a computer-based assignment list with variable block length. Participants in the exercise group received individual recommendations for exercise at face-to-face meetings and via a smartphone application, with the aim of doing 150 min physical activity per week. Activities were supervised and adapted using activity-monitor data, which were transferred to a central database. Participants in the control group continued their current lifestyle and were informed about the possibility to receive the supervised intervention after study completion. The primary outcome was the change in metabolic syndrome severity (metabolic syndrome Z score) after 6 months in the intention-to treat population. This trial is registered with ClinicalTrials.gov, number NCT03293264, and is closed to new participants.

Findings 543 individuals were screened between Oct 10, 2017, and Feb 27, 2018, of whom 314 (mean age 48 years [SD 8]) were randomly assigned to receive the intervention (n=160; exercise group) or to a waiting list (n=154; control group). The mean metabolic syndrome Z score for the exercise group was significantly reduced after the 6-month intervention period (0·93 [SD 0·63] before and 0·63 [0·64] after the intervention) compared with the control group (0·95 [0·55] and 0·90 [0·61]; difference between groups –0·26 [95% CI –0·35 to –0·16], p<0·0001). We documented 11 adverse events in the exercise group, with only one event (a twisted ankle) regarded as directly caused by the intervention.

Interpretation A 6-month exercise-focused intervention using telemonitoring systems reduced metabolic syndrome severity. This form of intervention shows significant potential to reduce disease risk, while also improving mental health, work ability, and productivity-related outcomes for employees at high risk for cardiovascular and metabolic disease.

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Introduction

Metabolic syndrome is a clustering of different abnormalities, including central obesity, dyslipidaemia, elevated blood pressure, and dysglycaemia, and is closely associated with the development of type 2 diabetes[1] and high risk for cardiovascular events and mortality.[2] The prevalence of metabolic syndrome has been estimated to be about 25% worldwide,[3] with the highest, and growing, numbers in the USA, and increased prevalence with age.[3,4] In addition to the prognostic risk of disease and mortality, metabolic syndrome has been shown to be associated with absence from work due to illness, productivity loss, and increased health-care costs.[5–8] Hence, metabolic syndrome is not only a health-related issue, but also has socioeconomic relevance, particularly in ageing societies where employees are expected to work to increasingly advanced ages. Changes in metabolic syndrome status over time hold the potential to slow or drive several of these cost factors,[6] making it important to establish programmes to increase the health and vitality of employees, while also improving cost and productivity outcomes. A recognised intervention shown to improve clinical outcomes in patients with metabolic syndrome is the maintenance of a physically active lifestyle, as well as regular exercise training.[9,10]

Research in context

Evidence before this study

Metabolic syndrome not only increases morbidity and cardiovascular mortality, but is also associated with loss of productivity and sickness absence in the working population, thereby increasing costs for the public-health system and the employer. Physical activity has an impact on metabolic syndrome severity and work ability, yet the influence of regular exercise on work ability in employees diagnosed with metabolic syndrome is not known. We searched PubMed for articles published from inception up to Dec 14, 2018, with the search terms "exercise", "physical activity", "work ability", "productivity", "sickness absence", and "metabolic syndrome" in various combinations. We found several cross-sectional and prospective studies for the effects of exercise and physical activity on metabolic syndrome severity or work ability. However, we could not identify a randomised study testing regular exercise training on work ability changes in employees diagnosed with metabolic syndrome.

Added value of this study

To our knowledge, this is the first prospective randomised trial to investigate the effects of exercise training on both metabolic syndrome severity and self-reported ability to work in employees at increased cardiometabolic risk. Our results show that regular and telemonitoring-supported physical activity decreased metabolic syndrome severity while increasing work ability, and this effect was independent of sex and occupation. Improvements in exercise capacity, depression severity, and the mental component score of the Quality of Life questionnaire after the 6-month intervention were associated with increased work ability.

Implications of all the available evidence

Sparse data are available regarding the effects of physical activity interventions on work ability in individuals with increased disease risk. Using a randomised controlled design, our study provides evidence for regular exercise as an effective measure for improving physical and mental health, which translates into a higher ability to work for company employees with various types of occupation. The fact that participants were equipped with a wearable activity-monitoring device that transferred data to a central database provided the opportunity to supervise and guide training activities for many participants, irrespective of their residence or workplace. The custom-designed smartphone application to receive health-promoting lectures and regular information about possible training facilities and courses close to the participant's home and workplace might also have contributed to a close investigator–participant relationship, with good adherence and outcomes. Our results suggest that offering similar interventions to a broader workplace population could not only reduce individual disease risk, but also ease the burden in public health care and employers' costs arising from metabolic syndrome conditions.

Previous studies on changes in factors related to work ability have reported inconsistent results after exercise,[11–14] showing the need for further studies. More importantly, data on the effectiveness of regular exercise on work ability are sparse for the growing and economically relevant group of employees with metabolic syndrome. It is still unclear whether improvements in health-related outcomes induced by physical activity are associated with changes in a patient with metabolic syndrome's ability to work. Furthermore, the widespread prevalence of metabolic syndrome requires technology-assisted interventions to manage the large target group, to assist in building a close relationship between participants and providers, to increase adherence, and to potentially strengthen the effectiveness of exercise interventions as a public health measure. Taking these aspects into account, we did a randomised controlled trial to test the hypothesis that a 6-month lifestyle intervention focusing on exercise training with individualised telemonitoring-based supervision will result in reductions in metabolic syndrome severity and improve work ability in company employees.

Methods

Study design and participants

This was a prospective, randomised, parallel-group, and single-blind (assessor-blind) study done as a collaborative project between Volkswagen AG and Hannover Medical School, at a single centre in Germany. To recruit volunteers at the main Volkswagen factory (Wolfsburg, Germany), we organised a series of information events on the factory premises during working hours. The personnel department also distributed advertisements of the study via email and intranet to all employees in the main factory. 60 100 employees (44 years [SD 11], 12 621 [21%] women) work in the factory, of whom 28 848 (48%) do manual work. Assessment of the five components of metabolic syndrome (according to the AHA/NHLBI criteria: abdominal obesity defined by waist circumference, high blood pressure, high concentrations of triglycerides and fasting glucose, and low HDL cholesterol), anthropometric data, and body composition at baseline and after the intervention was done in the occupational health-care centre at Volkswagen AG (Wolfsburg, Germany). According to predefined inclusion and exclusion criteria, we included female and male participants over the age of 18 years who had at least three of the five metabolic syndrome components according to the AHA/NHLBI criteria,[15] and who were not participating in an ongoing occupational health programme. Exclusion criteria were acute or chronic infections, oncological diseases, joint replacements or any surgery within the previous 6 weeks, pregnant or breastfeeding women, and any condition that precluded participation in an exercise intervention.

This study was done in accordance with the Declaration of Helsinki and current guidelines of good clinical practice. The institutional review board of Hannover Medical School (Hannover, Germany) approved the study (number 7531) and written informed consent was obtained before inclusion of study participants. The protocol was not amended following commencement of the trial and is available online.

Randomisation and masking

Volunteers were randomised (1:1) into an exercise group and a waiting-list control group, using a computer-based list of random numbers generated by an external collaborator. Variable block length, with block sizes of 2, 4, and 6, was used to avoid selection bias due to predictability. Physicians from Hannover Medical School enrolled participants and a research assistant implemented group assignments. After meeting the inclusion criteria, consenting to participate, and completing baseline assessements, participants were assigned to a study group via a phone call by the physician to a research assistant (not otherwise involved in the study) at Hannover Medical School. The assistant opened a password-protected file with the randomisation sequence and informed the physician about the study allocation. Study nurses and physicians at the occupational health-care centre at Volkswagen AG in Wolfsburg who screened volunteers and assessed the primary outcome at baseline and after 6 months had no access to the list of random numbers and were masked for the randomisation sequence. Following initial group assignment, the participants were no longer masked. Because of the nature of our research, we cannot rule out the possibility that at 6 months (final examination) participants disclosed their group assignment to their nurses or physicians unsolicited.

Procedures

After a general medical examination by a physician (including electrocardiogram, case history, and physical examination), bodyweight, waist circumference, height were measured in a standardised way, and body-mass index (BMI) was calculated with the formula bodyweight (kg) ÷ height (m^2). Fat-free mass and fat mass as markers of body composition were estimated by segmental, multifrequency, bioimpedance analysis (InBody720; Biospace, South Korea). After an overnight fast, venous blood samples were taken to determine blood lipids, fasting glucose, and a safety blood profile including creatinine, liver aminotransferases, electrolytes, C-reactive protein, thyroid-stimulating protein, thrombocytes, and leucocytes. Office blood pressure was measured after 5 min rest with an appropriate-sized automatic blood-pressure cuff (Critikon, Dynamap, USA) as a mean of two consecutive records. Using these measures, we calculated a continuous metabolic syndrome severity score specific for sex and race or ethnicity (metabolic syndrome Z score), which was developed with a factor-analysis approach using a large dataset from adults in the US National Health and Nutrition Examination Survey.[16] We used the equations for non-Hispanic white people[16] as they most closely reflect a European cohort. The equation for non-Hispanic white women is

For the **National Health and Nutrition Examination Survey** see https://www.cdc.gov/nchs/nhanes/index.htm

$$-7\cdot2591 + 0\cdot0254 \times \textit{waist circumference} - 0\cdot0120 \times \textit{HDL} + 0\cdot0075 \times \textit{systolic blood pressure} + 0\cdot5800 \times \ln(\textit{triglycerides}) + 0\cdot0203 \times \textit{fasting glucose}$$

For the **study protocol** see https://mhh-publikationsserver.gbv.de/receive/mhh_mods_00000008

and for non-Hispanic white men it is

$$-5\cdot4559 + 0\cdot0125 \times \textit{waist circumference} - 0\cdot0251 \times \textit{HDL} + 0\cdot0047 \times \textit{systolic blood pressure} + 0\cdot8244 \times \ln(\textit{triglycerides}) + 0\cdot0106 \times \textit{fasting glucose}$$

The resultant score can be interpreted as a Z score (mean=0, SD=1), with high scores representing an increased risk for, or severity of, metabolic syndrome.

To test exercise capacity (measured as peak power output in watts [W]), participants did incremental exercise on a bicycle ergometer (Schiller 911; BPplus, Germany). The test started with a workload of 50 W for men and 20 W for women and was increased in 10-W increments each minute until the participants could not maintain the requested 60 revolutions per minute pedal frequency (voluntary exhaustion) or the test was stopped by the physician due to predefined stopping criteria (appendix p 1).[17] We recorded heart rate and blood pressure and collected arterial blood samples from the earlobe at rest, 1 min after the start, and every 3 min during the test to determine blood lactate concentrations (Ebio 6666, Eppendorf, Germany). All assessments were repeated after the 6-month intervention.

See Onine for appendix

We distributed questionnaires for the estimation of health-related quality of life (QoL questionnaire, short form 36 [SF-36])[18] and anxiety and depression severity according to the Hospital Anxiety and Depression Scale (HADS),[19] as well as for daily physical activity (Freiburger physical activity questionnaire)[20] and work ability (Work Ability Index [WAI]).[21] The SF-36 questionnaire measures quality of life with eight subscales resulting in two sum scales, the mental and physical component scores of the questionnaire. For both scales, a score of 0 points represents a minimum and a score of 100 points a maximum quality of life. The HADS consists of 14 items pertaining to the two subscales for anxiety and depression. Scores range from 0 to 21, with higher scores indicating more severe anxiety or depression. Values can be interpreted as normal from 0–7 points, mild (8–10 points), moderate (11–14 points), and severe (15–21 points).[19] The Freiburger activity questionnaire determines the total and exercise-related physical activity of adults, both of which are specified as metabolic-equivalents-of-task (MET) hours per week. The WAI questionnaire contains seven questions concerning work, work ability, and health, resulting in a total score ranging from seven to 49, with higher values representing greater work ability.

Participants completed a 7-day food diary, which was analysed and reviewed by dietitians for macronutrient and micronutrient content using professional nutrition analysis software (Optidiet V3.1.0.004, GOE, Germany). All participants in the exercise group received nutritional counselling, which provided background information on healthy food choices based on general recommendations issued by the German Society for Nutrition.

For the **German Society for Nutrition** see https://www.dge.de/ernaehrungspraxis/vollwertige-ernaehrung/10-regeln-der-dge/10-guidelines-of-the-german-nutrition-society

On the basis of data from initial exercise tests, activity questionnaires, and medical history, participants in the exercise group received personal counselling with recommendations aiming to do 150 min of moderately intense physical activity per week for 6 months. For typical activities such as walking, running, cycling, and using an elliptical trainer, an individual heart rate with a target range of 65–75% relative to measured maximum heart rate, as calculated from the incremental exercise test done at baseline, was advised. Participants were also asked to maintain a high level of daily activity and were provided with concrete tips for their daily routine. The exercise scientist provided information on potential training facilities in the vicinity of the participant's home and at the workplace (eg, gyms, sport classes, rehabilitation courses). The participants were free to choose physical activities depending on personal preferences and available options to increase adherence and feasibility in daily life.

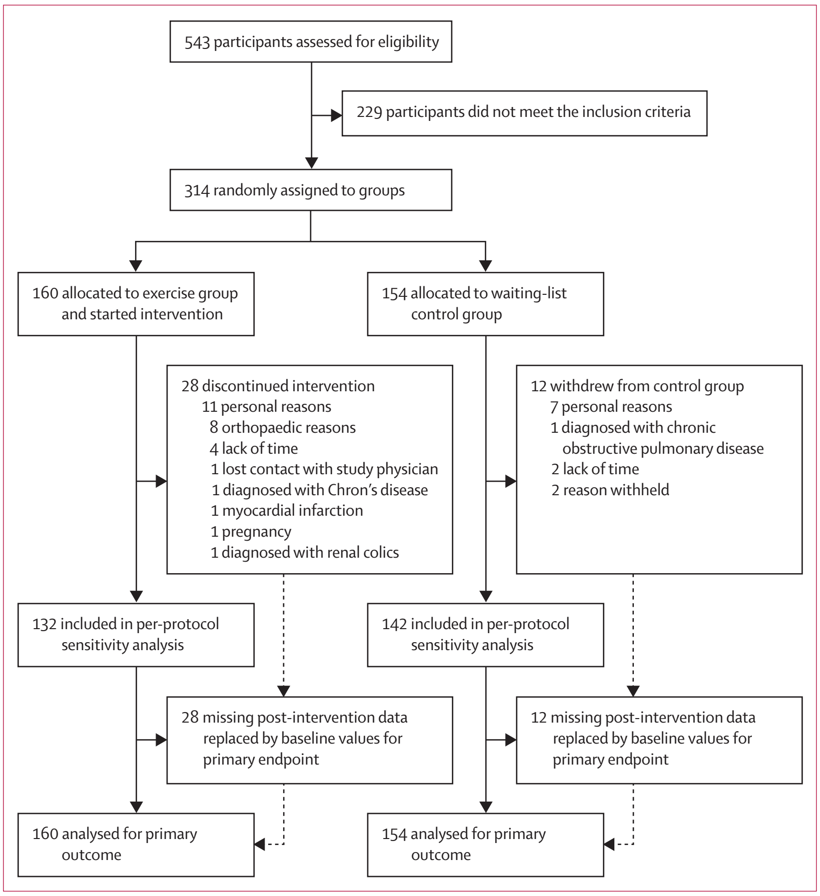

Figure 1: **Trial profile**

The exercise group was equipped with an activity monitor worn on the wrist of the non-dominant hand (Forerunner 35; Garmin, Germany). Participants were asked to wear the monitor throughout the intervention period and were trained to use the device. Wearing time and steps were recorded continuously. In addition, preset or self-defined activities (eg, cycling, cardio training, walking outdoors, and walking indoors) could be started and stopped by the participant, recording activity time, distance, and heart rate as assessed by an optical heart-rate sensor. Both continuous and self-started activity data were saved and directly forwarded via an interface from the Garmin server to a server at Hannover Medical School. The databases for each data type allowed the supervisor to see the activity type, duration, heart rate, distance, and steps recorded by the individual monitors. Additionally, all participants were asked to install the smartphone application Rebirth Active (d.velop AG; Germany), specifically designed for the study, on their mobile phone. The app was a tool to establish a close relationship between the participant and the supervising exercise scientist, and provided general information on the study, individual training goals, recommended heart rates for endurance activities, tips for increased physical activity in everyday life, and supervisor contact details. Information about new training opportunities (eg, courses), dates for planned study visits, and general facts on exercise, healthy nutrition, and mental health were uploaded by the attending supervisor. On the basis of the activity-monitor data and personal communication, the participants received feedback on, and adaptations to, their further training schedule during the monthly meetings with the exercise scientist. Participants were free to contact their supervisor by telephone or email at any time with questions. Adherence to the goal of 150 min of activity per week was assessed from self-started activities using the provided activity monitor. Participants in the waiting-list control group were asked to continue their current lifestyle and were informed about the possibility to have the same supervised 6-month intervention on completion of the study.

Outcomes

The primary outcome of our study was the change in metabolic syndrome Z score following a 6-month exercise intervention in the exercise group compared with the waiting-list control group. The secondary outcomes we assessed were work ability, exercise capacity, health-related quality of life, body composition, and adherence to the intervention. We documented adverse events, defined as any undesired or unfavourable event, not necessarily directly caused by the intervention.

Statistical analysis

On the basis of an earlier study[22] that reported changes in a metabolic syndrome Z score of 0·6 (95% CI –0·7 to –0·5) using a similar intervention, a sample size of 264 participants (132 per group) was calculated to achieve a substantial between-group difference (40% of the SD) for the primary outcome, with 90% power at a significance level of 0·05 (MedCalc statistical software, version 17.6). With an anticipated dropout rate of 18%, we calculated a final sample size of 312 participants for inclusion in the study.

The analysis for all outcomes was done in the intention-to-treat population, including all randomised patients. Missing values were replaced by the Baseline Observation Carried Forward method. For the analysis of the primary outcome, the analysis of covariance (ANCOVA) method was used with the change in the metabolic syndrome Z score (from 6 months to baseline) as the response variable. Explanatory variables were sex, the metabolic syndrome Z score at baseline, and the study group (intervention *vs* control). For the secondary outcomes of work ability, health-related quality of life (scores from the mental and physical components on SF-36, and anxiety and depression severity from the HADS questionnaire) exercise capacity, adherence to the intervention, and body composition (fat and fat-free mass), the same analysis method was used. Adverse events as communicated by the participants themselves or the company physician were compared between study groups with the χ^2 test. Normality distribution was tested using the Kolmogorov-Smirnov test.

We also did a per-protocol sensitivity analysis (only patients with pre-intervention and post-intervention data) for the primary outcome. To analyse subgroups, we grouped our cohort according to the types of work done: shift workers (those who work at different times of day and night on a rotating schedule) versus non-shift workers (those who work regular office hours between 0800 h and 1800 h), and office versus manual workers. For descriptive analyses, absolute frequencies were calculated for categorical variables, and mean and SD for continuous variables. An ANOVA for repeated measures was used to test for within-group differences from baseline to the end of the intervention. Univariate associations between parameters at baseline or between changes after the 6-month intervention were tested using linear regression analysis. We report the r value indicating simple correlation and the unstandardised β coefficient, which gives the degree of change in the outcome (dependent) variable for every unit of change in the predictor (independent) variable. Stepwise backward multivariate linear regression was used to estimate predictors of changes in work ability with the 6-month intervention. The type I error was set to 5% (two-sided). We evaluated heart-rate data from the activity device as a post-hoc analysed outcome. For a further post-hoc analysis, we stratified participants in the exercise group into tertiles according to their 6-month changes in exercise capacity, depression severity, and the mental component score of QoL. For these tertiles changes in the total work ability score were analysed with a one-way ANOVA and Bonferroni's post-hoc test. All statistical analyses were done with IBM SPSS Statistics (version 25; IBM Corporation, USA).

The study was registered with ClinicalTrials.gov, number NCT03293264.

	All participants (n=314)	Exercise group (n=160)	Control group (n=154)
Overall characteristics			
Sex			
Women	45 (14%)	24 (15%)	21 (14%)
Men	269 (86%)	136 (85%)	133 (86%)
Age (years)	48·1 (8·1)	48·3 (7·9)	47·8 (8·5)
Bodyweight (kg)	106·7 (19·1)	107·6 (18·3)	106·1 (20·3)
Body-mass index (kg/m²)	33·3 (5·4)	33·6 (5·3)	33·0 (5·4)
Body fat (%)	32·6 (8·1)	33·0 (8·4)	32·1 (8·0)
Fat-free mass (kg)	71·1 (12·0)	71·0 (11·4)	71·3 (12·8)
Systolic blood pressure (mm Hg)	138 (14)	138 (13)	137 (14)
Diastolic blood pressure (mm Hg)	89 (9)	88 (9)	88 (9)
HbA1c			
%	5·6 (0·9)	5·7 (1·0)	5·6 (0·9)
Mmol/mol	38 (11)	38 (11)	37 (11)
Total cholesterol (mg/dL)	214 (46)	215 (46)	214 (46)
LDL cholesterol (mg/dL)	137 (40)	138 (39)	137 (40)
HDL cholesterol (mg/dL)	44·6 (9·6)	45·1 (10·0)	44·1 (9·2)
Triglycerides (mg/dL)	188 (122)	189 (135)	187 (109)
Type of work			
Setting			
Manual work	114 (36%)	65 (41%)	49 (32%)
Office work	162 (52%)	80 (50%)	82 (53%)
Unclassified	38 (12%)	15 (9%)	23 (15%)
Work hours			
Shift work	66 (21%)	42 (26%)	26 (17%)
Non-shift work	226 (72%)	109 (68%)	112 (73%)
Unclassified	22 (7%)	9 (6%)	16 (10%)
Type of medication			
Antihypertensive	275 (88%)	124 (78%)	151 (98%)
Antidiabetic	68 (22%)	39 (24%)	29 (19%)
Lipid lowering	50 (16%)	19 (12%)	31 (20%)
Thyroid	31 (10%)	14 (9%)	17 (11%)
Anticoagulant	20 (6%)	11 (7%)	9 (6%)
Others	68 (22%)	35 (22%)	33 (21%)
Physical activity and exercise testing at baseline			
Total physical activity (MET h per week)	24·0 (20·8)	25·9 (23·8)	21·8 (16·5)
Exercise activity (MET h per week)	6·4 (11·7)	6·4 (13·7)	6·5 (9·0)
Exercise capacity (peak W)	175 (36)	174 (36)	176 (37)

Data are n (%) or mean (SD). MET=metabolic equivalent of task.

Table 1: **Baseline characteristics of the participants**

	Exercise group (n=160)			Control group (n=154)			Between-group difference over time	
	Baseline	6 months	p value	Baseline	6 months	p value	Mean (95% CI)	p value
Metabolic syndrome Z score (unit)	0·93 (0·63)	0·63 (0·64)	p<0·0001	0·95 (0·55)	0·90 (0·61)	p=0·167	–0·26 (–0·35 to –0·16)	p<0·0001
Waist circumference (cm)	115·6 (12·1)	110·8 (12·8)	p<0·0001	114·6 (12·6)	113·8 (13·0)	p=0·044	–4·0 (–5·2 to –2·8)	p<0·0001
Triglycerides (mg/dL)	189 (135)	162 (108)	p<0·0001	187 (109)	186 (110)	p=0·808	–25 (41–10)	p=0·001
HDL cholesterol (mg/dL)	45·1 (10·0)	45·3 (9·3)	p=0·546	44·1 (9·2)	43·5 (9·2)	p=0·188	0·8 (–1·9 to 0·3)	p=0·13
Systolic blood pressure (mm Hg)	138 (13)	132 (11)	p<0·0001	138 (14)	135 (12)	p=0·005	–2·7 (–4·9 to –0·4)	p=0·020
Fasting glucose concentration (mg/dL)	110·4 (22·1)	104·0 (16·6)	p<0·0001	109·4 (17·8)	108·8 (16·4)	p=0·486	–5·4 (–7·6 to –3·2)	p<0·0001

Differences between groups over time were analysed with the analysis of covariance method adjusted for sex and the respective baseline value. Data are mean (SD), unless otherwise indicated.

Table 2: **Change in metabolic syndrome components and the calculated metabolic syndrome severity Z score after the 6-month intervention**

Role of the funding source
The funder of the study had no role in the study design, data collection, data analysis, data interpretation, writing of the report, or decision to submit for publication. All authors had access to the raw data if needed. The corresponding author had full access to all study data and had final responsibility for the decision to submit for publication.

Results

Between Oct 10, 2017, and Feb 27, 2018, we screened 543 individuals, of whom 314 were recruited and randomly assigned to the exercise or control groups (figure 1, table 1). Of these 314 randomised participants, 274 (87%) completed the intervention phase, achieving our predefined sample size. We documented 11 adverse events in the exercise group and one in the control group (appendix p 1). Participants were followed up for a median of 27·7 weeks (IQR 26·6–29·7). Participants in the exercise group reported more questionnaire-estimated sporting activities at the end of the intervention (mean 9·4 MET h per week [SD 22·7]) than participants in the control group (4·1 [16·1], p=0·010). The average number of steps taken by participants in the exercise group during the intervention was 9612 [SD 2498] per day.

After 6 months, the metabolic syndrome Z score was significantly reduced only for the exercise group and the change was significantly greater in the exercise group compared with the control group; table 2, figure 2). With the exception of HDL cholesterol, all components of metabolic syndrome showed a significant between-group difference, favouring the exercise group (table 2).

The sensitivity analysis for the metabolic syndrome Z score (only participants with complete pre-intervention and post-intervention data) showed a similar result, with a significant decrease for the exercise (mean –0·37 units [SD 0·48], p<0·0001) but not the control group (0·04 units [0·39], p=0·167) and a mean difference between groups of –0·31 [95% CI –0·42 to –0·21], p<0·0001; appendix p 2).

For the whole study cohort, total work ability at baseline was related to exercise capacity (*r*=0·23, p<0·0001), BMI (*r*=–0·15, p=0·008), the mental (*r*=0·54, p<0·0001) and physical (*r*=0·44, p<0·0001) component scores of the QoL questionnaire, and the anxiety (*r*=–0·47, p<0·0001) and depression (*r*=–0·53, p<0·0001) severity score of the HADS questionnaire.

The total score of the work ability index increased in the exercise group (mean at baseline 36·9 points [SD 5·5] and 39·0 points [5·0] after 6 months, p<0·0001) but not in the control group (37·6 points [6·4] and 38·1 points [5·7], p=0·110; figure 2), with a difference of 1·50 points (95% CI 0·75–2·25, p<0·0001) between groups over time. Three of seven subscales of the work ability index (current work ability, work ability in relation to demands, and mental resources) improved more in participants after exercise training compared with control participants (appendix p 3). Our analysis of work ability changes for sex, and the type of work done showed that the exercise intervention significantly increased the total work ability score across all stratified subgroups (figure 3).

Changes in the total work ability score for the exercise group were positively related to changes in exercise capacity (*r*=0·27, p<0·0001, coefficient β=0·05, meaning 1 W increase in exercise capacity corresponds to a 0·05-point increase in the work ability score), the mental component score of QoL (*r*=0·46, p<0·0001, coefficient β=0·22), and negatively related to anxiety severity (*r*=–0·23, p=0·011, coefficient β=–0·37), depression severity (*r*=–0·42, p<0·0001, coefficient β=–0·68), and to body-mass index (*r*=–0·17, p=0·037, coefficient β=–0·44). After controlling for age, sex, and baseline work ability, associations remained significant for exercise capacity (*r*=0·31, p<0·0001), the mental component score (*r*=0·27, p=0·004), depression severity (r: –0·26, p=0·005), and BMI (*r*=–0·19, p=0·017), but not for anxiety severity (*r*=–0·16, p=0·090). There was no association between changes in work ability and changes in metabolic syndrome severity (*r*=–0·06, p=0·456).

For the exercise group, changes in exercise capacity (peak power output) after 6 months negatively correlated with changes in metabolic syndrome severity (*r*=–0·47, p<0·0001), and positively with the work ability subscales of current work ability (*r*=0·22, p=0·005) and mental resources (*r*=0·16, p=0·047). These associations remained

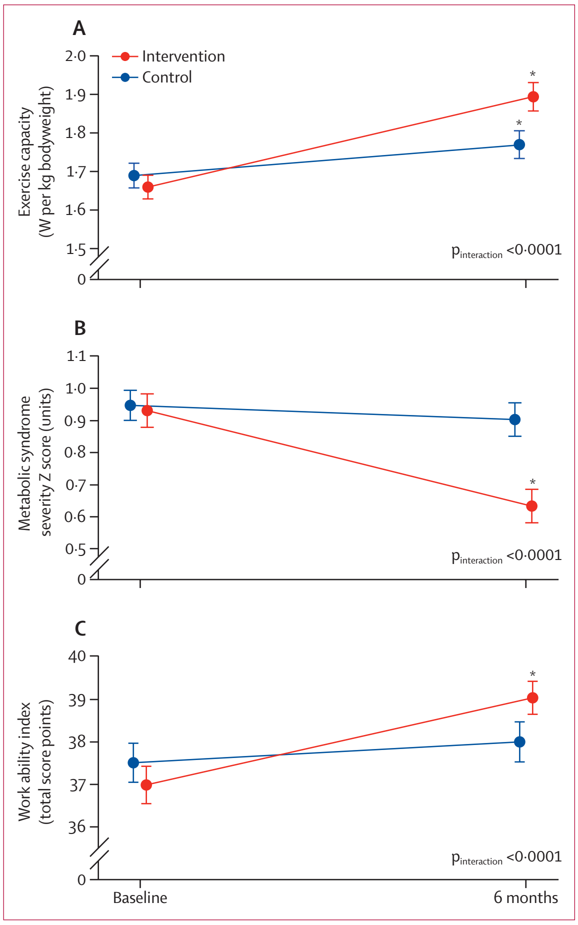

Figure 2: **Exercise capacity during incremental bicycle testing (A), metabolic syndrome severity Z score (B), and work ability index score (C) before and after the 6-month intervention**

The p values are given for between-group differences over time (time × group interaction), as analysed with an analysis of covariates method, controlled for sex and the respective baseline value. Data are mean (SE). *p<0·01 for within-group differences (before *vs* after intervention).

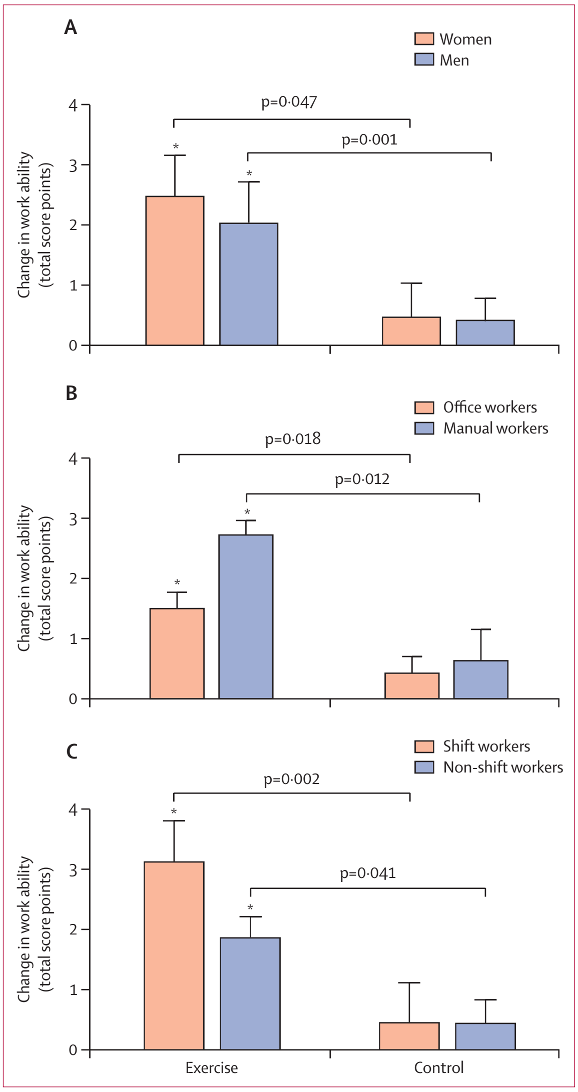

Figure 3: **Changes in total work ability index score after the 6-month intervention**

Changes for the exercise and control groups were stratified according to sex (A), manual versus office work (B), and shift versus non-shift work (C). The p values are given for between-group differences over time (time × group interaction), as analysed with an analysis of covariates method. Data are mean (SE). *p<0·01 for within-group differences (before vs after intervention).

significant after controlling for age, sex, and baseline exercise capacity (metabolic syndrome Z score *r*=–0·47, p<0·0001; current work ability *r*=0·21, p=0·012; and mental resources *r*=0·20, p=0·015).

The physical and mental component scores of the QoL questionnaire increased in the exercise group after the duration of the intervention, with a significantly greater increase compared with control participants for the mental component score (appendix p 3). For both groups, a decrease in severity scores for anxiety and depression on the basis of the HADS questionnaire was detected, with a greater improvement for participants in the exercise group than those in the control group. Following stratification into tertiles according to changes in exercise capacity, depression severity and the mental component score of the QoL questionnaire, individuals in the tertiles with the highest increases in these categories also showed the greatest benefits regarding work ability changes (figure 4).

Mean bodyweight was reduced more in the exercise group (107·4 kg [SD 18·2] at baseline *vs* 103·2 kg [17·9] after the intervention period, difference –4·3 kg [4·9], p<0·0001), than in the control group (106·1 kg [20·3] *vs* 105·3 kg [20·4], difference –0·8 kg [4·6], p=0·057; p<0·0001 between groups) than in the control group (–0·8 kg [4·6], p<0·0001 between groups). The mean percentage of body fat decreased in the exercise group (33·1% [SD 8·3] at baseline *vs* 31·0% [9·2] after the intervention period, p<0·0001), but not in the control group (32·2% [7·9] *vs* 32·0% [8·0], p=0·861; p<0·0001 between groups), with no significant changes in

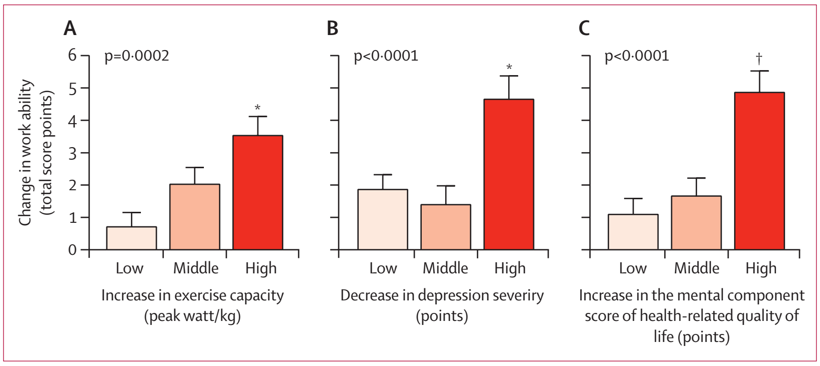

Figure 4: **Changes in total work ability index score according to changes in exercise capacity (A), depression severity (B), and mental quality of life (C)**

Changes in total work ability index score according to the three factors that were grouped into tertiles (low, middle, and high) according to their level of change during the 6-month exercise intervention. The p values are given for differences across tertiles, as analysed with a one-way ANOVA. Data are mean (SE). *Different to the low tertile. †Different to the middle tertile with p<0·01, as analysed with Bonferroni's post-hoc tests.

mean fat-free mass (70·9 kg [SD 10·9] at baseline *vs* 70·4 kg [10·7] after the intervention in the exercise group, p=0·101; 71·0 kg [12·6] *vs* 71·2 kg [13·3] in the control group, p=0·688; p=0·176 between groups).

As assessed by the activity monitor worn by participants in the exercise group, mean adherence to the scheduled target of 150 min of physical activity per week was 147 min per week (SD 46; 96·3 % of the target duration of weekly activity [SD 29·4]), with 77 (48%) of participants exercising 150 min per week or more. The average heart rate for manually started physical activities during the intervention was 117 beats per min (SD 11; 72·4% of the maximum heart rate [SD 9·8]). The maximum power during incremental exercise testing increased for the exercise group (mean 174 W [SD 36] at baseline and 191 W [38] after 6 months, p<0·0001) and the control group (175 W [37] and 181 W [40], p=0·001), with a significant difference between groups of 10 W (95% CI 5–14, p<0·0001; figure 2 for power in W per kg bodyweight). Duration of physical activity (in min per week) was positively associated with changes in total work ability (*r*=0·27, p=0·003) over the 6 months, but not with metabolic syndrome severity (*r*=–0·06, p=0·504). Activity intensity (absolute heart rate and heart rate relative to maximum heart rate) was unrelated to changes in measured outcomes.

In a stepwise backward multivariate linear regression analysis including age, sex, changes in exercise capacity, sporting activities, the mental component score of the QoL questionnaire, anxiety severity, depression severity, and body-mass index as independent variables, only changes in the mental component score of QoL (β=0·33, p=0·001) and depression severity (β=–0·24, p=0·012) predicted changes in work ability during the 6-month intervention. The model explained 24% of the total variation in work ability changes with the intervention.

Discussion

We investigated the effects of an exercise-focused lifestyle intervention on metabolic syndrome severity and associated changes in work ability in young and middle-aged employees. Our main finding is that the 6-month intervention, with guidance based on exercise tests and feedback from activity monitors, reduced metabolic syndrome severity and improved work ability regardless of sex and type of work of the participants. The observation that improvements in exercise capacity and mental health are associated with changes in work ability shows the need to offer similar interventions broadly across the working population, not only to reduce individual risk of disease, but also to possibly ease the health-care burden and economic costs arising from metabolic syndrome conditions in an ageing population, an issue that should be addressed in further studies.

Hormonal changes, obesity, and a sedentary lifestyle throughout early life and midlife promote metabolic and cardiovascular disturbances that can lead to premature ageing and multi-morbidity. The consequences are poor health with reduced productivity and a shortened overall productive lifetime.[23] In line with previous studies,[10,24] we showed that regular exercise training is an effective measure to improve distinct target parameters (eg, abdominal adiposity, hyperglycaemia, physical fitness, self-perceived quality of life, and mental health) in a large group of young to middle-aged individuals with different occupations. Our initial hypothesis that a 6-month telemonitoring-supported active lifestyle intervention will result in reductions in metabolic syndrome severity in employees was confirmed. In this regard, the metabolic syndrome components waist circumference, systolic blood pressure, triglycerides, and glucose, but not HDL cholesterol, ameliorated the metabolic syndrome severity score. For these parameters, the effect of our intervention was above average compared with values reported in a 2017 meta-analysis for exercise training interventions in people with metabolic syndrome.[10] Reasons for this increased effect might include the provision of an activity monitor to track information on completed activities and the opportunity to receive individualised feedback on the training process and content by a qualified exercise scientist. A further factor could be the use of a custom-built application, through which general information on healthy nutrition, stress management, and appropriate sports activities is provided. Finally, the nutritional advice at the start of the intervention might also have contributed to the achieved outcomes, a feature which we will monitor more closely in future studies.

The crucial question of our study was how regular exercise affects productivity at the workplace. Given the risk posed by metabolic syndrome for new onset of type 2 diabetes and cardiovascular diseases, which is beyond the associated component risk factors alone,[2] it is not surprising that health-care and economic costs are increased in patients with metabolic syndrome.[8] These costs are not restricted to disease management,[6] but extend to sick leave and productivity-related costs in the workplace.[5,6,8] Changes in metabolic syndrome status over time can have an impact on health-care and short-term disability costs, with individuals who reduce their risks also reducing associated costs and increasing work ability,[6] highlighting the potential to improve health-related productivity by reducing metabolic syndrome severity in the working population. Previous randomised trials on work ability or sick leave have mainly focused on apparently healthy individuals or patients with musculoskeletal disorders.[11–13,25] However, evidence for exercise-based interventions in the face of the rapidly spreading epidemics of obesity and metabolic syndrome remains scant and requires further research.[26]

Our study showed that work ability is improved after 6 months of exercise training in employees with metabolic syndrome, with parallel improvements in clinical status regarding blood pressure, fasting glucose, abdominal adiposity, and physical exercise performance. The observed association between changes in exercise capacity and changes in work ability link physiological exercise-induced response rates to productivity-related outcomes. Of course, changes in health-related work ability derive not only from improved physical performance, but also from the mental effects of exercise activities on overall wellbeing. This relationship was shown in our study, where we found that severity of anxiety and depression also improved after 6 months of exercise training, despite being already within a normal range at baseline. Moreover, changes in these parameters were associated with changes in the total work ability score, highlighting that both physiological and mental effects of exercise training contribute to an employee's self-perceived ability to work. By contrast, changes in metabolic syndrome severity were not related to changes in work ability, indicating that improvement in productivity-related factors are not necessarily dependent on changes in metabolic syndrome severity. Because of the nature of our research, we could not assess the impact of regular activity on long-term sick leave or early retirement due to cardiometabolic diseases. However, since the work ability index has been shown to predict sickness absence and early retirement,[27,28] one could speculate that the maintenance of a physically active lifestyle might also affect productivity and the ability to work in the long term for individuals with metabolic syndrome.

An important question in exercise research is the impact of exercise characteristics on tested outcomes. Our results suggest that increased activity duration per week relates to a greater increase in work ability. Since our study was not designed to compare exercise training regimens, these results should be interpreted with caution and addressed in more detail in further research. There is also evidence that social status and workplace characteristics have a role in health outcomes, with links between a lower social status and an increased disease risk for those with less leisure time for physical activity.[29–31] In our cohort, improvements in work ability occurred irrespective of the employee's sex and the type of work done (manual *vs* office worker and shift *vs* non-shift worker), suggesting that the intervention is effective and suitable for the broader workforce. Given the high acceptance of recommended activity and technologies by our participants, with a dropout rate commensurate to that commonly observed in exercise programmes, the intervention appears feasible for real-life application for the studied population. In this context, the transfer of activity data to a central database facilitates the monitoring of many individuals, regardless of their residence or workplace.

Our study has several limitations. Many unknown factors besides the supervised physical activities might have influenced the measured outcomes, including nutrition, stress management, smoking behaviour, or interest in using the provided technologies. Moreover, the exercise prescriptions were moderate regarding intensity and not overly restrictive, aiming at facilitating implementation and adherence in everyday life. However, this setup might have led to variations in exercise performance, which could have affected the results. The increase in sporting activities in the control group is an undesired but frequently observed effect in exercise studies, and it corresponds with improvements in some outcome measures (systolic blood pressure and waist circumference in our study). The main reason for this effect is likely to be a self-motivated change in the participants' physical activity habits, resulting from their inclusion in an exercise study. However, the increase was significantly smaller than in the exercise group and the pursued activities are most likely of lower quality than the recommended and individually adapted activities implemented in the exercise group.

In conclusion, our physical activity programme for company employees with diagnosed metabolic syndrome showed health benefits, increased work ability, and improved overall quality of life after 6 months. Our results indicate the potential benefit of personalised and telemonitoring-supported activity programmes and the need for further investigation on the links between exercise-induced health effects and socioeconomic benefits for an ageing workforce.

Contributors

SH, DB, CT, DH-K, AH, and TU planned and designed the study. RE, LN, and DL recruited participants. AK, GP, PB, HTS, SR, TS, CB, AAH, and RE collected the data. AK, GP, PB, HTS, SR, TS, CT, CB, AAH, and MK processed the exercise-test, anthropometric, body composition, and metabolic data. MK processed the dietary-intake data. SH and DB calculated the sample size and were responsible for the statistical analyses. SH and AK wrote the first draft of the manuscript. LN, DH-K, AH, MS, and UT contributed to the discussion and reviewed and edited the manuscript. All authors participated in data interpretation, commented on subsequent drafts, approved the final manuscript, and agreed to submit for publication.

Declaration of interests

We declare no competing interests.

Data sharing

Individual participant data that underlie the results reported in this article, after de-identification (text, tables, figures, and appendices), as well as the study protocol and the statistical analysis plan, will be shared, beginning 3 months and ending 5 years following publication of the Article. Data will be shared with researchers who provide a methodologically sound proposal to achieve aims in the approved proposal. Proposals should be directed to sportmedizin@mh-hannover.de to gain access, and data requestors will need to sign a data-access agreement.

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