Aleksander Tanem Almåsbakk

Effect of 3 years of aerobic exercise training on falling and risk of falling in community-dwelling older adults

Master's thesis in Physical Activity and Health
Supervisor: Jorunn Lægreid Helbostad
May 2023

Master's thesis

NTNU
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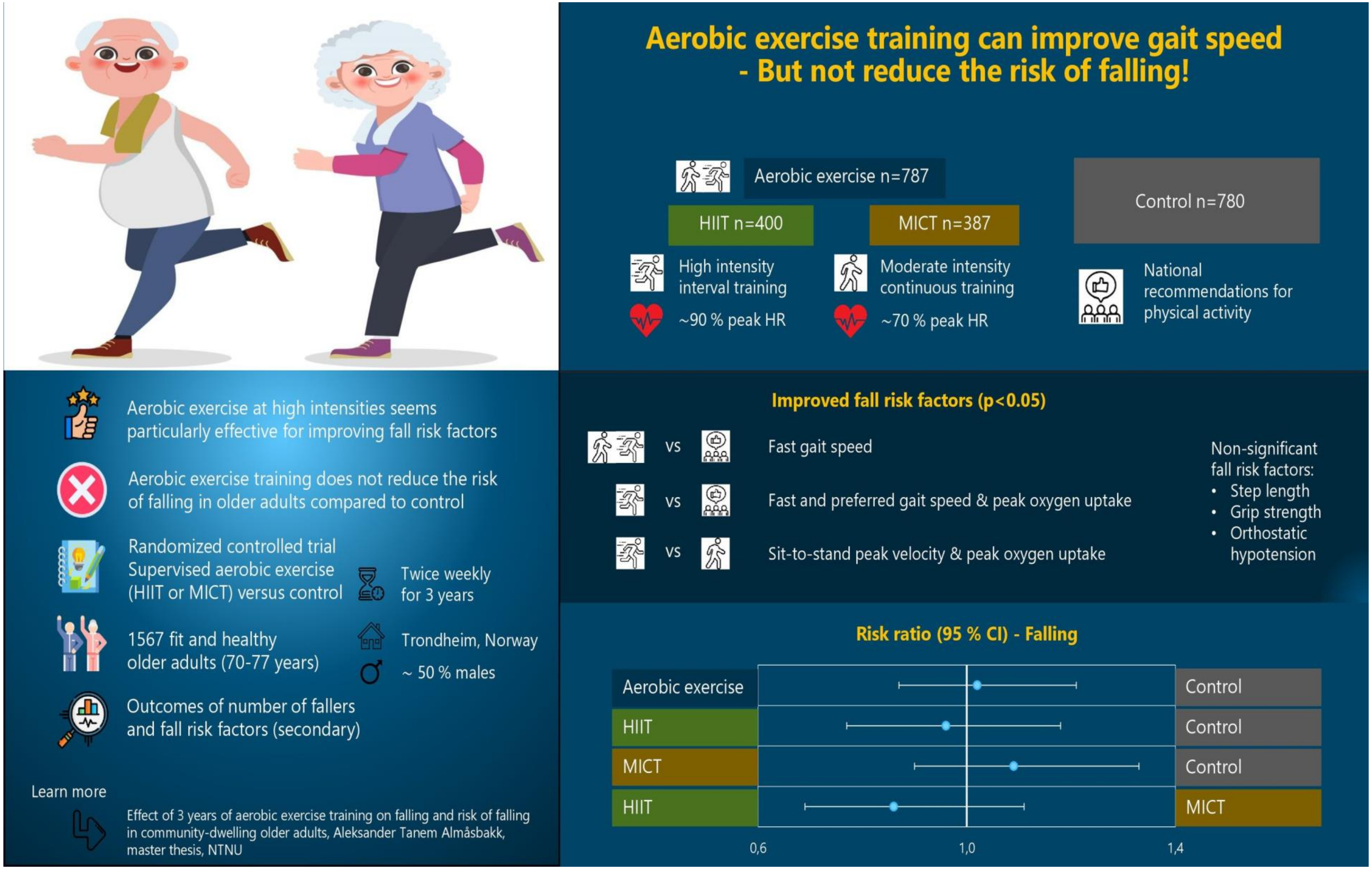

Aerobic exercise training can improve gait speed - But not reduce the risk of falling!
Aerobic exercise n=787
HIIT n=400
MICT n=387
Control n=780
High intensity interval training
~90 % peak HR
Moderate intensity continuous training
~70 % peak HR
National recommendations for physical activity
Aerobic exercise at high intensities seems particularly effective for improving fall risk factors
Aerobic exercise training does not reduce the risk of falling in older adults compared to control
Randomized controlled trial
Supervised aerobic exercise (HIIT or MICT) versus control
Twice weekly for 3 years
1567 fit and healthy older adults (70-77 years)
Trondheim, Norway
~ 50 % males
Outcomes of number of fallers and fall risk factors (secondary)
Learn more
Effect of 3 years of aerobic exercise training on falling and risk of falling in community-dwelling older adults, Aleksander Tanem Almåsbakk, master thesis, NTNU
Improved fall risk factors (p<0.05)
vs
Fast gait speed
vs
Fast and preferred gait speed & peak oxygen uptake
vs
Sit-to-stand peak velocity & peak oxygen uptake
Non-significant fall risk factors:
• Step length
• Grip strength
• Orthostatic hypotension
Risk ratio (95 % CI) - Falling
Aerobic exercise
Control
HIIT
Control
MICT
Control
HIIT
MICT
0,6
1,0
1,4

Content

Abstract

Background The world population is getting older, and one-third of people 65 years and older falls every year. Many falls among older adults result in injuries, which is a substantial source of increased morbidity, mortality, and health-care cost. Preventing falls among older adults is therefore a high priority. Previous studies have shown that multidimensional exercise including some sort of gait, balance and resistance exercise is effective to reduce the risk of falls, but the role of aerobic exercise in fall prevention remains unclear.

Purpose To evaluate if 3 years of structured aerobic exercise training, including subgroups of high-intensity interval training (HIIT) and moderate-intensity continuous training (MICT) reduces the risk of falling and improves fall risk factors in older adults compared to control.

Methods 1567 community-dwelling older adults 70-77 years of age in Trondheim, Norway were randomized to either follow national guidelines for physical activity (n=787) or perform two weekly sessions of aerobic exercise training (n=780). Aerobic exercise was further randomized to be performed as HIIT (~90 % of peak heart rate, n=400) or MICT (~70 % of peak heart rate, n=387) for 3 years. The main outcome measure was number of fallers.

Results Number of fallers was not different between the control and aerobic exercise group (Relative risk= 1.02, 95 % confidence interval (CI) 0.87 to 1.21). No statistically significant differences in number of fallers were observed when comparing HIIT and MICT to each other and control. Fast gait speed was significantly higher for aerobic exercise vs. control (4.76 cm/s, 95 % CI 1.24 to 8.28). Fast gait speed (6.48 cm/s, 95 % CI 2.21 to 10.75), preferred gait speed (3.20 cm/s, 95 % CI 0.10 to 6.30) and peak oxygen uptake (VO_{2peak}) (1.49 mL/kg/min, 95 % CI 0.49 to 2.50) was significantly higher for HIIT vs. control. HIIT showed higher VO_{2peak} (1.77 mL/kg/min, 95 % CI 0.65 to 2.90) and sit-to-stand peak velocity (0.04 m/s, 95 % CI 0.01 to 0.08) vs. MICT. MICT showed no significant differences compared to control. Other fall risk factors did not show significant between-group differences.

Conclusion This study suggests that 3 years of structured aerobic exercise in older adults does not reduce the risk of falling. However, aerobic exercise, especially at high intensities can improve some fall-related risk factors.

Sammendrag

Bakgrunn Verdens befolking blir stadig eldre, og en av tre eldre over 65 år faller hvert år. Mange fall blant eldre resulterer i skader, som er en betraktelig kilde til økt skrøpelighet, dødelighet og helsekostnader. Å hindre fall blant eldre er derfor høyt prioritert. Tidligere studier har vist at sammensatte treningsprogrammer som inkluderer gange, balanse og styrketrening er effektive for å redusere risiko for fall, men rollen til aerobisk trening i fallforebygging er fortsatt uklar.

Hensikt Evaluere om 3 år med strukturert aerobisk trening, inkludert delgrupper med høyintensitets intervalltrening (HIIT) og moderat-intensitet kontinuerlig trening (MICT) reduserer risiko for å falle og forbedrer risikofaktorer for fall blant eldre sammenlignet med kontroll.

Metode 1567 hjemmeboende eldre 70-77 år i Trondheim, Norge ble randomisert til enten å følge nasjonale retningslinjer for fysisk aktivitet (n=787), eller gjennomføre to ukentlige aerobiske treningsøkter (n=780). Aerobisk trening ble videre randomisert til å bli gjennomført som HIIT (~90 % av maksimal hjerterytme, n=400) eller MICT (~70 % av maksimal hjerterytme, n=387) over 3 år. Det primære utfallsmålet var antall fallere.

Resultater Antall fallere var ikke ulik mellom kontrollgruppen og den aerobiske treningsgruppen (Relative risiko= 1.02, 95 % konfidensintervall (KI) 0.87 til 1.21). Ingen statistisk signifikant forskjell i antall fallere ble observert ved sammenligning av HIIT og MICT til hverandre og kontroll. Rask ganghastighet var signifikant høyere i aerobisk trening vs. kontroll (4.76 cm/s, 95 % KI 1.24 til 8.28). Rask ganghastighet (6.48 cm/s, 95 % KI 2.21 til 10.75), normal ganghastighet (3.20 cm/s, 95 % KI 0.10 til 6.30) og høyeste oksygenopptak (VO_{2peak}) (1.49 ml/kg/min, 95 % KI 0.49 til 2.50) var signifikant høyere for HIIT vs. kontroll. HIIT viste høyere VO_{2peak} (1.77 ml/kg/min, 95 % KI 0.65 til 2.90) og sit-to-stand topphastighet (0.04 m/s, 95 % KI 0.01 til 0.08) vs. MICT. MICT viste ingen signifikante forskjeller sammenlignet med kontroll. Ingen signifikante gruppeforskjeller ble funnet for andre fall-relaterte risikofaktorer.

Konklusjon Denne studien viser at 3 års strukturert aerobisk trening for eldre, ikke reduserer risikoen for å falle. Likevel, aerobisk trening, spesielt ved høyere intensiteter kan forbedre enkelte fall-relaterte risikofaktorer.

Abbreviations

ARR	Absolute risk reduction
Gen100	Generation 100 study
HIIT	High-intensity interval training
MAR	Missing at random
MCAR	Missing completely at random
MICT	Moderate-intensity continuous training
NTNU	Norwegian University of Science and Technology
OH	Orthostatic hypotension
REK	Regional Committees for Medical and Health Research
RR	Relative risk
SD	Standard deviation
STS	Sit-to-stand
VO_{2max}	Maximal oxygen uptake
VO_{2peak}	Peak oxygen uptake
WHO	World Health Organization

1. Introduction

In most of the world, rising longevity increases the proportion of 60 years or older adults in the populations. In 2015, this group constituted 25% or more only in a few countries in the world, however by 2050 it is estimated that similar demographics are to be found in many countries, including Norway (World Health Organization [WHO], 2015). To meet the challenges with an older population, the World Health Organization (WHO) has among other strategies developed a concept called "Active ageing". This concept describes "the process of optimizing opportunities for health, participation and security, in order to enhance quality of life as people age" (WHO, 2002, p. 12). An important part of this concept was to develop a global strategy of fall prevention for older adults. This strategy was presented in WHO's report from 2021, where exercise alongside home assessment and modifications were identified as the best measures to prevent falls in home-dwelling older adults (WHO, 2021).

More than one-third of home-dwelling adults over 65 years of age experience a fall annually (Campbell et al., 1990; Tinetti et al., 1988). Higher age seems to increase the risk of falling and result in more fall-related injuries (Peel et al., 2002; Skjellegrind et al., 2021). Falling is the leading cause of fatal and non-fatal injuries for those 65 years and older (Centers for Disease Control and Prevention, 2023). Many falls have severe consequences, resulting in fractures and injuries that require substantial and time-consuming care in around 10 and 20 % of the cases respectively (Alexander et al., 1992; Campbell et al., 1990; Tinetti et al., 1988). These fractures have serious consequences for older adults, being a significant source of morbidity and mortality (Burns et al., 2016). Falls and their consequences also comes with substantial health-care costs. A single hip fracture is estimated to cost around 70,000 euros in Norway, but also the less severe fall-related injuries like bruises, lacerations, and sprains have consequences that result in large health-care expenses (Burns et al., 2016; Hektoen et al., 2016). Confidence loss and fear of falling are also common in older adults that falls. These psychological consequences can reduce daily life activities and promote sedentary behavior that over time can reduce physical function and health-related quality of life (Stenhagen et al., 2014; Yardley & Smith, 2002).

1.1 Risk factors for falls

Falls are associated with intrinsic (patient-related) and extrinsic (environmental) risk factors, or a combination of both. Most falls in older adults are multifactorial, and typically occurs while walking on even or uneven surfaces due to trips and slips (Berg et al., 1997; Voermans et al., 2007). Ambrose et al. (2013) found that extrinsic risk factors that increase fall risk are mainly linked to certain medication use, hazardous home environments and bad footwear like slippers. Intrinsic risk factors for falls include demographical factors, functional abilities, and diseases, where history of falls and impaired gait and balance are major risk factors (Ambrose et al., 2013). Older adults with gait problems have for instance been found to be two times more likely to fall compared to those without problems (Deandra et al., 2010). Other central intrinsic fall risk factors include female gender, ageing, cognitive deficits, impaired vision, and likely lower extremity muscle strength (Ambrose et al., 2013). Although strength training alone does not seem to reduce fall risk, it is an essential part of multidimensional exercise programs (Sherrington et al., 2019). Older adults with reduced lower extremity muscle strength are also reported to be 43 % more likely to fall at home compared to strong older adults (Menant et al., 2017).

Less known, but other relevant risk factors for falls include cardiorespiratory fitness and orthostatic hypotension (OH) (Gangavati et al., 2011; Mertz et al., 2010). Cardiorespiratory fitness is often closely linked with the concepts of maximal oxygen uptake (VO_{2max}) and peak oxygen uptake (VO_{2peak}) (Green & Askew, 2018). Aerobic exercise training, especially at high intensities has been reported to increase cardiorespiratory fitness in older adults (Stensvold et al., 2020). OH, has been defined as:

> A sustained reduction of systolic blood pressure of at least 20 mmHg or diastolic blood pressure of 10 mmHg within 3 min of standing or head-up tilt to at least 60 on a tilt table. Orthostatic hypotension is a clinical sign and may be symptomatic or asymptomatic. (Freeman et al., 2011, p. 69)

The prevalence of OH in community-dwelling older adults over 60 years old, has been reported to be 22,2 % (Saedon et al., 2020). To improve OH, it is recommended to perform light exercise programs and avoid deconditioning. Isotonic exercise in supine or sitting position is recommended to uphold venous return and avoid orthostatic drop in blood pressure (Figueroa et al., 2010).

1.2 Strategies to prevents falls

To implement knowledge and skill-based exercise programs is an important part of WHO's strategy to prevent falls in older adults (WHO, 2021). Exercise-based programs that improves balance, strength and physical function is particularly effective in fall-prevention and recommended by WHO for home-dwelling older adults. Programs using these recommendations like the Falls Management Exercise (FaME) programme has also been shown to be cost-effective (WHO, 2021, pp. 91-92). The effect of exercise in fall prevention is well studied and shown to reduce the number of falls by 23 %. With falls being the main cause of fractures, exercise training therefore seems to be an essential part of preventing fall-related fractures and injuries (Sherrington et al., 2019). International guidelines for physical activity recommend that older adults should do a minimum of 150 minutes of moderate-intensity or 75 minutes of high-intensity aerobic physical activity, every week. Adherence to these guidelines is reported to be around 65 % for those aged 70-79 years, and less than 50 % for people aged 80 years or older (Bauman et al., 2016). Lack of time, missing motivation, and interest are among the most central barriers for physical activity in older adults (Costello et al, 2011). Therefore, by reducing the time constraint, high-intensity interval training (HIIT) can have potential of increasing adherence among older adults to reach recommended levels of activity.

In their Cochrane review comparing a combination of balance and functional exercises with controls, Sherrington et al. (2019) found a reduced rate of falls by 24 %. Resistance exercise in combination with balance and functional exercise reduced the rate of falls by 34 %. Only Tai Chi was found to be effective as a single intervention in fall prevention (Sherrington et al., 2019). Therefore, it seems that multidimensional programs that include some sort of resistance, balance and functional exercises is most effective to prevent falls. The review does however, state that more studies are needed to determine the role of certain types of exercises, like aerobic exercise training where no studies were identified (Sherrington et al., 2019). However, the role of aerobic exercise at high intensities and moderate intensities on improving fall risk factors for healthy older adults has been reported in a recent systematic review, where HIIT improved important fall risk factors like lower extremity strength, gait and balance compared to control (Elboim-Gabyzon et al., 2021).

Summarized, there seems to be little knowledge on the role of aerobic exercise at moderate and high intensities in fall prevention for older adults, and more studies have been called for (Sherrington et al., 2019). Some studies have looked at the role of aerobic exercise training in improving fall-related risk factors, but despite this the role of aerobic exercise in fall prevention remains unclear. Moreover, while gait and balance are major fall risk factors, and lower extremity muscle strength assumed to be important, there is also a need to assess whether less studied potential fall risk factors like OH and VO_{2peak} can be associated with falls.

1.3 Aims

The aim of this study was to assess if aerobic exercise training over 3 years reduces the risk of falling in older adults compared to control. Second, we aimed to assess if aerobic exercise improves fall-related risk factors compared to control. Third, we aimed to assess the effect of aerobic exercise at high and moderate intensities compared to each other and control for these outcomes.

2. Methods

2.1 Design

This study uses data from the Generation 100 study (Gen100), which is a randomized controlled clinical study, a design suited to evaluate effect. The main Gen100 study objective was to evaluate the effect of aerobic exercise over 5 years on all-cause mortality in home-dwelling older adults. The inclusion in the study was set between August 2012 to June 2013. This study will use data from baseline and 3-year follow-up.

Participants were randomized 1:1 into an aerobic exercise group, and control group. The aerobic exercise group was further randomized 1:1 into HIIT and moderate-intensity continuous training (MICT). The randomizations were stratified by sex and cohabitation status (living alone vs. with someone). The unit for Applied Clinical Research, a center of expertise in clinical research at the Norwegian University of Science and Technology (NTNU) was used in the patient randomization to ensure impartial allocations.

2.2 Participants

All men and women (n=6966) between 70-77 years of age and residents of Trondheim, Norway were invited to participate in the Gen100 study. In addition to being born in the years between 1936-1942, the study has an inclusion criterion of being able to complete an exercise program determined by the researchers. Several exclusion criteria were set as reported by Stensvold et al. (2015), which further define the study population:

> Illness or disabilities that preclude exercise or hinder completion of the study. Uncontrolled hypertension. Symptomatic valvular, hypertrophic cardiomyopathy, unstable angina, primary pulmonary hypertension, heart failure or severe arrhythmia. Diagnosed dementia. Cancer that makes participation impossible or exercise contraindicated. Consider individually, in consultation with physician. Chronic communicable infectious diseases. Test results indicating that study participation is unsafe. Participation in other studies conflicting with participation in Generation 100. (p. 4)

Of the 1741 older adults that consented to participate and met the criteria, 1567 persons showed up for baseline testing and were included in the study.

2.3 Sample size

Sample size in the Gen100 study was calculated based on overall mortality as the primary outcome measure. There has been no sample sized calculated for this specific study. However, in a similar exercise study 200 subject per group were reported sufficient to show a 40 % reduction in number of falls (with 80 % power, and a two-sided significance level of 0.05) assuming 30 % drop-out rate and 60 % fall rate during a 11/2-year trial (Luukinen et al., 2007). A Cochrane review reports that most studies related to fall risk have sample sizes less than 500 participants and state a need for larger studies (Sherrington et al., 2019). The sample size of the Gen100 study (n ~1500) met this criterion and can, compared to the study of Luukinen et al. (2007), allow more power and therefore more chance to detect a true effect.

2.4 Intervention

2.4.1 High-intensity interval training

The participants in the HIIT group were asked to complete 40 min-long exercise sessions that consisted of 10 min of warm-up followed by 4×4 min intervals at ~90% of peak heart rate twice a week. This is equivalent to 16 on the Borg Scale (perceived exertion rating scale), a scale the participants were instructed to use as guidance for intensity of exercise (Nes et al., 2012). Supervised HIIT sessions was offered in different outdoor and indoor areas in Trondheim. The performed exercise training varied between walking, running, aerobics and cross-country skiing. To ensure that recommended intensities were being reached, supervised spinning session with an exercise physiologist and heart rate monitors were completed every sixth week. In addition, they were also asked to follow the national recommendations of physical activity three times a week.

2.4.2 Moderate-intensity continuous training

The participants in the MICT group were asked to exercise for 50 min at continuous work at ~70% of peak heart rate twice a week. This is equivalent to 13 on the Borg scale (Nes et al., 2012). The MICT group met for supervised spinning sessions like the HIIT group, but at separate time points to ensure that recommended intensities were followed. They were offered supervised exercised sessions within the same activities as the HIIT group and exercised according to the national recommendations three times a week.

2.4.3 Control group

The control group was asked to follow the Norwegian national recommendations on physical activity per 2012 (30 min of moderate physical activity almost every day) and were left to themselves without further supervision (Helsedirektoratet, 2011).

2.5 Adherence

To register and improve adherence the exercise groups were asked to fill in logs with information about type of exercise, duration, and intensity after each exercise session. The participants either used an internet-based form or sent in the logs monthly by prepaid envelopes. This procedure was abandoned at 1-year follow-up and replaced by a questionnaire about physical activity. This questionnaire was used to registerer adherence to prescribe exercise for the different groups at 3-year follow-up. To improve adherences for all groups, participants were invited to yearly information meetings, newsletters were sent out twice a year, and contact information to the administration of the study were always available for everyone. After the first year an adherence committee was established and tasked to implement measure that increased adherence in exercise groups.

2.6 Procedure

The participants were assessed at baseline and 3-year follow-up for different outcome variables, performed by trained personnel blinded for intervention at the St. Olav's University Hospital, Trondheim. Blood samples were obtained first (and after VO_{2peak}), then blood pressure, before weighing and height measurement. Thereafter, a physical examination including gait, strength, balance, cognitive function, and aerobic fitness.

In addition, four different questionnaires were used in this study for information related to general health, cognitive and psychical wellbeing. A general questionnaire with 21 questions related to general health, physical activity habits and background information were sent out to everyone alongside the invitation letter. Everyone was asked to fill in the questionnaire. Those included in the study received another questionnaire to be filled in before baseline testing with more specific questions related to lifestyle, social environment, and health, including questions related to falls. They also filled in a questionnaire about quality of life and chronic pain (the short-health form survey SF-8).

2.7 Primary outcome measure

In this study the primary outcome measure is number of participants who falls. Falls were assessed with a questionnaire, where participants were asked to report number of falls during the last year, according to four pre-set categories: zero, one, two or three or more falls. This was adjusted further in the analysis to a dichotomous variable of having a fall vs. not having a fall.

2.8 Secondary outcome measures

Relevant predefined secondary outcomes include OH, grip strength, sit-to-stand peak velocity, preferred and fast gait speed, step length during walking, and VO_{2peak}.

2.8.1 Orthostatic hypotension

OH, was determined according to the consensus statement reported by Freeman et al. (2011), as a change of 20 or more mmHg in systolic blood pressure or of 10mm diastolic blood pressure from sitting to standing, assessed by calculating the last blood pressure measurement at rest in the sitting position and the subsequent blood pressure measurement after standing for 1 min. Blood pressure was obtained with the IntellieVue MP50 (Philips Medizin Systeme, Germany). The participants rested for 5 min in a chair with their back, arms and feet supported before the first measurement. Resting blood pressure was then measured 2-3 times in the right arm (1-min apart), before standing up for 1 min followed by repeated measurements. The outcome measure was number of participants with OH.

2.8.2 Peak oxygen uptake

VO_{2peak}, defined as five beats higher than highest observed heart rate, was used instead of VO_{2max} as a measure of cardiorespiratory fitness, because 41 % could not meet the criteria for VO_{2max} (Stensvold et al., 2020). The measures are not considered to be equal. However, the difference is likely to be small in studies with appropriate quality control, and thus reliable estimates of cardiorespiratory fitness from VO_{2peak} attainable (Green & Askew, 2018). VO_{2peak} was assessed using a treadmill, or alternatively a bike for participants where physique or balance precluded them from using the treadmill. All participants warmed up for 10 min at a constant speed. Then the inclination or resistance increased by 2 % (or 10W for bike) after stabilized oxygen uptake at each workload until exertion or VO_{2peak} was reached. The outcome measure was VO_{2peak} (mL/kg/min).

2.8.3 Grip Strength

Grip strength has shown to be a predictor of future falls (Chan et al., 2007). Grip strength was assessed with the JAMAR Hydraulic Hand Dynamometer (Lafayette Instrument Company, USA). Participants were seated in an armless chair, with feet flat on floor and hips and knees in 90 degrees of flexion. The shoulder was adducted and in neutral position, elbow flexed at 90 degrees, forearm in neutral position and with the wrist between 0- and 30-degrees extension and between 0 to 15 degrees of adduction. At each of the three attempts the participants were instructed to use their dominant hand to hold a maximum contraction for 3 s, with 30 s rest between trials. The outcome measure was the mean isometric force (kg).

2.8.4 Sit-to-stand

Sit-to-stand (STS) data was obtained with a linear encoder from Musclelab and processed using the Musclelab V8 Software. By attaching the linear encoder (small box with string inside) close to the center of the masse to the participant, the change of length of string through time is measured in the box and transmitted to the software. The participants were seated in a 46 cm high armless chair with their lower back slightly touching the back of the chair. Then told to stand up as quickly as possible for a total of five times, without using their arms. Feet were planted at the ground during the whole trial. Participants were allowed breaks between each trial as needed. Non-successful trials were canceled, and the participant asked to perform a new trial immediately.

STS-average mean velocity adjusted for body weight have been found to be highly correlated too muscle power (r=0.98) (Helbostad, 2004). Average peak velocity from five-times STS-test can therefore be considered as a functional measure of maximal muscle power. Mean peak velocity (m/s) from five-times STS will therefore be used as an outcome measure to reflect maximal muscle power 1RM leg strength, due to lack of reliable data from the Gen100 study regarding leg-strength measures.

2.8.5 Gait

Gait data was obtained with the electronic walkway system GAITRite (CIR Systems Inc, USA) at baseline, and the Zeno walkway (ProtoKinetics LLC/ZenoMetrics LLC, USA) after 3 years. Both electronic walkways have similar hardware systems (PKMAS and GAITRite software) so data can be used interchangeably with high reliability and validity (Egerton et al., 2014; Lynall et al., 2017; Menz et al., 2004). The participants walked a total of 8.7 m. An acceleration and deacceleration phase of 1.6 m at both ends was set to ends secure a steady pace during the 5.5 m that were measured by the electronic walkway. The participants were instructed to walk back and forth at their preferred(usual) walking speed. Then they were instructed to repeat the lap as fast they could without running.

Gait speed and step length were chosen as outcome variables as previous studies have shown the variables have a strong correlation with increased risk of falling (Kyrdalen et al., 2019; Rodríguez-Molinero et al., 2019). The outcome measures were mean gait speed (cm/s) and step length (cm) at preferred and fast walking speed.

2.9 Data analysis and statistics

The primary outcome was number of fallers. For the main analysis the MICT and the HIIT groups was combined to an aerobic exercise group and compared to the control group. Secondary, the differences between HIIT and MICT to control, and HIIT vs. MICT were also evaluated.

Baseline characteristics are based on data from clinical outcomes and questionnaires. Education level was split into two groups. Those with college or higher education formed one group, and the rest the other. Physical activity level was split into three groups: exercising less than once a week, 1-3 times a week, and more than three times a week. Exercise intensity was split into two groups. One group with those exercising at intensities 13 or higher on the Borg-Scale, and the rest in the other.

THE IBM SPPS Statistics 28 program was used to perform the data analysis. The statistical significance level was set to a p-value less than 0.05. All data are presented with either number and percentages or means and standard deviation (SD). With the large sample size, visual inspection of QQ-plots was used to determine normal distribution. All continuous outcome measures were found to be normally distributed.

2.9.1 Binary outcome variables

To test for between-group differences in number of fallers a chi-square test was performed, comparing aerobic exercise, HIIT, and MICT groups to the control group, and HIIT vs. MICT. The same procedure was performed to compare OH between groups. The chi-square is a non-parametric significant test that compares if two or more nominal or ordinal variables, differ from what have been expected with a null hypothesis of no difference. It is regarded as one of the most useful statistical tests for nominal variables. For the test to be used the assumption of cell counts of cases, cell values higher than five for at least 80 % of the cells and independent data within and between groups must be met (McHugh, 2013).

In accordance with the recommendations for binary outcomes from the CONSORT statement described by Schulz et al (2010), relative risk (RR) and absolute risk reduction (ARR) is presented in the results for fallers and OH. Reporting both sizes is important to be able to provide a broader picture for interpreting the clinical relevance of the results (Schulz et al., 2010). Last, a binary logistic regression analysis was performed to assess the impact of covariates on number fallers and OH, and a description of missing data provided as recommended (Rombach et al., 2020). Two separate analyses with age and relevant outcome variables including either gender or mean grip strength were performed due to high correlation (r=0.8) between gender and mean grip strength.

2.9.2 Continuous outcome variables

A per-protocol or complete case analysis may have a bias related to maintaining the balance of the baseline randomization if the data are not randomly distributed across all observations, according to the missing completely at random (MCAR) assumption. A linear mixed model approach also has the advantage of being unbiased under the missing at random (MAR) assumption, that missing data are randomly distributed within observable variables (Chakraborty & Gu, 2019). The mixed model includes all participants data regardless of missing data. This helps to maintain the prognostic balance of the randomization from baseline, and answer if the intervention is statistically significant for the whole sample. We therefore performed a linear mixed model analysis adjusting for the stratification variables sex and age to assess change between groups over time in VO_{2peak}, fast and preferred gait speed, fast and preferred step length, grip strength and STS peak velocity. Step length was also adjusted for gait speed.

The between-group comparisons for each continuous outcome variable were performed for change between two and two groups after 3 years. Due to the randomization procedures, the data was constrained to be equal at baseline. The results will be presented with estimates of change from the Group x Year interaction adjusted for age, gender, and gait speed (step length) from a linear mixed model analysis.

2.10 Ethical considerations

The Gen100 study had a general approval for the entire study, where sub-studies could apply Regional Committees for Medical and Health Research (REK) for new approval to the data. An application for approval was sent to REK to use data from the Gen100 study in June 2022. The risk in the Gen100 study were considered very small, with potential health benefits for all participants due to promoting exercise for both the intervention and control group. Safety measures to reduce potential risk included reviewing mortality data, reviewed by an independent safety manager, and reporting potential health risk events to a medical director to determine need of further medical care. All participants signed an informed consent, after being provided with detailed information, to secure that they knew what they consented too. The participants were free to withdraw the consent and leave the study at any point. The risk within this study is limited to securing confidentiality and privacy of data obtained from the Gen100. This will be secured through storing of data at an NTNU server thus preventing access to the data from other parties not involved in the study, and to not present data in a manner that may identify participants.

3. Results

3.1 Participants

From the 1567 participant included at baseline, 780 were assigned to an aerobic exercise group, and 787 placed in a control group. The participants in the aerobic exercise group were further randomized to HIIT (n=400) or MICT (n=387). Baseline characteristics for background variables are shown in Table 1. Overall mean age was 72.4 (SD=2.0) and 49.6 % of the participants were males (n=777). In total, 31.3 % (n=466) of the participants had experienced a fall in the 12 months prior to baseline. No group differences were observed at baseline expect for grip strength (p=0.018).

Table 1 Baseline characteristics of participants in the control, HIIT and MICT group. Values are numbers (percentages) unless stated otherwise.

Characteristics		Control (n=780)	HIIT (n=400)	MICT (n=387)
Mean age (years) (SD)		72.4 (2.1)	72.5 (2.1)	72.4 (2.0)
Mean body mass index (SD)		25.9 (3.4)	26.2 (3.7)	25.9 (3.7)
Mean number of prescribed medications (SD)		2.0 (1.8)	2.1 (1.9)	2.2 (1.8)
Sex (male)		379 (48.6 %)	210 (52.5%)	188 (48.6%)
Physical activity level	High (almost every day)	162 (21.3%)	83 (21.6%)	87 (23.2%)
	Moderate (1-3 times a week)	528 (69.6%)	268 (69.6%)	262 (69.9%)
	Low (less than once a week)	69 (9.1%)	34 (8.8%)	26 (6.9%)
Higher education (college or university)		373 (49.5%)	196 (50.9%)	192 (51.9%)
Self-reported exercise intensity (Borg-Scale 13 or more)		520 (66.7%)	274 (68.5%)	244 (63.0%)
Self-reported good health		649 (87.3%)	340 (89.0%)	314 (86.1%)
Experienced falling during the last year		227 (30.6%)	239 (32.0%)	115 (30.2%)
Orthostatic hypotension		12 (1.5%)	18 (2.3%)	10 (2.5%)

HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; SD, standard deviation. Control group followed national recommendations for physical activity.

The overall drop-out from baseline to 3-year follow-up was 275 (17.5%). Of the 1292 remaining participants a total of 1143 participants filled in the question related to number of falls over the last 12 months in the questionnaire. For falls it therefore was missing data on 149 of the remaining participants. A total of 1075 participants met for clinical testing after 3 years. Figure 1 shows a flowchart of the sample size and dropout of the participants at baseline and 3-year follow-up.

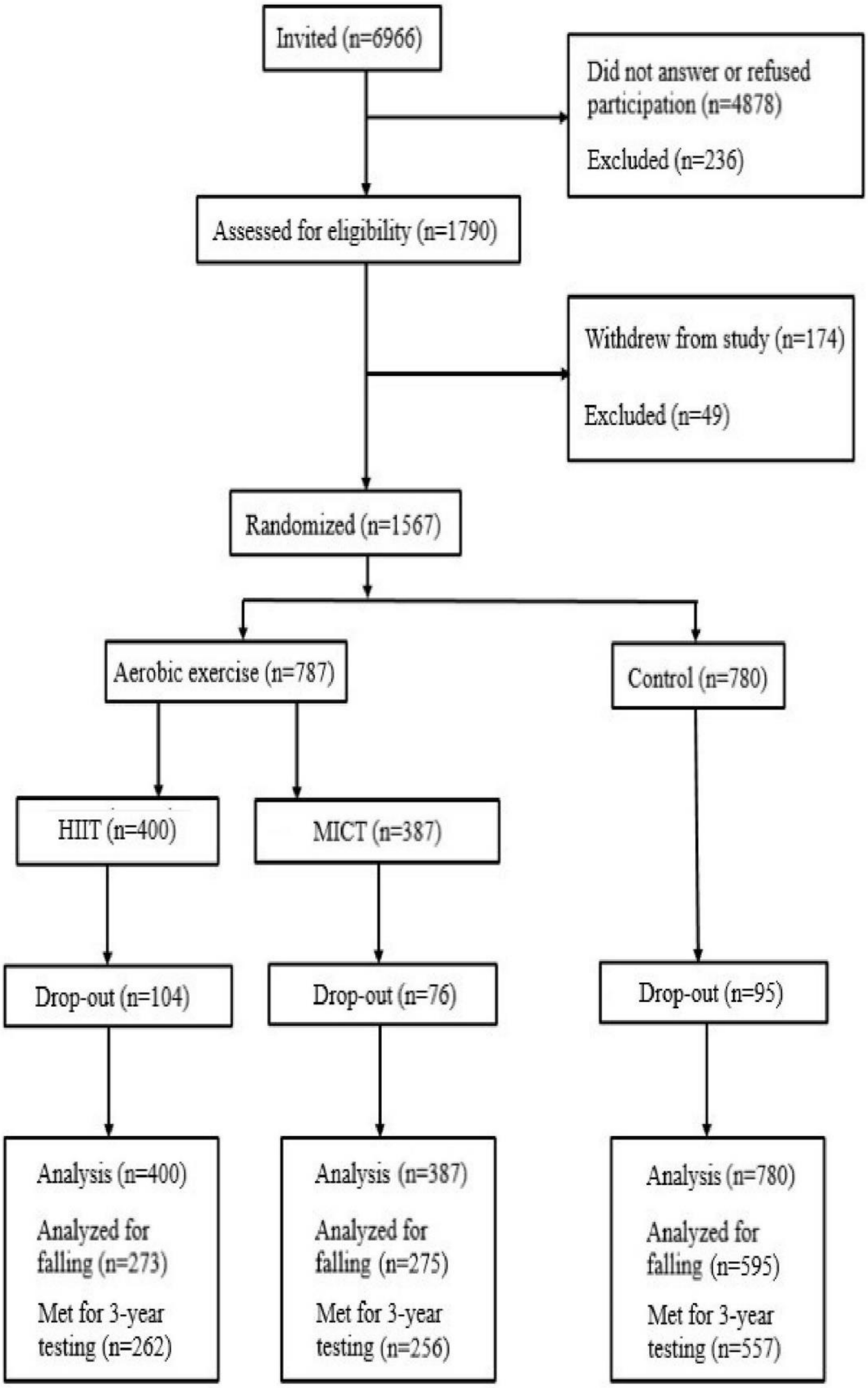

Figure 1 Flowchart of the study cohort for inclusion, drop-out and follow-up. The number of participants analyzed for continuous variables, falling after 3 years, and that met for 3-year testing are shown in the box below each intervention group. HIIT, high-intensity interval training; MICT, moderate-intensity continuous training.

3.2 Risk of falling

Falls are reported in Table 2. Fall data was missing from 27.1 % (n=424) of the participants randomized at baseline. The observed rate of fallers over the last 12-month period at 3- year follow-up was 33.0 % (n=377), with 33.4 % (n=183) within the aerobic exercise group and 32.6 % (n=194) in the control group. In the aerobic exercise group 35.6 % (n=98) of the participants with falls were found in the MICT group, and 31.1 % (n=85) in the HIIT group. With the control group as reference no statistically significant difference was observed between the groups. When HIIT was compared with MICT as reference, no statistically significant difference was observed.

Table 2 Results from chi-square tests with 95 % confidence interval for group differences in number of fallers for aerobic exercise, HIIT and MICT compared to control, and HIIT vs. MICT at Year 3.

Group	Number of fallers	Percentage	P-value	ARR - percentage	RR (95 % CI)
Control as reference					
Control	194	32.6 %	1.00 (reference)	0.00 (reference)	1.00 (Reference)
Aerobic exercise	183	33.4 %	0.78	-0.8 %	1.02 (0.87 to 1.21)
HIIT	85	31.1 %	0.67	1.5 %	0.96 (0.77 to 1.18)
MICT	98	35.6 %	0.38	-3.0 %	1.09 (0.90 to 1.33)
MICT as reference					
MICT	98	35.6 %	1.00 (reference)	0.00 (reference)	1.00 (Reference)
HIIT	85	31.1 %	0.26	4.5 %	0.86 (0.69 to 1.11)

ARR, absolute risk reduction; Aerobic exercise, MICT & HIIT; CI, confidence interval; HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; RR, relative risk. Control group followed national recommendations for physical activity.

A logistic linear regression model was performed to check the effect of age, gender, VO_{2peak}, OH, fast and preferred gait speed, mean grip, and STS peak velocity on probability of falling among participants. The models with either gender or mean grip strength explained 1.6 % and 3.2 % (Nagelkerke R2) of the variance between fallers and non-fallers. Increasing mean grip strength and fast gait speed was associated with lower odds of having a fall with 95 % CIs of 0.958 to 0.991 and 0.984 to 0.999 respectively.

3.3 Orthostatic hypotension

The proportion with OH after 3 years was 3.6 % (n=38) with 4.3 % (n=24) in control group, 2.7 % (n=14) in the aerobic exercise group, 3.5 % (n=9) in HIIT group and 2.0 % in the MICT group as shown in Table 3. With the control group as reference no statistically significant differences were observed between the groups. When HIIT was compared with MICT as reference, no statistically significant difference was observed.

Table 3 Results from chi-square tests with 95 % confidence interval for group differences in number of cases with orthostatic hypotension for aerobic exercise, HIIT and MICT compared to control, and HIIT vs. MICT at Year 3.

Group	Number of cases OH	Percentage	P-value	ARR - percentage	RR (95 % CI)
Control as reference					
Control	24	4.3 %	1.00 (reference)	0.00 (reference)	1.00 (Reference)
Aerobic exercise	14	2.7 %	0.16	1.6 %	0.63 (0.33 to 1.20)
HIIT	9	3.5 %	0.56	0.8 %	0.80 (0.38 to 1.70)
MICT	5	2.0 %	0.09	2.3 %	0.45 (0.18 to 1.18)
MICT as reference					
MICT	5	2.0 %	1.00 (reference)	0.00 (reference)	1.00 (Reference)
HIIT	9	3.5 %	0.30	-1.5 %	1.77 (0.60 to 5.20)

ARR, absolute risk reduction; Aerobic exercise, MICT & HIIT; CI, confidence interval; HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; OH, orthostatic hypotension; RR, relative risk. Control group followed national recommendations for physical activity.

A logistic linear regression model was performed to check the effect of age, gender, VO_{2peak}, falling, fast and preferred gait speed, mean grip, and STS peak velocity on probability of having OH among participants. The models with either gender or mean grip strength both explained 4.9 % (Nagelkerke R2) of the variance in cases of OH. Increasing fast gait speed was associated with higher odds (1.02) of OH with 95 % CI of 1.001 to 1.038.

3.4 Continuous fall risk factors and change over time between groups

The descriptive means of the different fall risk factors for the aerobic exercise and control group are shown at baseline and Year 3 in Table 4. The group differences at Year 3 for aerobic exercise, HIIT and MICT compared to control, and HIIT vs. MICT are shown in Table 5 as the Group x Time interaction effects controlled for age, gender, and gait speed (for step length) using a linear mixed model. Figure 2 shows the mean scores of the fall risk factors at baseline and after 3 years as the Group x Time interaction effects adjusted for age and gender for the aerobic exercise and control group.

Table 4 Descriptive means and standard deviations by intervention group at baseline and Year 3.

Fall risk factor	Year	Control Mean (SD)	Aerobic exercise Mean (SD)	HIIT Mean (SD)	MICT Mean (SD)
VO_{2peak} (mL/kg/min)	0	28.6 (6.41)	28.8 (6.47)	28.9 (6.38)	28.6 (6.57)
	3	29.3 (7.11)	30.0 (6.82)	30.9 (6.89)	29.0 (6.62)
Grip strength (kg)	0	34.0 (10.78)	34.9 (10.96)	35.8 (11.19)	34.0 (10.65)
	3	28.7 (10.68)	29.6 (10.54)	30.1 (10.93)	29.0 (10.13)
Preferred step length (cm)	0	70.2 (8.10)	70.4 (7.92)	70.2 (8.05)	70.6 (7.78)
	3	69.4 (8.63)	69.8 (8.24)	70.2 (7.95)	69.4 (8.53)
Fast step length (cm)	0	83.2 (10.05)	83.0 (10.18)	82.8 (10.22)	83.2 (10.14)
	3	82.0 (10.69)	82.7 (10.68)	83.0 (10.61)	82.3 (10.77)
Preferred gait speed (cm/s)	0	131.0 (19.94)	131.5 (20.04)	131.0 (20.50)	132.1 (19.54)
	3	130.4 (21.03)	132.0 (21.04)	133.8 (19.58)	130.2 (22.35)
Fast gait speed (cm/s)	0	188.6 (27.63)	188.5 (28.54)	188.3 (28.75)	188.8 (28.34)
	3	189.2 (29.95)	193.9 (29.39)	195.9 (28.50)	191.9 (30.20)
STS peak velocity (m/s)	0	1.06 (0.24)	1.07 (0.24)	1.08 (0.24)	1.06 (0.24)
	3	1.06 (0.25)	1.06 (0.24)	1.09 (0.22)	1.04 (0.25)

Aerobic exercise, MICT + HIIT; HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; VO_{2peak}, peak oxygen uptake. Control group followed national recommendations for physical activity.

Table 5 Group differences at Year 3 from linear mixed models controlled for age, gender, and gait speed (for step length). Treatment effect shown as Year x Group interaction with 95 % confidence interval. Descriptive mean (standard deviation) is shown for the control group.

Risk factor	Year	Control	Aerobic exercise vs. control			HIIT vs. control			MICT vs. control			HIIT vs. MICT		
		Mean (SD)	Estimate	95 % CI	P-value	Estimate	95 % CI	P-value	Estimate	95 % CI	P-value	Estimate	95 % CI	P-value
STS peak velocity (m/s)	0	1.06 (0.24)												
	3	1.06 (0.25)	-0.003	-0.03 to 0.02	0.841	0.02	-0.01 to 0.05	0.268	-0.02	-0.06 to 0.01	0.156	0.04	0.01 to 0.08	**0.026**
Grip strength (kg)	0	34.0 (10.78)												
	3	28.7 (10.68)	0.42	-0.36 to 1.21	0.29	0.65	-0.34 to 1.64	0.20	0.20	-0.75 to 1.15	0.68	0.45	-0.67 to 1.58	0.43
VO_{2peak} (mL/kg/min)	0	28.6 (6.41)												
	3	29.3 (7.11)	0.61	-0.20 to 1.42	0.139	1.49	0.49 to 2.50	**0.004**	-0.275	-1.27 to 0.72	0.587	1.77	0.65 to 2.90	**0.002**
Fast gait speed (cm/s)	0	188.6 (27.63)												
	3	189.2 (29.94)	4.76	1.24 to 8.28	**0.008**	6.48	2.21 to 10.75	**0.003**	3.02	-1.36 to 7.40	0.176	3.52	-1.58 to 8.62	0.176
Preferred gait speed (cm/s)	0	131.0 (19.94)												
	3	130.4 (21.03)	1.60	-0.99 to 4.18	0.225	3.20	0.10 to 6.30	**0.043**	-0.04	-3.31 to 3.22	0.979	3.27	-0.47 to 7.00	0.087
Fast step length (cm)	0	83.2 (10.05)												
	3	82.0 (10.69)	0.27	-0.70 to 1.23	0.589	0.38	-0.81 to 1.56	0.53	0.14	-1.04 to 1.32	0.814	0.22	-1.21 to 1.64	0.766
Preferred step length (cm)	0	70.2 (8.10)												
	3	69.4 (8.63)	0.17	-0.60 to 0.95	0.658	0.56	-0.38 to 1.49	0.241	-0.22	-1.20 to 0.75	0.652	0.75	-0.36 to 1.86	0.183

Aerobic exercise, HIIT & MICT; CI, confidence interval; HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; SD, standard deviation; VO_{2peak}, peak oxygen uptake. Control group followed national recommendations for physical activity. Bold font indicates statistical significance (p's <0.05).

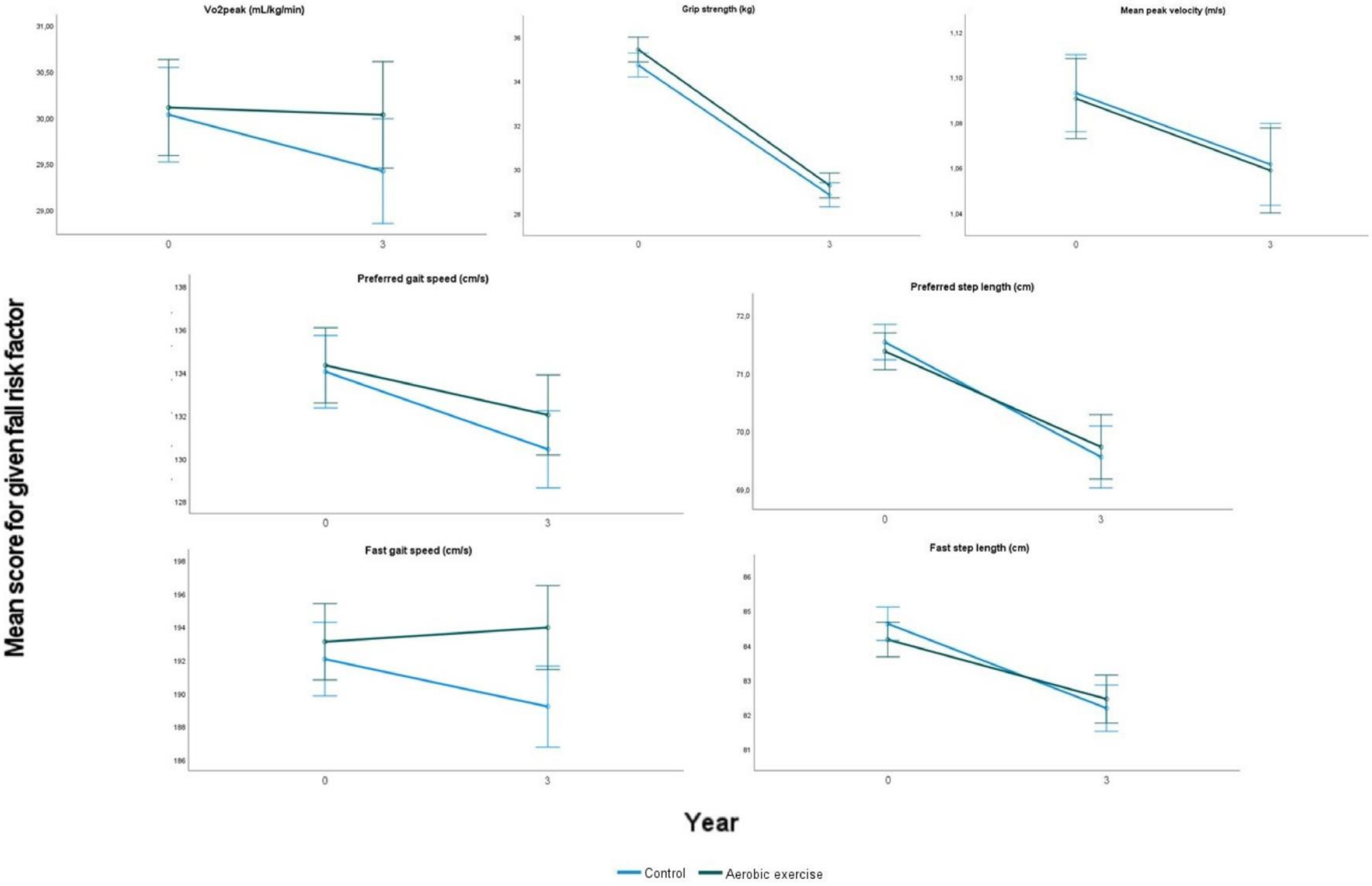

Figure 2 Means from the Year x Group interaction with 95 % confidence intervals for each fall risk factor controlled for age, gender, and gait speed (for step length) at baseline and after 3 years for aerobic exercise (HIIT & MICT) and control group. VO_{2peak}, peak oxygen uptake.

Table 5 shows that the fast gait speed was 4.76 cm/s higher in the aerobic exercise group compared to the control group after 3 years (95 % CI 1.24 to 8.28). No other significant between-group differences were found for aerobic exercise vs. control. HIIT significantly improved fast gait speed (6.48 cm/s, 95 % CI 2.21 to 10.75), preferred gait speed (3.20 cm/s, 95 % CI 0.10 to 6.30) and VO2peak (1.49 mL/kg/min, 95 % CI 0.49 to 2.50) compared to control. For MICT vs. control no significant differences were found. Compared to MICT, HIIT significantly improved VO2peak (1.77 mL/kg/min, 95 % CI 0.65 to 2.90) and STS peak velocity (0.04 m/s, 95 % CI 0.01 to 0.08) after 3 years. For grip strength, and step length at fast and preferred speed no significant between-group differences were found.

Figure 2 shows a significant decline within both the aerobic exercise and control group for grip strength, STS peak velocity, preferred gait speed and step length and fast step length over 3 years (all p's <0.003). The aerobic exercise group maintained their VO2peak over 3 years (p=0.669), while the control group had a significant reduction (p <0.001). For fast gait speed, the aerobic exercise group had a non-significant increase (p=0.358) and the control group a significant decrease (p=0.001).

4. Discussion

This long-term randomized controlled exercise study aimed to evaluate if structured aerobic exercise training (MICT and HIIT combined) reduces the risk of falling in older adults compared to control, and second if it improves fall-related risk factors. Third, the study aimed to assess effects of HIIT and MICT compared to each other and control for these outcomes. We found no difference in risk of falling between the aerobic exercise group and a control group following national recommendations for physical activity. We observed a non-significant absolute increased risk of 0.8 % in number of fallers in the aerobic exercise group compared to the control group, and within the aerobic exercise group a non-significant ARR of 4.5 % in the HIIT group compared to the MICT group. After 3 years a significant higher fast gait speed was found in the aerobic exercise group compared to the control group. HIIT significantly improved the fall risk factors preferred and fast gait speed and VO_{2peak} compared to control. Within the aerobic exercise group, a significant higher VO_{2peak} and STS peak velocity was found for HIIT compared to MICT.

4.1 Risk of falling

Looking at between-group differences in number of fallers at Year 3, no significant differences were found. Therefore, according to this study aerobic exercise training does not reduce the risk of falling for this study population. However, most studies that has shown effect of exercise on fall reduction has been interventions with a combination of two or more exercise types that included resistance, balance, and functional exercises. Alone, resistance exercise has not shown to prevent falls (Sherrington et al., 2019). It is also questionable if aerobic exercise training alone is a suitable intervention to reduce the risk of falling. It could therefore be more interesting to assess the role of aerobic exercise in fall prevention, by combining it with one or more resistance, balance, and functional exercises. HUNT data from community-dwelling older adults in Trøndelag has shown that the percentage of fallers (25%) remain constant between the age groups 70-74 and 75-79 (Skjellegrind et al., 2021). This group transition reflects the change many of the participants had during the intervention period. It is notable that our more fit and healthy study population had higher risk of falling both before and after the intervention compared to the general population. A possible explanation is that exercise patterns and health increase situations where environmental or activity related factors can increase demands to gait and balance, normal causes of falls due to displacements of feet or falling out of the center-of-mass line in movement (Voermans et al., 2007). Looking at number of fallers at baseline, the percentage of fallers had increased across all groups after 3 years, while only a small increase was observed for HIIT. It is noteworthy, that HIIT did not seem to have a negative impact on risk of falling and had a tendency of reduced number of fallers compared to MICT. After all, daily life activities that challenged balance and gait was probably high in this group.

In their study with over 10000 participants Mertz et al. (2010) found that the risk of falling was not different between young adults (20-44 years), middle aged adults (45-64 years), and older adults (+65 years). The more fit younger adults were more likely to fall during sports or exercise, while the older adults were more likely to fall while walking and get a fracture. It was the cause of the fall (active vs. harmless situations) alongside the consequences that was found to be different, two factors this study did not account for. In addition, low cardiorespiratory fitness and inactivity was found to reduce risk of walking-related falls. (Mertz et al., 2010) Therefore, with our very fit and active study population, a likely hypothesis is that among the fallers in our study less falls occurred in so called harmless situations (like indoor and daily walking), and possibly more related to sports or exercise.

Since aerobic exercise training by its nature have high demands to gait and balance, a reasonable assumption is that many of the falls happened due to some sort of challenging locomotion like HIIT exercise, and not in daily harmless situations. An interesting measure could therefore be to assess the effect of aerobic exercise training on frequency of falls per active hour.

4.2 Aerobic exercise training and fall risk factors

Number of participants with OH was higher in most groups at Year 3 than baseline, but no significant between-group differences were found. We observed a non-significant reduction in OH when comparing aerobic exercise to control (RR 0.63, 95% CI 0.33 to 1.20). The general prevalence reported in community-dwelling older adults over 60 is 22,2 %, increases with age and has to some degree been linked to frailty (Kocyigit et al., 2019; Saedon et al., 2020). Therefore, the substantially lower percentage of OH both at baseline and Year 3 in our study, may be related to age and health.

Aerobic exercise significantly improved fast gait speed compared to control (p=0.008). However, improvement of this strong fall risk factor did not reduce the risk of falling. This is probably related to the nonlinear relationship between gait speed and falling. Quach et al. (2011) found that older people with fast gait speed higher than 1.3 m/s had an increased risk of outdoor falling, and similar risk for elderly with lower gait speed than 1 m/s for indoor falling. Compared to normal gait speed (1.0 to 1.3 m/s) both fast and slow gait speed (<0.6 m/s) significantly increased incidence rate of falling. In our study the participants both at the baseline and Year 3 had a preferred gait speed higher than 1.3 m/s. Thus, our study also shows that improved gait speed does not change the risk of falling for this group. However, according to Quach et al. (2011), it may have reduced the number of indoor fallers in our study population. Considering the nonlinear relationship, where being fit with high gait speed is a strong fall risk factor, a potential more interesting question for this population is whether aerobic exercise training can prevent certain aspects of fall risk, than reduce number of fallers. Moreover, since older people with gait problems have been reported by Deandra et al. (2010) to be two times more likely to fall it is possible that aerobic exercise training can be a more suitable intervention to reduce number of fallers in older adults with gait problems.

Compared to control, HIIT significantly improved VO_{2peak} ($p=0.004$) and gait at preferred and fast speed (p's <0.05). None of the fall risk factors improved for MICT vs. control. HIIT also improved gait speed compared to both control and MICT in a study with 82 older adults by Jiménez-García et al. (2019). Within the aerobic exercise group in our study, HIIT significantly improved STS peak velocity ($p=0.026$) and VO_{2peak} ($p=0.002$) compared to MICT. Little is known of the role of VO_{2peak} in fall prevention, and our data primarily seem to support that HIIT is a suitable exercise to improve VO_{2peak} more than bringing clarity to its role in fall prevention. In a study with 54 older women Ballesta-García et al. (2019) found improved lower extremity strength using STS in both HIIT and MICT compared to control. This study is not directly comparable because it only included women, but it is interesting that our study did not find improved leg strength in HIIT vs. control, but in HIIT vs. MICT. It is possible this is related to the very active control group in our study, that was reported by Stensvold et al. (2020) to have higher adherence than the MICT group, and a considerable number of HIIT-exercisers (22 %). All considered, there seems to be some evidence that compared to MICT, HIIT is more suited to improve or maintain lower extremity strength over time. Summarized, a general improvement in the HIIT group in multiple fall risk factors was found. A positive effect on all-cause mortality, and reduced risk of cardiovascular disease has also previously been reported by Stensvold et al. (2020). Therefore, HIIT can be a potential supplement to current recommendation in fall prevention for community-dwelling older adults. However, more studies that combine recommended resistance and balance exercises with aerobic exercise at high intensities are needed to determine this.

4.3 Long-term exercise intervention

This study had an intervention period of 3 years. Most fall-related exercise studies have an intervention period of 3-12 months (Sherrington et al., 2019). In addition, no other studies with an HIIT intervention have been over 18 weeks, and all with less than 100 participants (Elboim-Gabyzon et al., 2021). The participants in the intervention groups in Gen100 are expected to exercise accordingly to the intervention two times a week and be moderate active for at least 30 minutes on three other days for a total of 5 years. This can possibly influence motivation, adherence, and healthy choices among participants as years pass. Factors that might make it harder to detect between-group differences in number of fallers.

4.4 Healthy and high functioning participants

The baseline characteristics shows that approximately 88 % of the participants had very high self-reported good health, over 90 % reported medium- or high levels of physical activity, and over 65 % exercised at intensities of 13 or higher on the Borg Scale. This means that a large proportion of the participants had very good health and exercised frequently at high intensities already before the interventions. Thus, there is a chance aerobic exercise training gave minimal functional gains, because participants met the upper threshold for improved function previously reported for healthy older adults (Bean et al., 2004). Furthermore, the mean preferred gait speed of this study was approximately 1.31 m/s. This is very different to the mean gait speed of 0.92 m/s that Studenski et al. (2011) found in 34485 older adults with a mean age of 73.5 years. This supports that our study population was more fit than average. It can also explain the high proportion of fallers in this study compared the general population, since older adults with gait speed over 1.3 m/s are the most frequent fallers alongside those with gait speed under 0.6 m/s. In other words, our study population held a strong fall risk factor in their gait speed, that was present both at baseline and Year 3.

4.5 Strength and limitations of this study

A methodological strength of the study is the blinded randomized control trial design known as the “gold standard” to estimate effect of an intervention. The randomization ensures that the different groups have equal and comparable baseline characteristics, reducing the effect of possible confounders. Further, with blinding of test personnel every treatment progress is measured independently and protected from potential bias that may occur from human opinion related to the different treatments. Additional strengths of this study are the long-term intervention period and large sample size compared to other studies looking at effect of exercise on fall reduction. The 3-year intervention period in this study makes it possible to assess long-term effects of exercise interventions. However, this can also be a limitation with lower adherence and motivation among participants over time.

The study has several potential limitations that could influence the results. By inviting all residents between age 70-77 in Trondheim there is a risk that the healthier and more active volunteered, introducing a healthy volunteer bias. The study also had strict inclusion criterions. The Gen100 study protocol reported that the participants were more active and healthier than non-included participants (Stensvold et al., 2015). Therefore, selection bias might have influenced our results and the generalizability to the general population. Moreover, the characteristics of our participants can question whether HIIT is a feasible intervention for community-dwelling older adults with poorer health. However, considering that 12 % had poor health and sickness at baseline, it’s not necessarily an obstacle. Adherence to prescribed intervention after 3 years was approximately 50 percent in the aerobic exercise group and 70 percent in the control group. Furthermore, a crossover to HIIT exercise was found for almost ¼ of the participants in the control group (Stensvold et al., 2020). This can have reduced the likelihood of detecting significant between-group differences in our study.

Although all randomized participants were analyzed with the mixed model design, there is a risk of selective dropout of participants changing the characteristics at 3-year follow-up. Loss to follow-up may therefore introduce potential attrition bias. This is even a larger issue with a dichotomous outcome variable, not adjusted for the loss to follow-up. That around 27 % of the randomized participants fall data was missing at Year 3 could potentially impact the results and the generalizability outside the study population. There is also a potential a recall bias, related to correct self-reporting of falls. However, with the dichotomous fall variable, participants only had to recall if they had fallen or not. Recall-bias is therefore assumed to have had minimal influence on the results. On the other hand, the necessary dichotomization of data led to the study being less sensitive to detect change, compared to continuous fall data. This has been reported by Sherrington et al. (2019) where previous studies with risk of falling as outcome measure detected less effect, with a significant 15 % reduction of number of fallers in exercise vs. control compared to 23 % for number of falls. Therefore, the dichotomous outcome measure can potentially have been a contributing factor to non-significant between-group differences in our study. The previous studies reported by Sherrington et al. (2019) also had a control group that either did not receive any intervention or had an intervention that was considered to not reduce falls. The very active control group with high crossover to HIIT could also potentially had an influence in our study. Another weakness in our study is that despite baseline differences was found for grip strength, the outcome was analyzed as constrained to be equal at baseline. Last, this study had multiple outcome measures that increases the risk of type I errors but did not adjust for multiple hypotheses beyond 95 % CI. This weakness implicates a small risk for finding significant between-group differences, when the null hypothesis of no difference is true.

5. Conclusion

Compared to control, 3 years of supervised aerobic exercise (HIIT and MICT combined) failed to show a significant reduced risk of falling in home-dwelling older adults. However, more studies that combine aerobic exercise with functional, balance and resistance exercises are needed to determine the role of aerobic exercise training in fall prevention. We did, however, find that aerobic exercise training, and mostly HIIT improves fall-related risk factors compared to control. Improved fall risk factors were also found when comparing HIIT to MICT. Hence, our data suggest that aerobic exercise at high intensities can be a well-suited long-term exercise intervention for improving fall risk factors. A dichotomous fall variable, and multiple biases related to recruitment of very healthy participants, adherence within and between interventions, and a very active control group challenged the ability to detect between-group differences. Also, the participants upheld a strong fall risk factor with their high fitness- and gait speed throughout the study. Future studies should therefore strive to include more frail and less active home-dwelling older adults or investigate if aerobic exercise training can prevent certain aspects of falling in fit and healthy older adults.

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