The effect of a six-month home-based HIIT intervention on cardiorespiratory fitness and lung function in older adults between 60-85 years

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CONTENTS

ABBREVIATIONS

CRF – Cardiorespiratory fitness

VO_{2peak} – Peak oxygen consumption

HIIT – High-intensity interval training

MICT – Moderate intensity interval training

HR_{peak} – Peak heart rate

FVC – Forced expiratory maneuver

FEV1 – Forced expiratory volume

MVV – Maximum voluntary ventilation

RER – Respiratory exchange rate

RCT – Randomized controlled trial

ABSTRACT

Objective: High-intensity interval training (HIIT) has been demonstrated to be a feasible method for enhancing cardiorespiratory fitness (CRF, measured as VO_{2peak}) in older adults (Wu et al., 2021). However, few studies have investigated the effect of HIIT outside of laboratory conditions. Therefore, the aim of the study was to investigate the effect of a six-month home-based HIIT regime on CRF and lung function in healthy older adults (68.5±5.3 years).

Methods: 139 older men and women were randomized to either a home-based HIIT intervention group (IG) (n=73) or a passive control group (CG) (n=66). Measurements were conducted using an oxygen analyzer (Jaeger Vyntus CPX) for measuring lung function (MVV, FVC, and FEV1) and CRF. CRF was measured using a modified incremental treadmill protocol (Balke) to determine each participant's VO_{2peak}. The IG followed a standardized HIIT program consisting of 3 sessions per week, two HIIT walking exercises, and one HIIT circuit training (>80% of HR_{peak}).

Results: The IG improved VO_{2peak} within the group and compared to the CG after the intervention period (6.22±7.84% versus -1.29±7.07%, $p \leq .001$). No improvements were seen in lung function within the IG, except for an increase in MVV (IG 2.92±8.43%, $p \leq .05$ and IG men 4.73±8.07%, $p \leq .05$) from pre- to post-intervention. There was no difference in lung function measurements between the IG and the CG from pre- to post-intervention.

Conclusion: The current study revealed that a six-month home-based HIIT program improved cardiorespiratory fitness in healthy older adults. The IG improved their VO_{2peak} compared to the passive CG, but no improvement in lung function was detected from pre- to post-intervention.

Keywords: Aging, CRF, VO_{2peak}, Maximal voluntary ventilation, Forced vital capacity,

SAMMENDRAG

Introduksjon: Høy-intensitets intervall trening (HIIT) har blitt demonstrert som en gunstig metode for å forbedre kardiorespiratorisk kondisjon (KRF, målt som VO_{2peak}) hos eldre voksene (Wu et al., 2021). Det er imidlertid få studier som har undersøkt effekten av HIIT utenfor laboratoriske forhold. Målet med denne studien var derfor for å undersøke effekten av ett seks måneders hjemmebasert HIIT program på KRF og lungefunksjon hos friske eldre voksene (68.5±5.3 år).

Metode: 139 eldre menn og kvinner ble randomisert til enten en hjemmebasert HIIT intervensjons gruppe (IG) (n=73) eller en passiv kontrollgruppe (KG) (n=66). Målinger ble utført ved bruk av en oksygenanalysator for undersøkelse av lungefunksjon (MVV, FVC og FEV1) og CRF. CRF ble målt ved å bruke en modifisert inkrementell tredemølleprotokoll (Balke) for å avgjøre deltakerens $VO_{2peak.}$ Intervensjonsgruppen fulgte ett standardisert HIIT-program bestående av 3 økter per uke, to HIIT-gå-økter og en HIIT-styrkesirkel (kroppsvekts øvelser) (>80% av HR_{peak}).

Resultat: IG forbedret VO_{2peak} innad i gruppen, i tillegg til forbedring sammenliknet med kontrollgruppen fra pre- til post-intervensjon (6.22±7.84% versus -1.29±7.07%, $p \leq .001$). Det var ingen endring i lungefunksjon innad i intervensjonsgruppen, bortsett fra en økning i MVV (IG 2.92±8.43%, $p \leq .05$ and IG menn 4.73±8.07%, $p \leq .05$). Det var ingen endring i lungefunksjonsmålinger i intervensjonsgruppen sammenliknet med kontrollgruppen fra pre- til post-intervensjon.

Konklusjon: Den gjennomførte studien viste at ett seks måneders hjemmebasert HIIT-regime forbedret kardiorespiratorisk kondisjon hos friske eldre voksene. Intervensjonsgruppen forbedret VO_{2peak} sammenliknet med den passive kontrollgruppen, men ingen forbedring i lungefunksjon ble påvist fra pre- til post-intervensjon.

Nøkkelord: Aldring, KRF, VO_{2peak}, Maksimal voluntær ventilasjon, Forsert vitalkapasitet

STRUCTURE OF THE THESIS

This master’s thesis consists of two different parts:

Part 1 presents the experiment and is supported by a theoretical framework in the first chapter, while the following chapter outlines the methodology and how the study was utilized. Additionally, a chapter is dedicated to discussing the methodological considerations.

Part 2 presents a research paper written according to the standards of the “Journal of Aging and Physical Activity” from the conducted study.

The study's results, discussion, and conclusion are only presented in the research paper (Part 2) due to the word limitations of this master's thesis.

PART 1

THEORETICAL BACKGROUND AND METHODS

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May, 2023

TABLE OF CONTENTS

1.0 INTRODUCTION

The increasing older population is a global phenomenon, and the world's population above 65 years reached 703 million in 2019 (United Nations, 2019). Older adults have excelled from 6% of the world population in 1990 to 9% in 2019 and are predicted to be 16% by 2050 (United Nations, 2019). Aging is associated with a decrease in physical function (ability to perform everyday activities and tasks such as carrying, pulling/pushing, cardiovascular tolerance, and balance) (Roman et al., 2016; Wu et al., 2021). An effective strategy for preventing loss of physical function is attending regular physical activity (PA). PA defines as "any bodily movement produced by skeletal muscles that require energy expenditure" (World Health Organization, 2022). Evidence supports a positive association between regular PA for maintaining physical function and preventing disability (Marzetti et al., 2017). The World Health Organization (2022) recommends a PA level of at least $\geq$150 minutes of moderate-intensity aerobic exercise or $\geq$75 minutes of vigorous-intensity aerobic exercise a week from age 18-65 years of age and above intensity (World Health Organization, 2022). In addition to these recommendations, individuals above 65 should emphasize balance and strength training at moderate or higher intensities (World Health Organization, 2022).

Previous research investigating regular exercise and PA has stated that Regular exercise and PA have indicated an improvement in physical function, independent lifestyle, quality of life, and reduced health problems in the older population (Mazzeo et al., 1998; Spirduso & Cronin, 2001). Although previous research indicates that exercise can improve function and quality of life, older adults use much of their daily time sedentary (Lohne-Seiler et al., 2014). Previous research indicated that approximately 66% of the daily time was sedentary among Norwegian older adults aged 65-85 years (Lohne-Seiler et al., 2014). Inactivity and sedentary behavior are associated with mortality, health problems, and reduced health-related quality of life and are one of the primary reasons for most chronic diseases (Booth et al., 2012; Katzmarzyk et al., 2009). A decline in lung function is associated with age-related changes, where the thorax wall gets stiffer, the lungs lose the elastic recoil, and impaired respiratory function (Janssens et al., 1999). The impairment of the lungs in older age may be a limiting factor in increasing cardiorespiratory fitness (CRF) (Hassel et al., 2015). CRF is defined as "the capacity of the circulatory and respiratory systems to supply oxygen to skeletal muscle mitochondria for energy production needed during physical activity" (measured as peak oxygen uptake: VO_{2peak}) (Raghuveer et al., 2020).

Recent research has demonstrated that high-intensity interval training (HIIT) ameliorates CRF and positively influences oxidative stress, insulin sensitivity, and inflammation in older adults

(Keating et al., 2020; Ramos et al., 2015). Furthermore, various forms of aerobic exercise may ameliorate CRF and are differentiated by duration and intensity. Research on moderate continuous training (MICT) has indicated positive outcomes regarding CRF (Weston et al., 2014; Wu et al., 2021). MICT comprises a lower intensity (60-75% of HR_{peak}) and longer duration than HIIT (Roman et al., 2016; Wu et al., 2021). On the other hand, HIIT includes exercise at a higher intensity ($\geq$80% of HR_{peak}) with a shorter duration than MICT and could potentially be a more efficient stimulus to influence CRF and improve body composition in older individuals (Weston et al., 2014; Wu et al., 2021). This makes HIIT a presumably more attractive option as a time-efficient training method (Weston et al., 2014). Gray et al. (2016) address the need for more data regarding HIIT in different populations outside of the gym, with low cost, in a more assessable form, and without a strict follow-up. The research also indicates that few studies imply a longer duration in HIIT interventions ($\geq$12 months) (Gray et al., 2016). Reitlo et al. (2018) further assess the significant challenge of having older adults adhere to an extensive exercise program and how to make an effective HIIT program in a randomized controlled trial. The research indicated that older adults were able to handle a HIIT regime over a 12-month period, and the most frequent training locations were at home and outdoors (Reitlo et al., 2018).

This current study is part of a more extensive ongoing study in Norway and the UK, The Fitness, aging, and bilingualism project (The FAB Project) (UiA, 2022). The main project's objective is to investigate if regular aerobic exercise in conjunction with speaking a second language can ameliorate the decline in cognitive function in older adults (UiA, 2022). In conjunction with The FAB study, the present study uses a home-based HIIT regime (>80% of HR_{peak}) with three HIIT sessions per week in a six-month intervention period.

1.1 Main aim and hypothesis

As far as the author knows, few studies investigate the effect of home-based HIIT programs in a healthy older population. Therefore, the main objective of this study was to determent the effectiveness of a home-based HIIT program on CRF and lung function in healthy older adults between 60-85 years.

The working hypothesis was that a six-month home-based HIIT program could ameliorate CRF (VO_{2peak}) and lung function in older adults between 60-85 years.

2.0 THEORETICAL FRAMEWORK

Aging is simply defined as “The chronological time something has existed or the number of elapsed standard time units between birth and a date of observation” (Spirduso et al., 2005, p. 4). This theoretical framework intends to establish a brief understanding of aging and physiological changes related to an increase in chronological age. The overall focus is to explain how changes in CRF and lung function affect aging older individuals. Additionally, describing how different exercise protocols can affect CRF and lung function in older adults.

2.1 Physiological changes with aging

The physiological alterations that appear with aging are multiple and will gradually lead to functional impairment, loss of adaptability, and demise (Spirduso et al., 2005). Aging is greatly affected by environmental factors and individual genetics (Spirduso et al., 2005). The aging process happens throughout the organism's lifespan and is categorized as primary and secondary aging (Booth et al., 2011; Taylor & Johnson, 2008). Primary aging is described as the physiological changes that occur over time in all aging individuals and are independent of diseases and the environment (Booth et al., 2011; Taylor & Johnson, 2008). Primary aging is associated with decreased muscular strength, decreased oxygen uptake, maximum heart rate, and increased reaction time (Booth et al., 2011; Taylor & Johnson, 2008). These factors are just a few of the primary physiological changes that occur in an aging body (Taylor & Johnson, 2008). Secondary aging is associated with the causes of environmental factors and diseases, such as exposure to ultraviolet radiation, physical activity level, and alcohol or smoking (Booth et al., 2011). These physiological changes are not inevitable. Although secondary aging alters life expectancy (a population's average length of life), it does not affect the maximum life span (Booth et al., 2011; Taylor & Johnson, 2008).

2.1.1 Aging and cardiovascular function

To maintain homeostatic and bodily function, the cardiovascular system needs to deliver oxygen, remove waste from living cells and deliver nutrients as a sort of “cooling” system in the body (Spirduso et al., 2005). As the individual age, the cardiovascular system is affected and impaired by the changes that occur with increased chronological age (Lakatta, 1990; Spirduso et al., 2005). Increased thickness in the left ventricle, stiffness in the aorta, reduced maximal heart rate and maximal stroke volume, and increased systolic blood pressure at rest and during exercise are evident with increased age (Nes et al., 2013; Spirduso et al., 2005;

Strait & Lakatta, 2012). In healthy adults, increasing age leads to a gradual weakening of the cardiovascular system, where the maximal heart rate is reduced by 0.7 beats per min^{-1} $year^{-1}$ from birth (Spirduso et al., 2005; Tanaka & Seals, 2008). Maximum stroke volume is reduced by approximately 25% in healthy adult men and women up to the age of 80 (Spirduso et al., 2005; Tanaka & Seals, 2008). The sum of these factors will reduce the maximal cardiac output, which leads to a reduction of maximal oxygen consumption and then CRF in older adults (Figure 1) (Lakatta, 1990; Tanaka & Seals, 2008). The reduction in maximal cardiac output happens more rapidly in sedentary older adults than in older individuals that maintain regular exercise (Tanaka & Seals, 2008).

As described above, there are primary and secondary age-related changes, and the impairment in the vascular system is mainly conflicted by the primary factors (Taylor & Johnson, 2008, pp. 17-20). Nevertheless, the primary age-related changes are rarely the cause for physical impairment or morbidity in older adults (Spirduso et al., 2005; Taylor & Johnson, 2008).

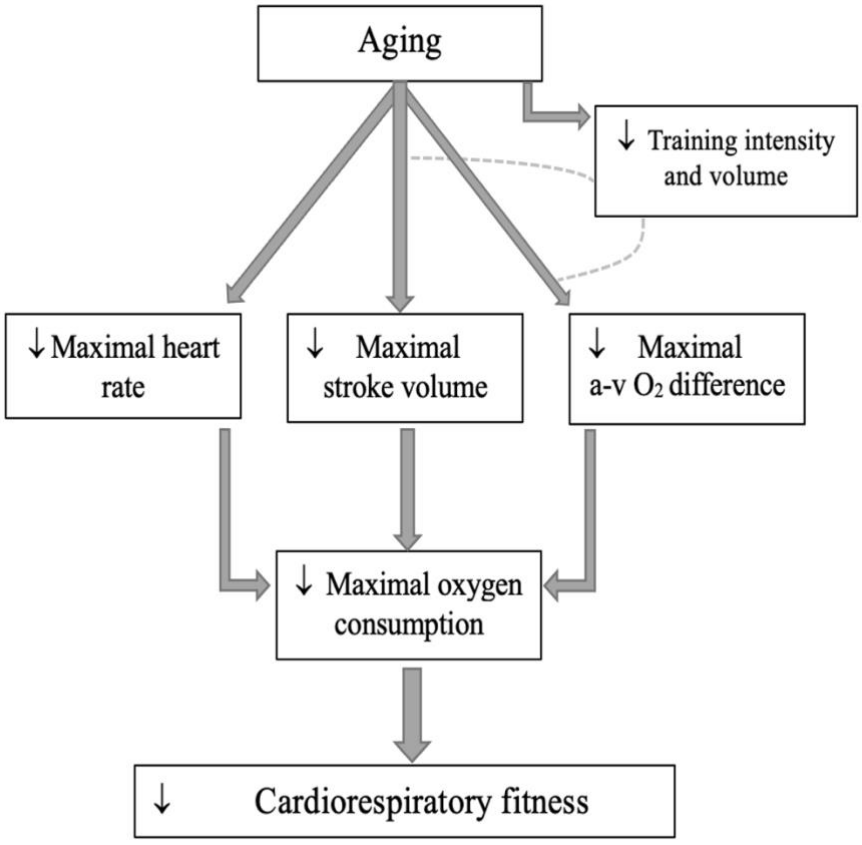

Figure 1: Factors that contribute to a reduction in cardiorespiratory fitness in older adults with advancing age. The figure is a self-modified version (Erichsen, 2023c) from (Tanaka & Seals, 2008).

At an older age, fewer individuals participate in regular physical activity, which may lead to an increased risk of morbidity from cardiovascular diseases, type 2 diabetes, high blood pressure, depression, or bone fractures (Spirduso et al., 2005; Taylor & Johnson, 2008). On the other hand, healthy aging is associated with regular aerobic training at sub-maximal or maximal exercise. Training at sub-maximal or maximal intensities may maintain or increase oxygen consumption at an older age and is associated with health benefits and lower risk of traditional cardiovascular diseases (Bangsbo et al., 2019; Letnes et al., 2020). Therefore, maintaining an active lifestyle, in general, is vital for healthy living (Spirduso et al., 2005; Taylor & Johnson, 2008).

2.1.2 Implications in an aging lung

Similar to the rest of the body, the lungs mature and grow for the first two decades of the human lifespan before reaching their maximal function in the mid-twenties for men and women (20-25 years) (Janssens et al., 1999). However, with advancing age, the lungs progressively decline in function (Spirduso et al., 2005; Thomas et al., 2019). The impairment of the lung with advancing age is associated with changes in the structure of the lungs (reduction in alveolar surface area), lung volume (declining vital capacity and increased residual volume), and reduced gas exchange efficiency (reduced arterial oxygenation) (Spirduso et al., 2005). These changes are related to decreased strength in respiratory muscles, reduction of elastic recoil, and compliance of the chest wall (Janssens et al., 1999; Spirduso et al., 2005). Alterations in gas exchanges are widely observed in older adults. This is related to a reduction in the alveolar surface area which is decreased by 15% from age 20 to 70 years of age, giving less surface for gas exchange (Spirduso et al., 2005).

The abovementioned factors also relate to reduced mitochondrial content and mass in older individuals' locomotor muscles, limiting aerobic capacity and increasing ATP costs, contributing to increased ventilatory requirements in submaximal exercise (Roman et al., 2016). The decline in lung function is inevitable, does not seem to respond to exercise, and is more rapidly decreasing after the sixth and seventh decade of life (McClaran et al., 1995; Roman et al., 2016).

However, most older men and women do not perceive these deteriorations in lung function due to a decreased physical activity level with advancing age (Roman et al., 2016). Moreover, healthy individuals without respiratory diseases are more likely to perceive proportional ventilatory limitations if they maintain high levels of physical activity into senescence (Roman et al., 2016; Spirduso et al., 2005).

2.1.3 Increasing age and maximal oxygen consumption

As described above, aging is associated with a decline in the cardiovascular and respiratory systems' efficiency. The observed decline in arterial-venous (a-v O_2) difference, cardiac output, and decreased strength in respiratory muscle all affect the maximal oxygen consumption with age (Taylor & Johnson, 2008).

Rosen et al. (1998) studied the effect of aging on VO_{2max} in healthy, athletic, and sedentary individuals. Their results suggest a 9-11% decline in VO_{2max} each decade from 25 years of age and were the same for both sedentary and athletic older individuals (Rosen et al., 1998). The decline in VO_{2max} is evident and happens for all aging individuals and accelerates from age 65-75 and 75-85 in healthy men and women (Spirduso et al., 2005). Nevertheless, studies on this topic have demonstrated that maintaining an active lifestyle accompanied by regular exercise could reduce the rate of decline in VO_{2max} (Spirduso et al., 2005; Taylor & Johnson, 2008). In addition, older adults that pursue regular exercise could potentially maintain or enhance their VO_{2max} in comparison to sedentary younger individuals (Figure 2) (Spirduso et

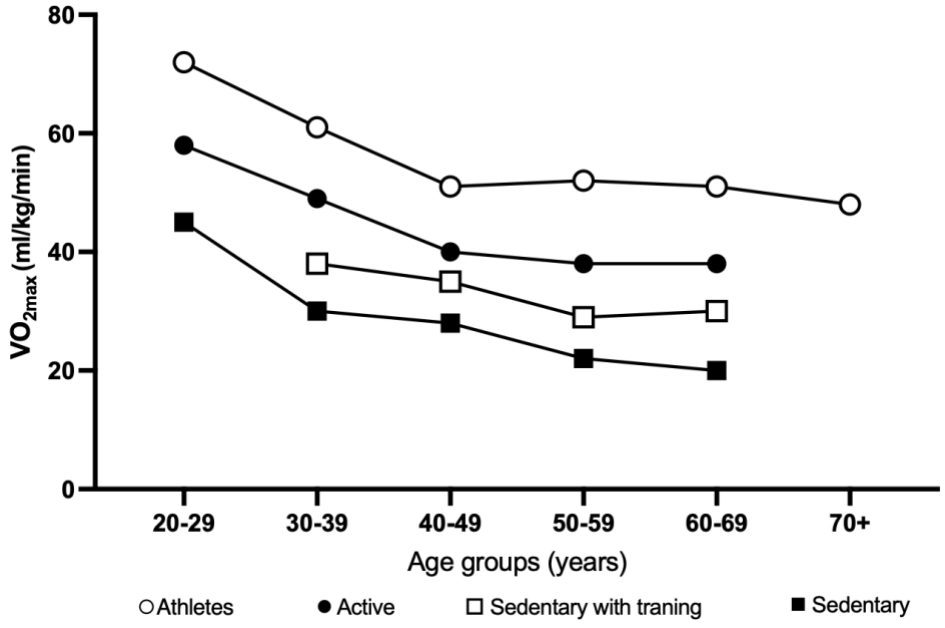

Figure 2: Average maximal oxygen uptake by physical activity and age. The figure is a self-modified version (Erichsen, 2023a) from (Spirduso et al., 2005).

al., 2005). The linear decrease in VO_{2max} is inevitable, regardless of activity level (Spirduso et al., 2005). Still, sedentary individuals in middle age or older adults can increase their VO_{2max} ranging from 10-30% by starting a training program (Figure 2, "sedentary with training") (Chodzko-Zajko et al., 2009; Spirduso et al., 2005). Research shows that the frequency and length of the training program need to be three days ($\geq$ 3) a week for $\geq$16 weeks (with sub-

maximal training or maximal training intensity) to improve VO_{2max} in middle-aged and older men and women (Chodzko-Zajko et al., 2009). Trappe et al. (2013) studied octogenarian athletes versus untrained octogenarian values in VO_{2max}. The study's results showed that even above the eighth decade of life, regular endurance exercise is beneficial for maintaining overall health and physical function and reduces mortality in individuals above 80 years of age (Trappe et al., 2013).

2.2 Endurance training and cardiorespiratory fitness in older adults

Increasing age often results in more sedentary time among older adults. Previous research indicated that Norwegians aged 65-85 used approximately 66% of their daytime sedentary, and few older adults maintain recommended physical activity levels at older age (Helsedirektoratet, 2019; Lohne-Seiler et al., 2014; Loland, 2004). As mentioned previously, inactivity and sedentary behavior are associated with mortality, health problems, and reduced health-related quality of life and are one of the primary reasons for most chronic diseases (Bangsbo et al., 2019; Booth et al., 2012; Katzmarzyk et al., 2009). Moreover, regular exercise at submaximal and maximal training intensities may enhance CRF in older adults ($\geq$3 days a week, $\geq$16 weeks) and reduce the risk of chronic diseases (Chodzko-Zajko et al., 2009; Spirduso et al., 2005; Trappe et al., 2013). However, what is the most efficient and preferred way to train CRF in older adults?

2.2.1 High-intensity interval training and cardiorespiratory fitness

There is a manifold of research on HIIT in older adults. HIIT alternate between short intervals with bursts of high intensities ($\geq$80% of HR_{peak}) and complete periods of rest with lower intensity (Wu et al., 2021). HIIT protocols are most commonly carried out as 4x4 intervals (4min duration, 4 sets, 2-3min rest) or 1-2x10 intervals (1-2min duration, 10 sets, 1min rest) in existing literature regarding HIIT interventions in older men and women (Marriott et al., 2021; Wu et al., 2021). However, no consensus exists on the most effective protocol for increasing CRF in an older population (Marriott et al., 2021).

Nevertheless, Tjønna et al. (2008) used a HIIT protocol to investigate thirty-two subjects described as metabolic syndrome patients (52.3 ± 3.7 years). The participants were randomly allocated to either a HIIT group (n=12), MICT group (n=10), or a passive control group (n=10) and conducted three training sessions per week over a 16-week period (Tjønna et al., 2008). The HIIT subject used walking/running uphill at $\geq$90% of HR_{peak} in four minutes

intervals with three minutes of rest between efforts (Tjønna et al., 2008). The study results indicated that HIIT could be a more efficient way to enhance CRF compared to MICT. However, both the HIIT group and the MICT group improved their CRF (measured as VO_{2max}) from pre- to post-intervention after a 16-week intervention period (HIIT 35% change versus MICT 16% change in VO_{2max} from pre- to post-intervention) (Tjønna et al., 2008). Additionally, Hwang et al. (2016) used a similar HIIT protocol and investigated the effect of all extremity HIIT in healthy sedentary older adults (65±1 years). The study included 51 older adults that were randomly assigned to either a HIIT group (n= 17), a moderate-intensity continuous training (MICT) group (n= 18) or a passive control group (n=16) (Hwang et al., 2016). Participants in the HIIT group conducted an eight-week intervention period with four training sessions per week at $\geq$90% of peak heart rate (HR_{peak}) (Hwang et al., 2016). The HIIT group improved their CRF after a period with all-extremity HIIT from pre- to post-intervention, measured as VO_{2peak} (23.1± 0.7 versus 25.7 ± 0.8 ml/kg/min). The study demonstrates that HIIT influenced CRF more than MICT and could be a sufficient way to enhance CRF in older adults (Hwang et al., 2016).

Furthermore, Brown et al. (2021) investigated the effect of a HIIT protocol on CRF and cognitive function in normal older adults (aged 60-80 years). The participants were randomized to either a HIIT group (n=33), a MICT group (n=34), or a passive control group (n=32). The subjects conducted a six-month training intervention with two training sessions a week (Brown et al., 2021). The HIIT sessions were performed on a bike ergometer at $\geq$80% of aerobic capacity ($\geq$18 on the Borg RPE scale), with 11x1 minute intervals and 2 minutes of active recovery between efforts (Brown et al., 2021). The HIIT group had a greater improvement in CRF (measured as VO_{2peak}) compared to the MICT from pre- to post-intervention (HIIT 24.3% change versus MICT 12.4% change in VO_{2peak}). The study demonstrated that both HIIT and MICT could improve CRF compared to a passive control group, but no differences in cognitive function were found from pre- to post-intervention (Brown et al., 2021).

The abovementioned studies imply that HIIT could be a feasible and efficient way to enhance CRF in older adults (Brown et al., 2021; Hwang et al., 2016; Tjønna et al., 2008). In addition to the abovementioned studies, recent meta-analysis investigating HIIT indicates that HIIT seems to be a favorable training intensity compared to training at lower intensities (Ramos et al., 2015; Wu et al., 2021). The studies also imply that HIIT could positively affect CRF,

body fat, systolic blood pressure, and reduced risk of cardiovascular risk factors in older adults (Ramos et al., 2015; Wu et al., 2021).

2.2.2 Moderate-intensity versus high-intensity interval training

A vast range of studies implements moderate-intensity continuous training (MICT) versus HIIT in their research to find the most efficient stimulus to influence CRF (peak/max oxygen consumption) and improve body composition in older individuals (Ramos et al., 2015; Weston et al., 2014; Wu et al., 2021). Although MICT seems to impact CRF positively, it is often more laborious and performed at a lower intensity (60-75% of HR_{peak}) than HIIT (Weston et al., 2014).

The abovementioned studies all conducted an intervention period comparing HIIT and MICT to a passive control group (Brown et al., 2021; Hwang et al., 2016; Tjønna et al., 2008). Although there were considerable changes in CRF in the use of HIIT and MICT, all studies concluded that HIIT seems superior to MICT as a more time-efficient and effective method for enhancing CRF (Brown et al., 2021; Hwang et al., 2016; Tjønna et al., 2008). However, a recent systematic review conducted by Keating et al. (2020) compares HIIT and MICT programs to investigate the overall effect of the different training intensities (HIIT versus MICT). The research implies that HIIT could be a time-efficient and safe training regime for older adults, which may lead to improved CRF (Keating et al., 2020). Nevertheless, they were not able to determine if HIIT were superior to MICT in an older population (≥65 years) (Keating et al., 2020). The study suggests that more research is needed on HIIT regimes conducted by older adults (≥65 years) (Keating et al., 2020).

2.3 High-intensity interval training and lung function

There are few studies investigating the effect of HIIT on lung function in healthy older adults. However, a recent meta-analysis investigated HIIT interventions in individuals with chronic obstructive pulmonary disease (COPD) (Gao et al., 2022; Sawyer et al., 2020). The research mainly included studies that examined older adults with COPD (Gao et al., 2022; Sawyer et al., 2020). The results indicated that HIIT might improve lung function in individuals with COPD (Gao et al., 2022). Moreover, as described previously, lung function is associated with an age-related decline with reduced lung for gas diffusion and increased dead space to tidal volume ventilation ratio (Hassel et al., 2015; Roman et al., 2016). Therefore, the age-related decline in lung function could potentially be a limiting factor for enhancing lung function

with older age (Hassel et al., 2015; Roman et al., 2016). McClaran et al. (1995) investigated the longitudinal effect of aging on lung function in active older adults over a six-year period. Eighteen healthy subjects were included in the study (n= 14 men and n= 4 women) (67-73 years) and were tested in lung function measurements as forced expiratory maneuver (FVC and FEV1) and maximal voluntary ventilation (MVV) (McClaran et al., 1995). Participants were tested once at baseline, remained active for the next six years, and then retested in the same lung function measurements. Although the participants were categorized as active fit individuals (maintained an active lifestyle), the retest of lung function after a six-year period showed a substantial decrease in lung function measurements (McClaran et al., 1995). The study implies that lung function does not seem to respond to exercises, and lung function progressively declines with advancing age, even in older adults that maintain an active lifestyle (McClaran et al., 1995).

Nevertheless, Hagberg et al. (1988) studied lung function in healthy sedentary younger individuals (24± 4 years) versus older athletes (65± 3 years). Despite a decrease in lung function, the older athletes had 37% higher VO_{2peak} (l/min) and similar lung function values (MVV and FEV1) to the younger sedentary individuals (Hagberg et al., 1988). The results indicate that prolonged aerobic exercise can possibly slow the deterioration of lung function with increasing age (Hagberg et al., 1988).

2.3.1 Possible gasp in the literature

As mentioned above, HIIT intervention seems to be a favorable method for enhancing CRF and potentially reducing the risk of cardiovascular risk factors (Ramos et al., 2015; Wu et al., 2021). Nevertheless, Gray et al. (2016) assess the problem of recent HIIT studies and the evidence demonstrating a range of health benefits with studies using HIIT interventions. As mentioned above, the data from recent HIIT studies are clear and convincing concerning the benefits of HIIT interventions (increased CRF, reduction in body fat, and decreased systolic blood pressure) (Brown et al., 2021; Hwang et al., 2016; Tjønna et al., 2008; Wu et al., 2021). However, these studies are often completed with the use of expensive equipment, strict follow-up, and in laboratory conditions (Gray et al., 2016). The lack of long-term studies and low cost easily assessable HIIT programs are needed to translate to public health conditions, where individuals don’t need a laboratory or gym and are able to achieve the required exercise intensity in a location of their own choosing (Biddle & Batterham, 2015; Gray et al., 2016). Reitlo et al. (2018) researched the most common exercise location in an older

population (70-77 years) using a HIIT regime for a one-year period (2-3 HIIT sessions a week) (Figure 3).

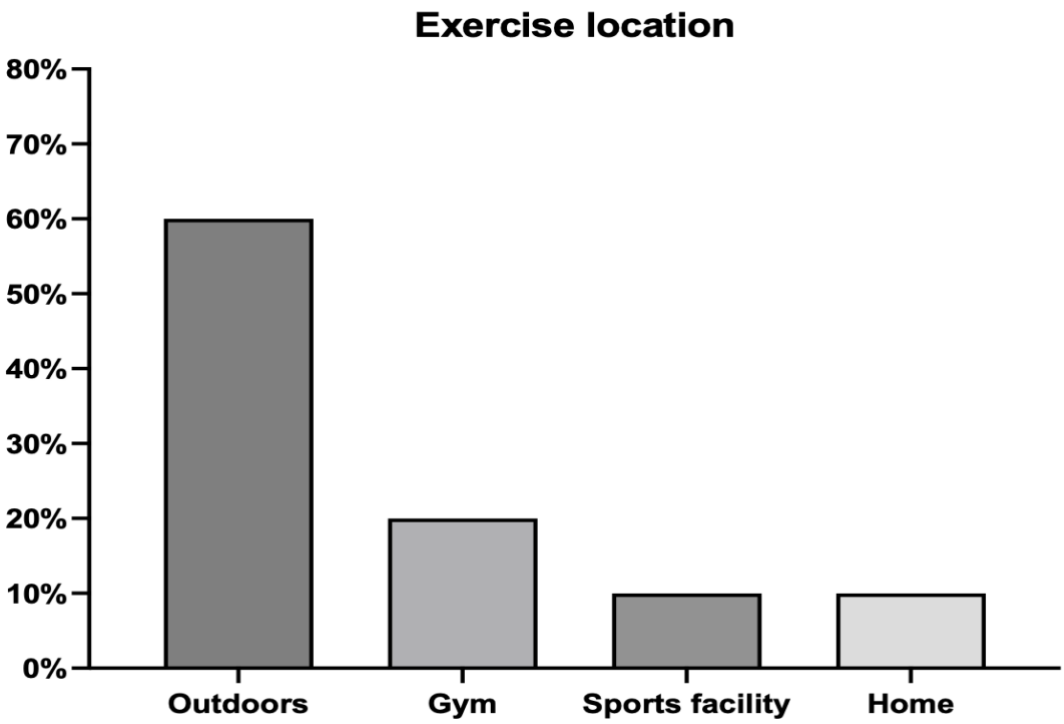

Figure 3: Data of proportions of the total number of HIIT sessions and most frequent training location of older adults in (Reitlo et al., 2018). The figure is a self-modified version (Erichsen, 2023b)from (Reitlo et al., 2018).

The results showed that older men and women could maintain a HIIT regime for a year (without strict supervision), and walking/jogging outdoors was the most frequent exercise used by the participants (Reitlo et al., 2018). Reitlo et al. (2018) also state that the intensity and workload of each participant with different base levels of CRF needed to be adjusted to reach the intended stimuli. Therefore, some individuals jogged were others walked at a high pace to achieve the intended intensity (Reitlo et al., 2018). The results of this study may help future health clinicians to provide exercise programs targeting older adults that could be used at home and to improve long-term participation in regular exercise (Reitlo et al., 2018).

3.0 METHOD

3.1 Study design

This master's thesis were, as mentioned above, a part of an extensive study in the south of Norway, the FAB project (Fitness, aging and bilingualism) (UiA, 2022). The main project sought to determine the relative benefit of regular physical activity and how it can influence age-related cognitive decline in older adults. The research group comprised older men and women above the age of 60 years. The intervention group used a home-based high-intensity interval training regime for six months to determine the effect of regular physical activity on cognitive function in relation to language skills.

As mentioned above, this present study will focus on and use the data collected in the six-month home-based training regime and asses the effect of HIIT on lung function and VO_{2peak}. Therefore, the other components (health-related quality, physical function, lactate threshold, and language cognitive tests) that the primary study assessed will not be included. The study design was a randomized controlled trial with an intervention group and a control group. This study's subjects were randomly assigned to either a home-based HIIT intervention or a passive control group stratified by age and gender. A standardized test protocol was used during pre- and post-testing to ensure identical execution for each participant. The protocol was performed in the following order: Forced expiratory maneuver (FVC), Maximal voluntary ventilation (MVV), and Aerobic fitness test (VO_{2peak}). The pre-tests started in late September 2021 and were completed in mid-September 2022. Post-test started in late March 2022 and was completed in early March 2023 (Figure 4).

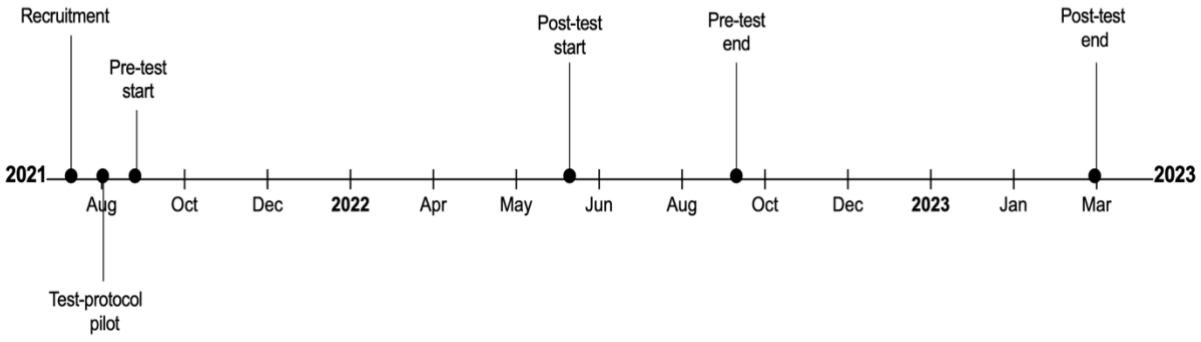

Figure 4:Timeline of the study design, illustrating when the various parts of the project took place.

3.2 Participants

A total of 139 (n=59 men and n=80 women) voluntary home-dwelling participants were recruited from the south of Norway through advertisements on Facebook, in local newspapers in addition to The FAB website, and invitations to information meetings at UiA. The study sample consisted of only older men and women between 60 to 85 years of age, with equal allocations in the intervention and control groups (68.5±5.3 years) (Figure 5).

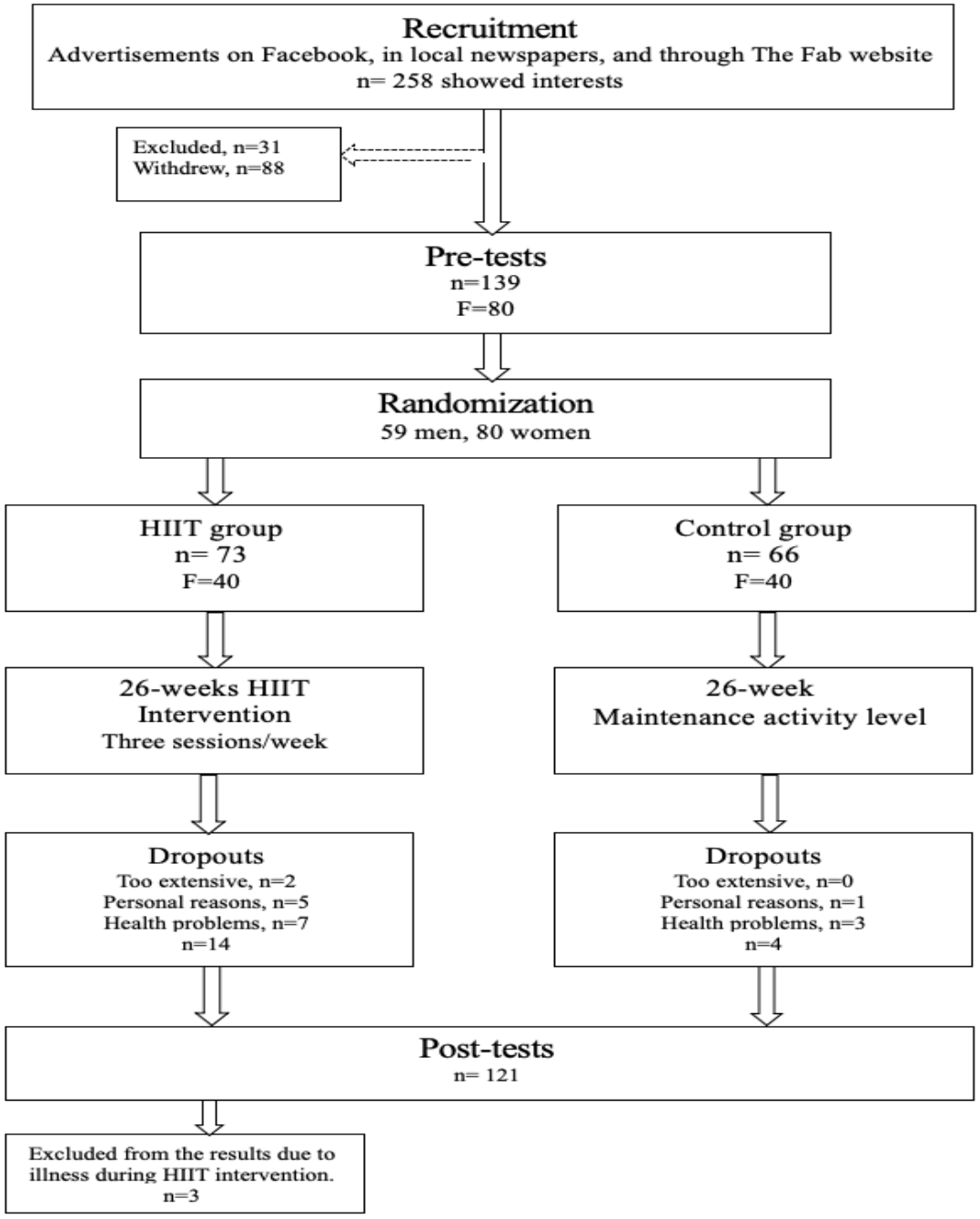

Figure 5: Flowchart of the study design, showing the timeline for recruitment, randomization, pre-tests, intervention period and post-tests for the High-intensity interval training group (HIIT) and control group.

3.2.1 Inclusion and exclusion criteria

A balanced number of men (n= 33 men in the intervention group and n= 26 men in the control group) and women (n= 40 women in the intervention group and 40 women in the control group) were recruited to ensure the results were valid for both sexes. Since the study is a part of The FAB project, all participants were bilingual. Participants had no diagnosis of language impairments (dyslexia or stuttering), corrected-to-normal hearing and vision, and had less than 150 minutes of moderate physical activity a week, according to the physical activity guidelines (Helsedirektoratet, 2019). Participants that reported acute terminal illness, respiratory, neurological, severe cardiovascular, or musculoskeletal disease were excluded. All participants in the intervention group had to provide a thorough health screening by a medical professional and a written confirmation of a suitable health level. The overall inclusion and exclusion criteria aimed to ensure that the participants were relatively inactive and homogeneous concerning their health status and physical activity levels.

3.3 Ethical considerations

The study in its entirety was approved by the Norwegian Center for Research Data (ref. number: 163931) (Appendix 4). A project description based on this master`s thesis was also ethically approved by The Ethical Board at de Faculty of Health and Sport Science, University of Agder (ref. number: RITM0193703) (Appendix 5).

3.4 Exercise intervention

The intervention group pursued an exercise intervention over six months, designed to examine the benefits of a HIIT home-based training program against a passive control group. The training consisted of one HIIT interval circuit session and two HIT walking/running sessions each week, and the sessions were simple and safe to do at home or outside.

After inclusion, the participants started the training program with a familiarizing period. The purpose of this period was for the participants to use and get to know the training equipment and training program. Each subject was given a logbook and activity monitor (Polar Unite activity watch), including an external heart rate sensor in the inclusion of the study (Polar H9 heart rate sensor) (Polar Electro, 2023a, 2023b). The activity monitor was used to register the average, and HR_{peak} during every workout, and the data was downloaded at follow-up meetings. With the downloaded data, it was possible to adjust the duration or intensity for each participant. The aim of each interval was to have an average heart rate above 80% of the

subject's HR_{peak}. Adjustments were made at the follow-up meetings for each participant in conjunction with a training instructor. The instructor viewed the data from the participant's heart rate monitor to adjust HR_{peak} and to give corrections in duration, intensity, or frequency to achieve the intended stimuli. Participants used the logbook to track all workouts done within the six-month period. They registered the date, activity, sets, duration, HR_{peak}, and self-perceived exertion using the Borg RPE scale (Borg, 1970) after each session (Figure 6). The duration for each workout was approximately 45 minutes, with a 5–10-minute general warm-up. In the first four weeks, the intensity of the sessions was supposed to be sub-maximally (40-60% of HR_{peak}). Thereafter, the program switched from submaximal to high intensity (80-90% of HR_{peak}) with progressive volume throughout the intervention. Data from the heart rate monitor were downloaded at follow-up meetings with a training instructor once a week during the first four-week familiarizing period and thereafter once a month throughout the entire intervention period. In addition, the participant got pre-recorded exercise videos at the start of the intervention and guidance in the follow-up meetings to ensure they mastered the program.

Both the intervention and the control group used an activity monitor (Actigraph GT3X+) to monitor their physical activity level (seven consecutive days), at three different periods of the intervention, at the start, mid-point, and end. The control group was supposed not to change their physical activity level during the intervention period, meaning not pursuing additional physical activity or exercises than usual. Data collected from the activity monitor (Actigraph GT3X+) are not included in this master's thesis or presented.

3.4.1 Training program

As described above, the intervention group of this present study followed a progressive standardized HIIT program. The program involved simple circuit training (once a week) and walking/walking uphill exercises (twice a week). All participants in the intervention group were instructed to complete all sets/efforts at >80% HR_{peak} in the six-month training period. Each workout included a standardized warm-up prior to the workout and a mobility part at the end of each session. Subjects were instructed to log all workouts in the logbook (Figure 6) and use the heart rate monitor for every workout.

	Date	Type of activity	Number of sessions/ sets	Duration of sessions/sets	Peak heart rate at the end of the workout	Rate of perceived exertion at the end of the workout (6-20)
Week	12.05.2022	Walking uphill	5	2 min. Whole workout 20 min.	172	18
	15.05.2022	Circuit training	3	45 sec. Whole workout 20 min.	158	15
	17.05.2022	Walking uphill	5	2 min. Whole workout 20 min.	168	17

Figure 6: Example of Logbook page for walking exercise and circuit training

3.4.2 Walking exercise

The walking exercise focused on a HIIT regime and consisted of a standardized exercise program with a progressive training load over the course of six months. The familiarizing period was concluded after four weeks, and then the program switched from low-moderate intensity (40-50% of HR_{peak}) to high intensity (80-90% of HR_{peak}) for each session. The program had a progressive number of efforts and increased every four weeks (+ 1 effort), from week four (five efforts) to week 26 (ten efforts), as shown in Table 1. Subjects were instructed to warm up for at least 10 minutes before starting each workout at low-moderate intensity (40-50% of HR_{peak}). The intensity of workouts was high intensity (80-90% of HR_{peak}), and the duration of each set was two minutes of exercise (walking, walking uphill, or running) and two minutes of active rest between every effort. Participants were instructed to complete two weekly interval sessions during the intervention period.

Table 1. Overview of walking exercise and the progressive volume and intensity throughout the intervention

Week	*Intensity*	*Number of sets*	*Duration of each effort*	*Active rest between each effort*	*Total exercise session duration*
1	Low-moderate	1	20 min	N/A	20 min
2	Low-moderate	1	20 min	N/A	20 min
3	Moderate	5	2 min	2 min	18 min
4-7	High	5	2 min	2 min	18 min
8-11	High	6	2 min	2 min	22 min
12-15	High	7	2 min	2 min	26 min
16-19	High	8	2 min	2 min	30 min
20-23	High	9	2 min	2 min	34 min
24-26	High	10	2 min	2 min	38 min

3.4.3 Circuit training

The Circuit training consisted of a standardized training regime, where the participants conducted six different exercises each session, with a progressive training load over six months. The program started with a four-week familiarizing period where the participant did 12 repetitions of each exercise with a progressive number of sets each week (1 set in week one, 2 sets in week two, 3 sets in week three, and 2 sets of 45 seconds of work at each exercise in week four). After the familiarizing period, each effort lasted 45 seconds, with 60 seconds rest between efforts and 90 seconds rest between each exercise. The total time of the sessions was approximately 30 minutes, with a 10-minute standardized warm-up as described above in 3.4.2 and stretching (end of session). Each exercise was performed in three sets at 80-90% of HR_{peak}, after week four (Table 2).

Table 2. Example of Circuit training from week 5

Exercise	*Number of sets*	*Repetitions/Duration*	*Rest between sets*	*Rest between exercises*
Air squat	3	45 s	60 s	90 s
High knee lifts	3	45 s	60 s	90 s
Step-Ups	3	45 s	60 s	90 s
Push-ups	3	45 s	60 s	90 s
Reverse lunges	3	45 s	60 s	90 s
Mountain climbers	3	45 s	60 s	90 s

3.5 Measurements

The measurements for this project were forced expiratory maneuver, maximum voluntary ventilation (Graham et al., 2019; Miller et al., 2005), and an aerobic fitness test (Balke & Ware, 1959). All measurements were conducted in a physiology lab using an incremental treadmill (Lode Katana sport XL, Netherlands) and oxygen analyzer (Jaeger Vyntus CPX, Germany, SentrySuite) at the Spicheren test laboratory facility and were performed before and after the six-month intervention in the intervention group and control group. In addition to the test performed pre- and post-intervention, all subjects within the training group got a Polar Unite activity watch to track heart rate in the home-based training period, as described above. Measurements were carried out in the same order in pre-test and post-tests (Forced expiratory maneuver, maximum voluntary ventilation, and Aerobic fitness test). All

participants pictured on the various test gave their written consent to be photographed (Appendix 3).

3.5.1 Training adherence

A Polar H9 chest sensor connected to a Polar Unite HR monitor was used for objectively measuring training adherence in the training program (Polar Electro, 2023a, 2023b). With the polar flow software, the exercise data from the HR monitor could be downloaded physically or digitally. The software provided information about the intensity, frequency, type, and duration of each training session. Monitoring heart rate for every workout was essential, ensuring that the participants reached the intended training intensity. In addition, with the Polar software, it was possible to correct the participant's intensity, frequency, or duration during the follow-up meetings. The training data were downloaded from each participant's Polar Unite watch once every week during the familiarizing period and once a month after the familiarizing period was completed. The data were downloaded at the follow-up meetings and at the post-test.

3.5.2 Forced expiratory maneuver

Forced expiratory maneuver (FVC) has three steps: maximal inspiration, a "burst" of exhalation, and continued total exhalation to the end of the test (Miller et al., 2005).

Before the actual execution of the test, the participant was oriented on how to sit and perform the test. For analyzing each effort, an oxygen analyzer was used (Jaeger Vyntus CPX, Germany, SentrySuite). The participant was tested in a sitting position, given a nose clip (Hans Rudolph clip 9014), and explained how to put it on. A disposable breathing tube (NeumoFilt ERGO) was given to the participant, ensuring the lips were closed around the mouthpiece and that the tongue did not impede it. Before the participant conducted the test, the researcher demonstrated a suitable technique. First, the participant performed approximately three tidal breaths, and thereafter the participant took a complete inhalation. Next, participants were cued to "blast," not just "blow," the air from their lungs, and then they were encouraged to exhale fully. The test personnel used energetic coaching and appropriate body language and phrases throughout the maneuver. At least three attempts were performed with one-minute rest between trials. The test result was valid when a minimum of three acceptable FVC maneuvers was acquired. Completion of the FVC test varied from 5-15 minutes, depending on how quickly the participant understood how to perform an acceptable

maneuver. For acceptable repeatability, the difference between the highest and the second highest FVC maneuvers had to be within $\leq$ 0.150L (FVC and FEV1) (Graham et al., 2019; Miller et al., 2005). Three nearly identical measurements are shown in Figure 7.

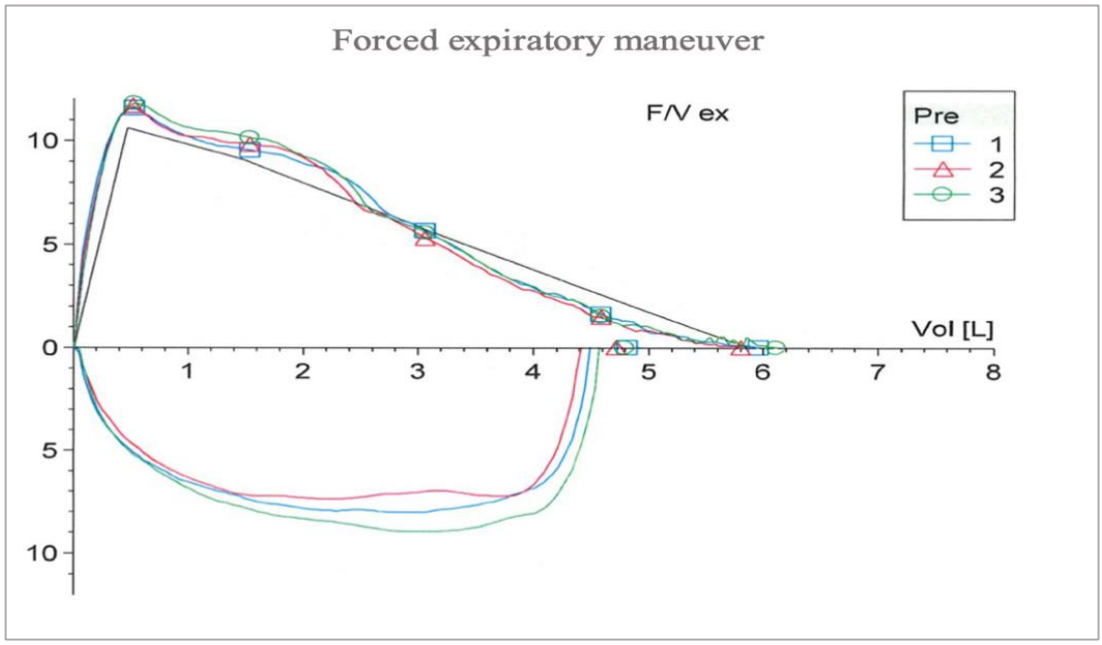

Figure 7: Three acceptable Forced Expiratory maneuvers within the repeatability requirement (Graham et al., 2019; Miller et al., 2005).

Figure 8: Photos showing participants performing acceptable FVC maneuver. Participants gave their written consent to be photographed during maneuvers (Appendix 3).

3.5.3 Maximal voluntary ventilation

As with the FVC, the researcher provided thorough instructions and demonstrated the maneuver before the participant completed the maximum voluntary ventilation (MVV) maneuver. An oxygen analyzer was used to analyze each effort (Jaeger Vyntus CPX, Germany, SentrySuite). MVV was tested for 12 seconds and measured the subject's total lung volume in the specified time domain (Miller et al., 2005).

The participant was tested in a sitting position wearing a nose clip (Hans Rudolph clip 9014). A disposable breathing tube (NeumoFilt ERGO) was given to the subject and self-inserted into the mouth, ensuring the lips were sealed around the mouthpiece. The test started with at least three resting tidal breaths (inhalation and exhalation during relaxed respiration), followed by breathing as rapidly and deeply as possible. The tongue and teeth had to be positioned not to obstruct airflow. The test leader enthusiastically coached the subject throughout the maneuver and could suggest faster or slower breathing to achieve an ideal rate of 90–110 breaths per minute. A good attempt was performed maximally without evidence of leakage, hesitation, or measurement artifact. The test interval was 12 seconds, and the participant had to accomplish two acceptable maneuvers with two minutes of rest between each trial. Completion of the MVV test varied from 5-10 minutes, depending on how quickly the participant understood how to perform an acceptable maneuver. A valid test result contains a minimum of two similar MVV curves. Two acceptable maneuvers were valid when the variance was under a 20% difference (MVV L/min) (Miller et al., 2005). Figure 9 shows two acceptable maneuvers.

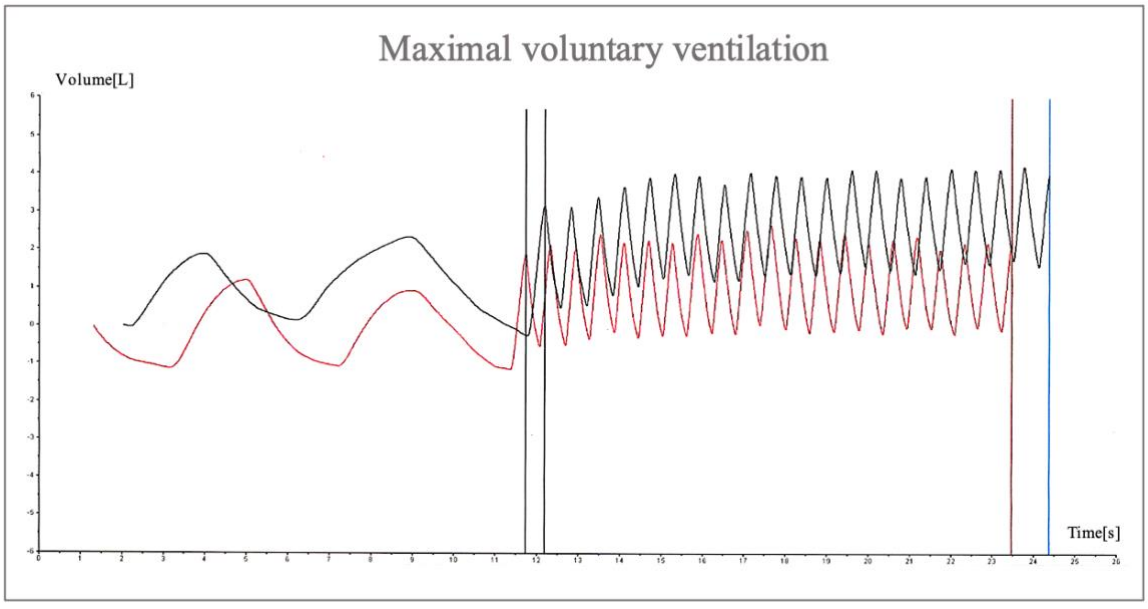

Figure 9: *Two acceptable Maximal voluntary ventilation maneuvers within the repeatability recruitment* (Miller et al., 2005).

Figure 10: Photos showing participant performing acceptable MVV maneuver. Participants gave their written consent to be photographed during maneuvers (Appendix 3).

3.5.4 Aerobic fitness test

The aerobic fitness test was specified by a modified standardized treadmill protocol (Balke & Ware, 1959) with progressive stages and with the intent of reaching VO_{2peak}. The protocol was executed by walking on an incremental treadmill, starting at 3,8km/t and a 4% incline. Participants got a thorough review of the protocol and were instructed to walk to maximum volitional exertion. A Hans Rudolph mask (7450 Series V2, Hans Rudolph, inc Kansas, USA) was fitted, checked for leaks, and used for measuring oxygen with an oxygen analyzer (Jaeger Vyntus CPX, Germany, SentrySuite). For registering heart rate during the test, a polar pulse belt (Polar H9) was fitted around the subject's chest. The protocol began with a 5-minute self-paced warm-up. The oxygen analyzer was calibrated prior to each test (volume and gas calibration). Humidity and temperature were performed with an average room temperature of 18-24 ° C and relative normal humidity (30-60%).

The test began with a 4-minute adoption period to check if pulse and oxygen levels were working correctly, and a baseline lactate sample was acquired. The stage incline was increased by 3% after each interval until the lactate exceeded 2,1 mmol/L over baseline (lactate threshold) (Dickhuth et al., 1999) (Figure 11). Every stage was four-minute, with a rest period of one minute on each stage. A timer (Hanhart 1882, Prisma 200 (interval up x

down timer), Germany) was used to keep track of each interval and reset after every rest period. During the interval, VO_2 (at 02:00, 02:30: 03:00), heart rate (at 03:30), and flow volume loop (at 03:00) were measured. Lactate was measured by acquiring a blood sample from the participant's finger during the rest period (Accu-check, safe-t-pro plus Roche, Mannheim Germany) and then analyzed using a lactate analyzer (EFF diagnostics, Biosen C-line). Borg RPE scale was registered after each stage (Borg, 1970). The protocol switched to one-minute stages when lactate levels were above the threshold. Thereafter heart rate was registered every minute, the incline was increased by 2% to a maximum of 20%, and then the speed was increased by 0,5 km/t per minute until absolute fatigue (participant reached self-perceived absolute exertion, specified by Borg RPE scale). The test leader made sure to motivate and help the participants reach maximum voluntary exertion. After completion, the participants were asked about the Borg RPE scale, and the last lactate sample was acquired one minute after test completion. A test was valid if the participant specified Borg RPE scale $\geq$17 or reached a respiratory exchange ratio (RER) $\geq$1.10. VO_{2peak} was defined as the average of the two highest measurements recorded over 30 seconds.

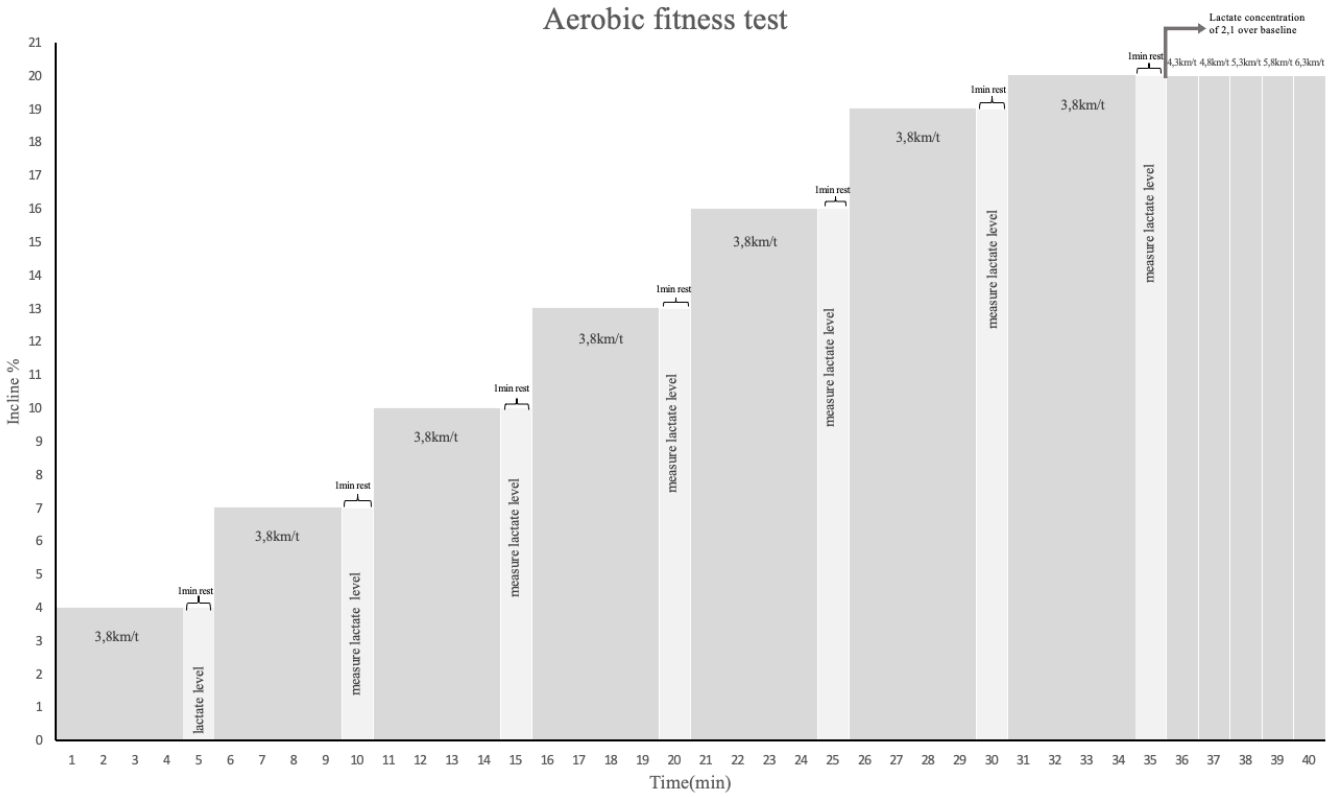

Figure 11: The progressive stages in the aerobic fitness test.

Figure 12: Photos of the participant completing the Aerobic fitness test and requiring lactate sample after completion of the aerobic fitness test (Kunsstoff-Kapillaren end-to-end, EKF diagnostic). Participants gave their written consent to be photographed during the aerobic fitness measurements (Appendix 3).

3.6 Statistical analysis

All statistical analyses were conducted using IBM SPSS statistics for Macintosh, version 28.0 (IBM Corp Armonk, NY). Tables and figures were made using Microsoft Word for Mac version 16.77 (MS, Redmond, WA, USA), GraphPad Prism version 9.5.1 for Mac (GraphPad Software, San Diego, California, USA), and Microsoft Excel for Mac version 16.72 (MS, Redmond, WA, USA). The dataset was checked for non-normality by using the Shapiro-Wilk test and visual confirmation of histograms. All data were considered normally distributed and were presented as mean ± standard deviation (SD) or mean + 95% confidence interval (CI). Power analysis was evaluated by researching the smallest sample size an experiment needs, given the required significance level, effect size, and statistical power. Based on previous studies investigating the effectiveness of aerobic training programs in older adults (Bouaziz et al., 2020; Huang et al., 2016; Vigorito & Giallauria, 2014), we needed ≥20 participants in each group to detect a 10% (SD 9) group difference in VO_{2peak}, with 80% power and an α-level at 5%. Within-group comparisons were conducted using a paired sample t-test (All and within sexes), and comparisons between the intervention and control groups were performed

using an independent sample t-test (All and within sexes). All test was two-tailed, with a selected statistical significance *p*-level of .05.

4.0 METHODICAL DISCUSSION

4.1 Study design

In this present study, an experimental design was implied to be the most appropriate approach for investigating the primary research objective. Experimental designs involve manipulating the independent variable to observe its impact on the dependent variable aiming to establish a causal relationship (Polit & Beck, 2010). Such designs yield the highest level of evidence when assessing the effect of an intervention (Polit & Beck, 2010). However, designing an experiment appropriately with adequate duration and intensity is crucial to evaluate the intervention accurately (Gerlach et al., 2020; Polit & Beck, 2010).

Nonetheless, limitations in resources and economic constraints may impede the control of several variables that may influence CRF (activity level of the subjects, training intensity, or follow-up meetings). To address this, a randomized controlled design was utilized in the present study, considered the gold standard in experimental research for examining causal relationships (Polit & Beck, 2010). Variables such as baseline physical activity level were kept as equal as possible between the groups by only including participants that were less physically active than the physical activity recommendations (less than 150min of moderate-intensity aerobic exercise or less than 75min of vigorous-intensity aerobic exercise a week) by the World Health Organization (2022). Subjects were randomized to either the intervention group or the control group, and stratified randomization was used to ensure the groups were alike regarding sex, age, physical activity levels, aerobic fitness measurements (VO_{2peak}), and lung function measurements (MVV, FVC, and FEV1).

4.2 Participants

In this current study, 118 participants completed the pre and post-test, with 56 subjects assigned to the intervention group and 62 to the control group. Based on the power analyses employed, which included a significance level of 5%, an effect size of 10%, and statistical power of 80%, our study had the ability to detect possible group differences in VO_{2peak}. Moreover, our study sample was well above the minimum requirement of 20 participants in each group. Furthermore, sub-analyses comparing sex within the intervention group (23 men

and 33 women) and the control group (25 men and 37 women) also exceeded the target of having more than 20 participants in each group.

When determining whether the results of this research can be generalized, it is crucial to evaluate if the population aged 60-85 years would significantly differ from the study's selection. Participants of this current study were generally in good health at the beginning of the study and were instructed to complete a questionnaire about themself and their activity level before inclusion. As the participants were voluntary, it was challenging to determine whether they had less than 150 minutes of moderate physical activity a week, despite what they answered in the questionnaire. Additionally, all participants used an activity monitor (Actigraph GT3X+) to determine their activity level at the start of the study (the data from the activity monitors are not presented in this master thesis). Moreover, the subjects of the FAB study seem superior in VO_{2peak} at baseline compared to a clinical trial performed by Søgaard et al. (2017), investigating the metabolic benefit of HIIT in older sedentary individuals (63±1 year). The subjects of the FAB study were superior at baseline in both men (30.7±5.2 versus 27.4±2 ml/min/kg) and women (25.7±4.3 versus 23.1±1 ml/min/kg), even with a considerably older population (68.5±5.7 years) compared to Søgaard et al. (2017).

However, a study by Edvardsen et al. (2013) investigated Norwegian reference values for VO_{2max} on a treadmill in a large randomly sampled population from 20-90 years of age (n= 904). The reference values for VO_{2max} (ml/kg/min) in older men (60-85 years) (31.25±5.6, respectfully) and women (60-85 years) (26.1±5.35, respectfully) detected by Edvardsen et al. (2013) were nearly identical to the baseline characteristics of this present study (60-85 years). Moreover, a randomized controlled trial conducted by Hassel et al. (2015) investigated the association between lung function and VO_{2peak} in healthy older men and women. The baseline values for VO_{2peak} and FEV1 for this present study were nearly identical to Hassel et al. (2015) for men (VO_{2peak}, 30.7±5.2 and 31.3±6.7 ml/kg/min and FEV1, 3.07±0.57 and 3.13±0.60 liters) and women (VO_{2peak}, 25.7±4.3 and 26.1±5 ml/kg/min and FEV1, 2.33±0.48 and 2.24±0.37 liters) but with a considerable difference population size (n=139 and n=1567). Nevertheless, Hassel et al. (2015) did not have any inclusion criteria regarding the participants' physical activity level and with a narrower study selection (69-77 years). A self-selection bias may have occurred in the present research because the voluntary participants could have been more physically active than they stated before entering the study, as there are

reasons to assume that healthier, more physically active individuals wish to attend an exercise intervention (Polit & Beck, 2010).

4.3 Exercise intervention

The exercise intervention used in the present study was a home-based HIIT regime. As previously mentioned, few studies have investigated HIIT interventions outside of laboratory conditions (Gray et al., 2016). There were various variables to consider regarding the exercise intervention used in the present study. The present study's intervention was based on their recommendations regarding frequency, intensity, and duration from recent research regarding HIIT interventions (Vigorito & Giallauria, 2014). Vigorito and Giallauria (2014) investigated the effect of exercise on cardiovascular performance in older adults and offered guidelines for creating suitable training regimes for the older population, including baseline levels, intensity, duration, and frequency. The study recommends extended exercise interventions (>12 weeks), three sessions a week, with a target duration of 30 minutes per session (Vigorito & Giallauria, 2014).

A systematic review by Keating et al. (2020) compared HIIT versus MICT in older adults. The study investigated exercise modality, sessions per week, intervention period, training intensity (% of HR_{peak}), interval time, total interval time, and total exercise duration (Keating et al., 2020). This study indicated that HIIT could be a useful training regime, and the recommendations about duration, intensity, and frequency were nearly identical to Vigorito and Giallauria (2014) (Keating et al., 2020). Additionally, the present recommendations from the literature suggest that HIIT programs may be more efficient for enhancing CRF in healthy older adults (Keating et al., 2020; Vigorito & Giallauria, 2014; Wu et al., 2021). However, it is still difficult to determine whether HIIT programs are more beneficial than alternative training programs using different training intensities (MICT) in the same population.

Various methods were utilized to control variables that may affect the intervention in the current study. To determine the training intensity (% of HR_{peak}) of each participant HR_{peak} was measured in the aerobic fitness test (see 3.5.4). With the heart rate monitor given to each participant at study inclusion, a FAB training instructor entered the HR_{peak} for all individuals in the intervention group.

One possible limitation was that some participants may not have reached their HR_{peak} during the aerobic fitness test. However, during the four-week familiarization period, the HR_{peak} was adjusted under guidance from an instructor in the case of submaximal levels. Furthermore, to

adjust the intensity and exercise modality accurately, the participants had frequent meetings (once a week) with a FAB training instructor during the familiarizing period (four weeks). Exercise modalities were adjusted for every individual to ensure the training program suited their level (walking, walking uphill, or running).
A strength of this study was the use of a heart rate monitor during every session, with data collected at monthly follow-up meetings. During these meetings, the training instructor where able to give feedback on duration, intensity, and frequency or adjust the HR_{peak} for the participant, which helped to give the exercise group a better understanding of the intended stimuli of the program. A possible concern was the motivation of the older individuals and whether or not they were able to maintain the exercise level throughout the intervention period, even if they did not feel an immediate physical benefit (Ory et al., 2006).

All training sessions were also recorded in a logbook, which was provided to every individual in the intervention group at the beginning of the study. As the program was home-based, the heart rate monitor and logbook could be used post-intervention to determine if the participant reached the intended frequency, intensity, and duration for each session throughout the intervention period. Due to the submission deadline of this master's thesis, the data from the heart rate monitor and logbook were not completed and will not be presented. Participants were instructed to log every session during the intervention period. The data from the logbook and heart rate monitor provided essential information regarding the training sessions of each participant in the intervention group. The logbook provided subjective measures of how and if the sessions were completed. The heart rate monitor provided objective measurements of the participant's heart rate and the duration of each training session. With the information required, it was possible to compare the data from the logbook to the data from the heart rate monitor, providing information on the subjective and objective measurements during the intervention period. A potential concern with the heart rate monitor was that some individuals could have problems understanding the software, and therefore increased the risk of measurement errors. To minimize these faults, the training instructor addressed these concerns at the follow-up meetings to help and guide the participants. Additionally, the training program may have been interrupted by illness, covid-19, vacation, mental problems, or injuries. In such cases, the participants were instructed to write down interruptions in the intervention period in the logbook. As mentioned above, the due to the submission deadline of this master's thesis, the data from the heart rate monitor and logbook are not completed and will not be presented.

Finally, the HIIT program used in this present study was designed to ameliorate CRF and lung function in older adults and followed the recommendations regarding HIIT interventions in the existing literature (Keating et al., 2020; Ramos et al., 2015; Vigorito & Giallauria, 2014; Wu et al., 2021). This study may contribute to the existing knowledge about home-based HIIT programs that are safe, convenient, and do not require special equipment or gym memberships, making them a time-efficient training method. Furthermore, a strength of the present HIIT program was the long-term home-based exercise intervention over six months. As Gray et al. (2016) addresses in their paper, more research is needed regarding "real world" effectiveness studies, and this present study may add new knowledge to this topic.

4.4 Measurements

In sports science, it is essential to perform testing to evaluate the impact of an exercise intervention. There are various factors to consider in conducting test procedures: ensuring that the test is reliable and valid, acquiring accurate measurements from the test equipment, controlling the work condition, and making sure that the same standardized protocol is used in both pre-and post-measurements (Thomas et al., 2015). The test procedure in the present study followed the abovementioned factors when completing the pre- and post-measurements. To minimize faults in the testing procedure, the participants got a thorough review of each test by an instructor. Each participant also underwent a familiarizing period (5-min self-paced warmup) when completing the aerobic fitness measurements. Nevertheless, even though the research protocol was properly designed and made by qualified personnel, it's difficult to rule out measurement errors that may occur due to variations in a measurement tool or individual biological errors (Atkinson & Nevill, 1998). All measurements were conducted using a Jaeger Vyntus CPX (Germany, SentrySuite) oxygen analyzer. Jaeger Vyntus CPX has been demonstrated to be a valid and reliable measuring tool in previous research (Groepenhoff et al., 2017; Jeu et al., 2018). Therefore, the Jaeger Vyntus CPX was suggested to be a reliable measuring tool for assessing VO_{2peak} and lung function in this present study.

4.4.1 Forced expiratory maneuver

The repeatability of the FVC maneuver was addressed in the article of Miller et al. (2005). As mentioned in 3.5.2, an acceptable FVC test was completed when the participant has achieved three FVC maneuvers within $\leq$ 0.150L difference between maneuvers (FVC and FEV1). Unacceptable maneuvers (cough, unusable curve, and fault start) were excluded from the test

result. The present study followed the same test criteria as in Miller et al. (2005) and Graham et al. (2019) for the FVC measurements of each participant pre and post-intervention. Ensuring that all values for FVC were within the requirement for repeatability. The participants got thorough instructions on how to sit and complete the maneuver to minimize test variations. Several maneuvers were completed to ensure the participant had reached their max FVC and the measurements had comparable curves. Each maneuver was evaluated and analyzed, and unsuitable maneuvers were discarded from the results. Additionally, the test equipment was calibrated (gas and volume) between each participant.

A study by Enright et al. (2004) tested the repeatability of FVC within a large database (n=18.000) with participants ranging from 20-90 years of age. The study concluded that the repeatability was high, and nine of ten participants could perform suitable FVC maneuvers within test requirements (Enright et al., 2004). Repeatability was not affected by subject characteristics (age or height), but the quality of maneuver mainly depended on the skills of the technician (Enright et al., 2004). Therefore, it is crucial to have qualified personnel when performing maneuvers such as the FVC. Additionally, a pilot study was completed prior to the pre-test of the present study to minimize potential measurement error.
In summary, the forced expiratory maneuver was suggested to be a reliable method for lung function measurements in this current study. Using a standardized protocol, recommended test criteria, and qualified personnel improves test repeatability.

4.4.2 Maximum voluntary ventilation

The present study used the MVV maneuver to evaluate the subject's maximum air volume within a specified period (12 seconds). Following a standardized protocol for the MVV maneuver, the test criteria were the same for pre-and post-measurements (Miller et al., 2005). Participants got thorough instructions on how to sit and perform the maneuver to minimize the variance between subjects. Acceptable repeatability of the MVV maneuvers needed to be within 20% difference (L/min) between the highest and second highest measurements (Miller et al., 2005). In addition, the subjects were instructed to breathe at maximal effort and with a breathing frequency between 90-115 breaths per minute (Miller et al., 2005). Several trials were completed to ensure the participant reached max MMV with eligible repeatability criteria. The equipment was calibrated (gas and volume) for every participant. However, even with strict test criteria, measurement errors could occur due to the participant, the equipment, or the technician (Thomas et al., 2015). Measurement errors may also occur due to the test

leader's limited skill and experience, although we tried to limit such errors as mentioned above. Additionally, the participant's mood or motivation may inflict the ability to perform several maneuvers to reach acceptable repeatability (Thomas et al., 2015).

In summary, there are few studies regarding the repeatability of the MVV maneuver (Miller et al., 2005). The present study suggested that MVV was a reliable measurement for evaluating lung function in older men and women, following the test criteria from Miller et al. (2005).

4.4.3 Aerobic fitness test

The peak oxygen consumption of each participant was measured using an Aerobic fitness test. To determine VO_{2peak}, a modified incremental treadmill protocol developed by Balke and Ware (1959) was used. The protocol included both subjective (Borg RPE scale) and objective (RER and lactate) end criteria measurements to evaluate the rate of exertion of each participant (Edvardsen et al., 2014). Participants were thoroughly instructed on how to perform the test and got 5-7 minutes of familiarization on the treadmill before starting the measurement. In Norway, CRF (VO_{2peak}) has been assessed in several studies using various modified Balke protocols (Edvardsen et al., 2013; Wisløff et al., 2007). The protocol used in this present study was standardized, and the participant was tested under the same conditions (humidity 30-60%, temperature 18-24°C and test order) in pre-and post-measurements.

Edvardsen et al. (2014) evaluated the end criteria for reaching maximal exertion in continuously graded exercise measurements using treadmills. The study suggests new recommendations for sexes and ages regarding end criteria for maximal exertion, including RER and blood lactate concentration (Edvardsen et al., 2014). A lower estimate of RER (men and women $\geq$ 1.00 VCO_2/VO_2) and lactate (men $\geq$ 4.0 mmol/L and women $\geq$ 3.5 mmol/L) was presented for evaluating maximal exertion in older men and women (Edvardsen et al., 2014). The present study was well over the end criteria values for RER and lactate in older men and women recommended by Edvardsen et al. (2014). The RER was evaluated in both men (pre-testing 1.12±0.06 and post-testing 1.1±0.07 VCO_2/VO_2) and women (pre-testing 1.1±0.07 and post-testing 1.08±0.06 VCO_2/VO_2) for pre-and post-tests. Moreover, the blood lactate concentration was evaluated in both men (pre-testing 8.5±2.19 and post-testing 8.08±2.39 mmol/L) and women (pre-testing 7.7±1.91 and post-testing 7.16±1.91 mmol/L for pre-and post-tests. The end criteria measurements of the present study indicated that the

participant reached maximal exertion and VO_{2peak} in the aerobic fitness test for pre-and post-testing.

The present study used a more laborious protocol for aerobic fitness measurements than similar treadmill protocols (Edvardsen et al., 2013; Wisløff et al., 2007). The protocol aimed to evaluate the lactate threshold and VO_{2peak} for each participant. Therefore, four-minute intervals were used to measure lactate for every stage until the lactate threshold was achieved. Furthermore, the protocol was standardized for both sexes, and the fitter individuals used approximately 35-50 minutes to complete the test. Due to the long duration of the test for fitter individuals, fatigue could inflict the participant's ability to reach VO_{2peak} at the end of the protocol. Nevertheless, with strict end criteria for evaluating maximal exertion, the aerobic fitness test used in this study seems reliable for measuring VO_{2peak} in older men and women.

4.5 Main strengths and limitations

The main strength of this current study was the use of an extensive intervention period and considerable population size compared to similar research regarding HIIT in older adults (Ramos et al., 2015; Wu et al., 2021). In addition, further strengths of the present study are the representative population regarding baseline physical activity levels (Ramos et al., 2015; Vigorito & Giallauria, 2014), strict monitoring of training volume in the intervention group (intensity, duration, and frequency), frequent follow-up meetings to maintain the participant's motivation, direct measurements of VO_{2peak} performed to maximal exertion on an incremental treadmill (with strict end criteria requirements) and a home-based training intervention with low cost, was easily accessible and were safe to use for older men and women. In addition, as stated previously, the data from the logbook and HR monitor would be a strength of this present study, but they were not completed before the submission deadline of this master’s thesis and were therefore not presented.

However, some limitations need to be addressed. Although the home-based intervention is presented as a strength, it can also be a limiting factor in the present study. There is often lower feasibility in home-based interventions. Meaning that it was difficult to determine whether the participants reached the intended stimuli (duration, intensity, and frequency) for

each session with limited supervision. The lack of these data regarding the frequency, duration, and intensity of the home-based HIIT sessions was a limitation in this current study. Furthermore, a potential “selection bias” could be a limiting factor as the current study is part of a more extensive study, which only included participants with basic English skills. The inclusion criteria may contribute to a population with more highly educated subjects.

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PART 2

RESEARCH PAPER

The effect of a six-month home-based HIIT intervention on cardiorespiratory fitness and lung function in older adults between 60-85 years

The following paper is written according to the standards of the following journal:

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May, 2023

The effect of a six-month home-based HIIT intervention on cardiorespiratory fitness and lung function in older adults between 60-85 years

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Abstract

This study aimed to investigate the effect of home-based high-intensity interval training (HIIT) on cardiorespiratory fitness (VO_{2peak}) and lung function in older adults (68.5±5.3 years). 139 participants were randomized to either the HIIT intervention group or a passive control group. Measurements were conducted using a modified incremental treadmill protocol (Balke) and an oxygen analyzer. The intervention group followed a HIIT program consisting of 3 sessions/wk, two HIIT walking exercises, and one circuit HIIT (>80% of HR_{peak}). The intervention group improved VO_{2peak} within the group and compared to the control group after the intervention period (6.22±7.84% versus -1.29±7.07%, $p \leq .001$). No improvements were seen in lung function, except for an improvement in MVV within the intervention group (IG 2.92±8.43%, $p \leq .05$ and IG men 4.73±8.07%, $p \leq .05$), no increases were seen in lung function. A six-month home-based HIIT regime improved cardiorespiratory fitness in older adults, whereas no improvements in lung function were detected.

Keywords: Aging, VO_{2peak}, Maximal voluntary ventilation, Forced vital capacity

The increasing older population is a global phenomenon, and the world's population above 65 years reached 703 million in 2019 (United Nations, 2019). Older adults have excelled from 6% of the world population in 1990 to 9% in 2019 and are predicted to be 16% by 2050 (United Nations, 2019). Aging is associated with a decline in physical function (ability to perform everyday activities and tasks such as carrying, pulling/pushing, cardiovascular tolerance, and balance) (Roman et al., 2016; Wu et al., 2021). An effective strategy for preventing loss of physical function is attending regular physical activity (PA). PA defines as "any bodily movement produced by skeletal muscles that require energy expenditure" (World Health Organization, 2022). Evidence supports a positive association between regular PA for maintaining physical function and preventing disability (Marzetti et al., 2017). The World health organization recommends a PA level of at least >150 minutes of moderate-intensity aerobic exercise or >75 minutes of vigorous-intensity aerobic exercise a week from age 18-65 years of age and above (World Health Organization, 2022). In addition to these recommendations, individuals above 65 should emphasize balance and strength training at a moderate or higher intensity (World Health Organization, 2022).

Previous research investigating regular exercise and PA has stated that Regular exercise and PA have indicated an improvement in physical function, independent lifestyle, quality of life, and reduced health problems in the older population (Mazzeo et al., 1998; Spirduso & Cronin, 2001). Although previous research indicates that exercise can improve function and quality of life, older adults use much of their daily time sedentary (Lohne-Seiler et al., 2014). Previous research indicated that approximately 66% of the daily time was sedentary among Norwegian older adults aged 65-85 years (Lohne-Seiler et al., 2014). Inactivity and sedentary behavior are associated with mortality, health problems, and reduced health-related quality of life and are one of the primary reasons for most chronic diseases (Booth et al., 2012; Katzmarzyk et al., 2009). A decline in lung function is associated with

age-related changes, where the thorax wall gets stiffer, the lungs lose the elastic recoil, and impaired respiratory function (Janssens et al., 1999). The impairment of the lungs in older age may be a limiting factor in increasing cardiorespiratory fitness (CRF) (Hassel et al., 2015). CRF is defined as "the capacity of the circulatory and respiratory systems to supply oxygen to skeletal muscle mitochondria for energy production needed during physical activity" (measured as peak oxygen uptake: $VO2_{peak}$) (Raghuveer et al., 2020).

Recent research has demonstrated that high-intensity interval training (HIIT) ameliorates CRF and influences oxidative stress, insulin sensitivity, and inflammation in older adults (Keating et al., 2020; Ramos et al., 2015). Furthermore, various forms of aerobic exercise may ameliorate CRF and are differentiated by duration and intensity. Research on moderate continuous training (MICT) has indicated positive outcomes regarding CRF (Weston et al., 2014; Wu et al., 2021). MICT comprises a lower intensity (65-75% of HR_{peak}) and longer duration than HIIT (Roman et al., 2016; Wu et al., 2021). On the other hand, HIIT includes exercise at a higher intensity ($\geq$80% of HR_{peak}) than MICT and could be a more efficient stimulus to influence CRF and improve body composition in older individuals (Weston et al., 2014; Wu et al., 2021). This makes HIIT a presumably more attractive option as a time-efficient training method (Weston et al., 2014).

Gray et al. (2016) address the need for more data regarding HIIT in different populations outside of the gym, with low cost, in a more assessable form, and without a strict follow-up. The research also indicates that few studies imply a longer duration in HIIT interventions (>12 months) (Gray et al., 2016). Reitlo et al. (2018) further assess the significant challenge of having older adults adhere to an extensive exercise program and how to make an effective program in a randomized controlled trial. The research indicated that older adults could handle a HIIT regime over a 12-month period, and the most frequent training locations are at home and outdoors (Reitlo et al., 2018).

This current study is part of a more extensive ongoing study in Norway and the UK, The Fitness, aging, and bilingualism project (The FAB Project) (UIA, 2022). The main project's objective is to investigate if regular aerobic exercise in conjunction with speaking a second language can ameliorate the decline in cognitive function in older adults (UIA, 2022). In conjunction with The FAB study, the present study uses a home-based HIIT regime (>80% of HR_{peak}) three times a week in a six-month intervention period.

As far as the author knows, few studies investigate the effect of home-based HIIT programs on an older population. Therefore, the aim of this study was to test the hypothesis that a home-based HIIT program could ameliorate CRF (VO_{2peak}) and lung function (MVV, FVC, and FEV1) in older adults between 60-85 years.

Methods

Study design and participants

The participants were recruited through advertisements on Facebook, in local newspapers, through The Fab website, and invitations to information meetings at UiA. A total of 139 (68.5±5.3 years) voluntary home-dwelling participants were recruited from the south of Norway. The study sample consisted of only older men and women between 60 to 85 years of age, with equal allocation in the intervention and control groups. The present study was part of a more extensive study in the south of Norway, the FAB project (Fitness, aging, and bilingualism) (UIA, 2022). The study design was a randomized controlled trial (RCT) with an intervention group and a passive control group. A balanced number of men and women were recruited to ensure the results were valid for both sexes (59 men and 80 women). This study's participants were randomly assigned to either a home-based HIIT intervention or a passive control group stratified by age and gender (Figure 1). Before participation, all participants in

the intervention group had to provide a thorough health screening by a medical professional and a written confirmation of a suitable health level.

Since the study was part of the FAB project, all participants were bilingual. Therefore, participants had no diagnosis of language impairments (dyslexia or stuttering), corrected-to-normal hearing and vision, and were less than 150 minutes of moderate physical activity a week, according to the physical activity guidelines (Helsedirektoratet, 2019). Participants that reported acute terminal illness, respiratory, neurological, severe cardiovascular, or musculoskeletal disease were excluded. The overall inclusion and exclusion criteria aimed to ensure that the participants were relatively inactive and homogeneous concerning their health status and physical activity levels. The pre-tests started in late September 2021 and were completed in mid-September 2022. Post-test started in late March 2022 and was completed in early March 2023.

The study in its entirety was approved by the Norwegian Center for Research Data (ref. number: 163931). A project description based on this master`s thesis was also ethically approved by The Ethical Board at de Faculty of Health and Sport Science, University of Agder (ref. number: RITM0193703). The present study has not been submitted to another journal previously and should include sufficient information about the subject matter.

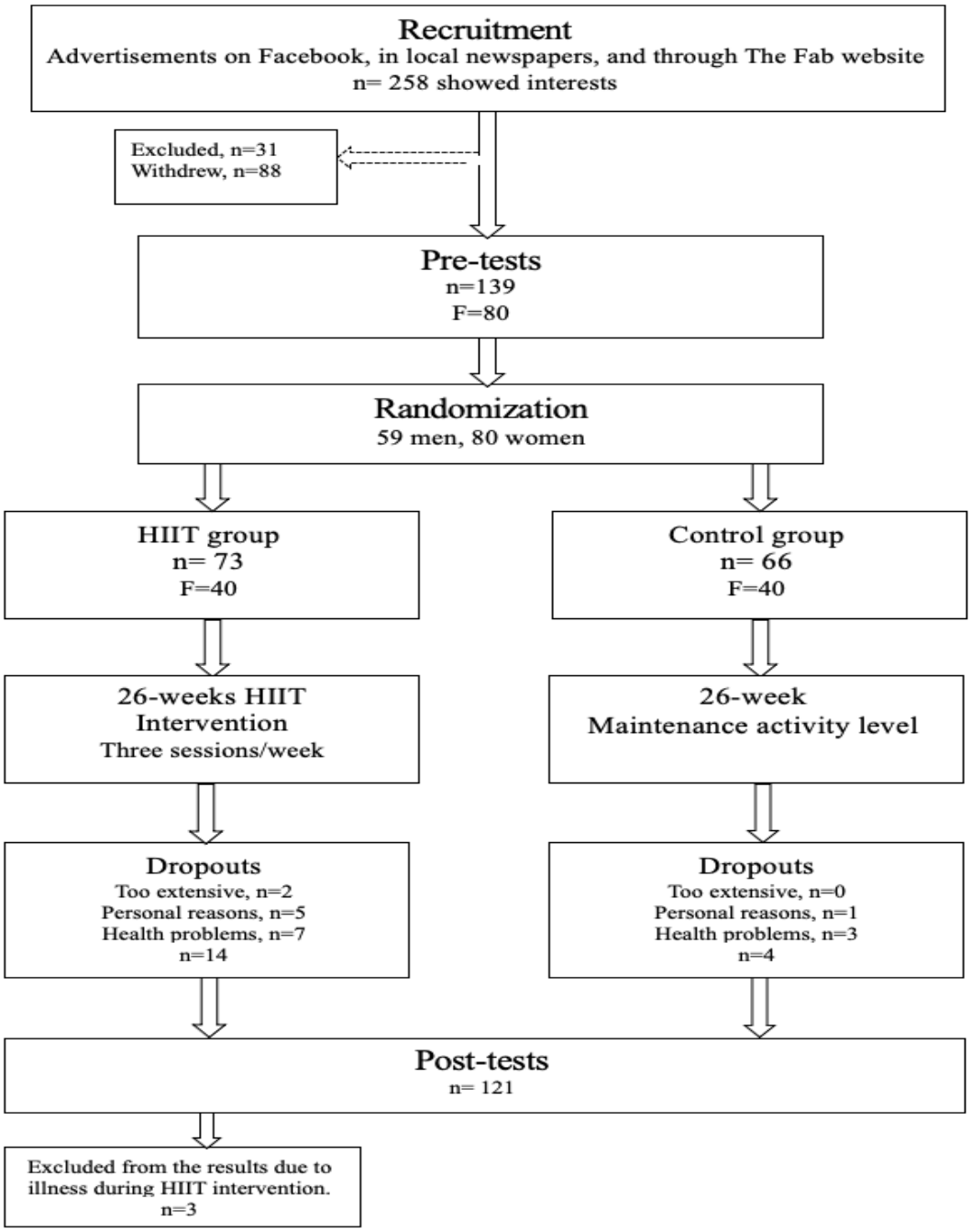

Figure 1 – Flow- chart of the study design, showing the timeline for recruitment, randomization, pre-tests, intervention period and post-tests. High-intensity interval training group (HIIT) and control group.

Exercise intervention

The intervention group pursued an exercise intervention over a six-month period designed to examine the benefits of a home-based training program against a passive control group. The

training consisted of one interval circuit session and two interval walking/running sessions each week, and the sessions were considered simple and safe to do at home or outside. After inclusion, the training program started with a familiarizing period. The purpose of this period was for the participants to use and get to know the training equipment and training program. Each individual in the intervention group was given a logbook and heart rate monitor (Polar Unite Activity watch), including an external heart rate sensor (Polar H9 heart rate sensor) in the inclusion of the study (Polar Electro, 2023a, 2023b). The activity monitor was used to register the average and peak heart rate (HR_{peak}) for every workout, and the data was downloaded at frequent follow-up meetings. With the downloaded data, it was possible to adjust the duration or intensity. The aim of each interval was to have an average heart rate above 80% of the participant's HR_{peak}. Adjustments were made at the follow-up meetings for each participant in conjunction with a training instructor. The instructor viewed the data from the participant's heart rate monitor to adjust HR_{peak} and to give corrections in duration, intensity, or frequency to achieve the intended stimuli.

The logbook aimed to track all workouts done within the six-month period. The participant registered the date, activity, sets, duration, HR_{peak}, and self-perceived exertion using the Borg RPE scale (Borg, 1970) after every session. Each workout was approximately 45 minutes, with a 5–10-minute general warm-up. In the first four weeks, the intensity of the sessions was supposed to be sub-maximally (40-60% of HR_{peak}). Thereafter, the program switched from submaximal to high intensity (80-90% of HR_{peak}) with progressive intensity and volume throughout the intervention. Participants got pre-recorded exercise videos and follow-up meetings with a training instructor throughout the intervention. Data from the heart rate monitor were downloaded at follow-up meetings with a training instructor once a week during the first four-week familiarizing period and thereafter once a month throughout the

entire intervention period. In addition, as stated above, the participant got guidance in these meetings to ensure they mastered the training program.

Walking exercise

The walking exercise focused on a HIIT regime and consisted of a standardized exercise program with a progressive training load over six months. The familiarizing period was concluded after four weeks, and then the program switched from low-moderate intensity (40-50% of HR_{peak}) to high intensity (80-90% of HR_{peak}) for each session. The program had a progressive number of efforts and increased every fourth week (+1 effort) from week four (5 efforts) to week 26 (10 efforts). Participants were instructed to warm up for at least 10 minutes before starting each workout at low-moderate intensity (40-50% of HR_{peak}). The intensity of workouts was high (80-90% of HR_{peak}), and the duration of each set was two minutes of exercise (walking, walking uphill, or running) and two minutes of active rest between every interval. Participants were instructed to complete two weekly interval sessions during the intervention period.

Circuit training

The Circuit training consisted of a standardized training regime, where the participants conducted six different exercises (air squats, high knee lifts, step-ups, push-ups, reverse lunges, and mountain climbers) in each session, with a progressive training load over six months. The program started with a four-week familiarizing period where the participant did 12 repetitions of each exercise with a progressive number of sets each week (1 set in week one, 2 sets in week two, 3 sets in week three, and 2 sets of 45 seconds of work at each exercise in week four). After the familiarizing period, each effort lasted 45 seconds, with 60 seconds rest between efforts and 90 seconds between each exercise. The total time of the

sessions was approximately 30 minutes, with a 10-minute standardized warm-up as described above and stretching (end of session). After week four, each exercise was performed in three sets at 80-90% of HR_{peak}. The participants were supposed to conduct one “circuit training” each week.

Measurements

The measurements used for this project were forced expiratory maneuvers, maximum voluntary ventilation (Miller et al., 2005), and aerobic fitness test (Balke & Ware, 1959). All measurements were conducted in a physiology lab using an incremental treadmill (Lode Katana sport XL, Netherlands) and oxygen analyzer (Jaeger Vyntus CPX, Germany, SentrySuite) and were performed before and after the six-month intervention in both the intervention and control group. In addition to the measurements performed pre- and post-intervention, all participants in the intervention group got a Polar Unite activity watch to track heart rate for every session when conducting the home-based training period, as described above. Measurements were performed in the same order in both pre-test and post-tests (Forced expiratory maneuver, maximum voluntary ventilation, and Aerobic fitness test). All participants pictured on the various test gave their written consent to be photographed.

Forced expiratory maneuver

Forced expiratory maneuvers (FVC) were performed with three steps: maximal inspiration, a "burst" of exhalation, and continued total exhalation to the end of the test (Miller et al., 2005).

The participant was oriented on how to sit and perform before executing the maneuver. For analyzing each effort, an oxygen analyzer was used (Jaeger Vyntus CPX, Germany, SentrySuite). The participant was tested in a sitting position, given a nose clip (Hans Rudolph clip 9014), and explained how to put it on. A disposable breathing tube

(NeumoFilt ERGO) was given to the participant, ensuring the lips were closed around the mouthpiece and that the tongue did not impede it. Before the participant conducted the maneuver, the researcher demonstrated a suitable technique. The maneuver started with a complete inhalation, and then the participant was cued to "blast," not just "blow," the air from their lungs and encouraged to exhale fully. The test leader used energetic coaching and appropriate body language and phrases throughout the maneuver. At least three attempts were performed with one-minute rest between trials. The test result was valid when a minimum of three acceptable FVC maneuvers was acquired. For acceptable repeatability, the difference between the largest and the second largest FVC maneuvers must be $\leq$ 0.150L (FVC and FEV1) (Miller et al., 2005).

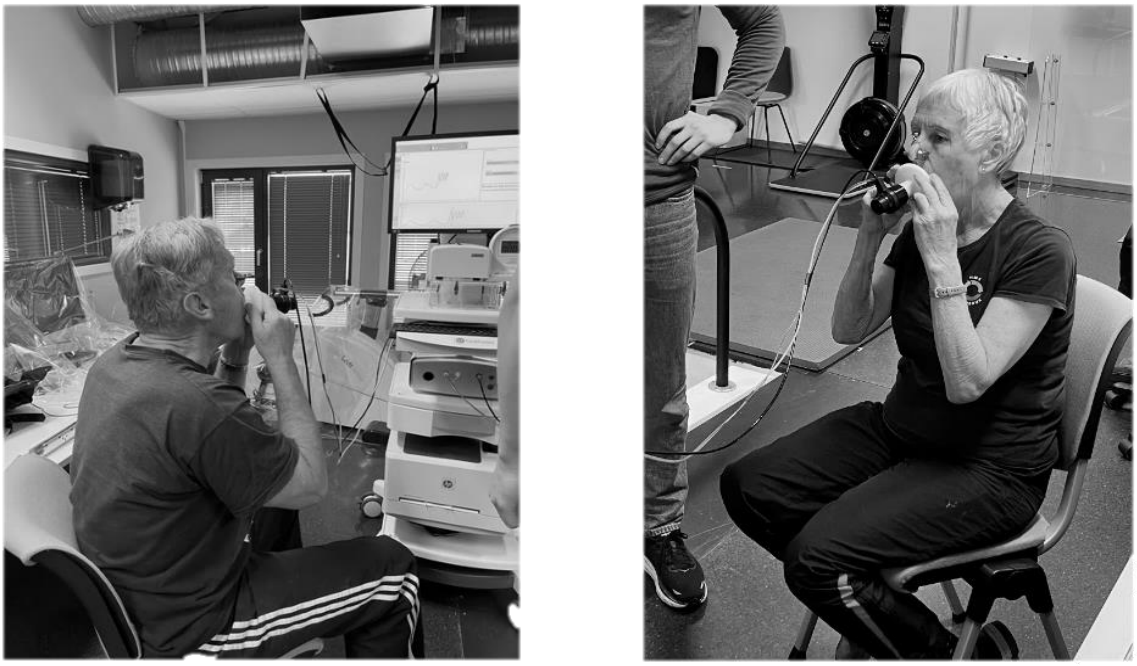

Figure 2 – Photos showing participants performing acceptable FVC maneuver. Participants gave their written consent to be photographed during maneuvers.

Maximal voluntary ventilation

Maximum voluntary ventilation (MVV) was used to measure the participant's total lung volume in a specific time domain (12 seconds) (Miller et al., 2005). The test leader provided

thorough instructions and demonstrated the maneuver before the participant performed the MVV maneuver. An oxygen analyzer was used to analyze each effort (Jaeger Vyntus CPX, Germany, SentrySuite). The participant was tested in a sitting position wearing a nose clip (Hans Rudolph clip 9014). A disposable breathing tube (NeumoFilt ERGO) was given to the participant and self-inserted into the mouth, ensuring the lips were sealed around the mouthpiece. The test started with at least three resting tidal breaths (inhalation and exhalation during relaxed respiration), followed by breathing as rapidly and deeply as possible. The tongue and teeth had to be positioned not to obstruct airflow. The test leader enthusiastically coached the participant throughout the maneuver and instructed them to breathe faster or slower to achieve an ideal rate of 90–110 breaths per minute. A good attempt was performed maximally without evidence of leakage, hesitation, or measurement artifact. The test interval was 12 seconds, and the participant had to accomplish two acceptable maneuvers with two minutes of rest between each maneuver. A valid test result contains a minimum of two similar

Figure 3 – Photos showing participant performing acceptable MVV maneuver. Participants gave their written consent to be photographed during maneuvers.

MVV curves. Two acceptable maneuvers were valid when the variance between the highest and the second highest maneuver was within a 20% difference (MVV L/min) (Miller et al., 2005).

Aerobic fitness test

The aerobic fitness test was specified by a standardized treadmill protocol (Balke & Ware, 1959) with progressive stages and with the intent of reaching VO_{2peak}.

The protocol was executed by walking on an incremental treadmill, starting at 3,8km/t and a 4% incline. Participants got thorough instructions before starting the protocol and were told to walk to maximum volitional exertion. A Hans Rudolph mask (7450 Series V2, Hans Rudolph, inc, Kansas, USA) was fitted, checked for leaks, and used for measuring oxygen with an oxygen analyzer (Jaeger Vyntus CPX, Germany, SentrySuite). Additionally, a polar pulse belt (Polar H9) was fitted around the participant's chest to register heart rate during the test. The protocol started with a 5-minute self-paced warm-up. The oxygen analyzer was calibrated prior to each test (volume and gas calibration). Humidity and temperature were performed with an average room temperature of 18-24 ° C and relative normal humidity (30-60%). The trial began with a 4-minute adoption period to see if pulse and oxygen levels were working correctly, and a baseline lactate sample was acquired. The stage incline was increased by 3% after each interval until the lactate exceeded 2,1 mmol/L over baseline (Dickhuth et al., 1999). Every stage was four-minute, with a rest period of one minute on each stage. A timer (Hanhart 1882, Prisma 200, interval up x down timer, Germany) was used to keep track of each interval and reset after every rest period. VO2, heart rate, and flow volume loop were measured during each interval. Lactate was measured by acquiring a blood sample from the participant's finger during the rest period (Accu-check, safe-t-pro plus, Roche,

Mannheim Germany) and then analyzed using a lactate analyzer (EFF diagnostics, Biosen C-line). Borg RPE scale was registered after each stage (Borg, 1970).

The protocol switched to one-minute stages when lactate levels exceeded the threshold (2.1 mmol/L). Thereafter heart rate was registered every minute, the incline was increased by 2% to a maximum of 20%, and then speed was increased by 0,5 km/t per minute until absolute fatigue (participant reaches self-perceived absolute exertion, specified as Borg $\geq$17). The test leader made sure to motivate and help the participants reach maximum voluntary exertion. After completion, the participants were asked about the Borg RPE scale, and the last lactate sample was acquired one minute after test completion. A test is valid if the participant specified $\geq$17 Borg or reaches a respiratory exchange ratio (RER) $\geq$1.10. VO_{2peak} was the average of the two highest measurements recorded over 30 seconds.

Figure 4 – Photos showing participants the aerobic fitness test and the lactate sample after completion of the test. Participants gave their written consent to be photographed during maneuvers.

Statistical analysis

All statistical analyses were conducted using IBM SPSS statistics for Macintosh, version 28.0 (IBM Corp Armonk, NY). Tables and figures were made using Microsoft Word for Mac version 16.77 (MS, Redmond, WA, USA), GraphPad Prism version 9.5.1 for Mac (GraphPad Software, San Diego, California, USA), and Microsoft Excel for Mac version 16.72 (MS, Redmond, WA, USA). The dataset was checked for non-normality by using the Shapiro-Wilk test and visual confirmation of histograms. All data were considered normally distributed and were presented as mean ± standard deviation (SD) or mean + 95% confidence interval (CI). Power analysis was evaluated by researching the smallest sample size an experiment needs, given the required significance level, effect size, and statistical power. Based on previous studies investigating the effectiveness of aerobic training programs in older adults (Bouaziz et al., 2020; Huang et al., 2016; Vigorito & Giallauria, 2014), we needed ≥20 participants in each group to detect a 10% (SD 9) group difference in VO_{2peak}, with 80% power and an α-level at 5%. Within-group comparisons were conducted using a paired sample t-test (All and within sexes), and comparisons between the intervention and control groups were performed using an independent sample t-test (All and within sexes). All test was two-tailed, with a selected statistical significance p-level of .05.

Results

Participant characteristics

The main baseline characteristics of all participants in the study, including values for the VO_{2peak}, end criteria aerobic fitness measurements (RER, lactate, and Borg RPE scale), and lung function measurements (MVV, FVC, and FEV1), are presented in Table 1. There were no significant differences between the intervention (IG) and control group (CG) at baseline,

except for FEV1 values between IG and CG (2.51±0.61 versus 2.74±0.63, $p \leq .05$) and FVC and FEV1 in the CG women group compared to the IG women group at baseline (3.13±0.61 versus 2.79±0.55, $p \leq .05$ and 2.47 ± 0.49 versus 2.2 ± 0.44, $p \leq .05$).

Within-group pre- to post changes

VO_{2peak} within-group changes (IG)

A home-based HIIT program significantly increased VO_{2peak} (ml/kg/min) within the IG group after a six-month intervention period (6.22±7.84%, $p \leq .001$) (Figure 1) (Table 3). There were no significant differences in end criteria measurements (Borg RPE scale or RER) from pre- to post-intervention within the group, except for a significant decrease in lactate (-5.05±17.6%, $p \leq .05$) (Table 3). Comparison within sexes showed a significant increase in VO_{2peak} in both the IG men (5.04%±9.6%, $p \leq .05$) and in the IG women (7.05±6.38%, $p \leq .001$) from pre- to post-intervention (Figure 1) (Table 2). There were no significant differences in end criteria measurements (Borg RPE scale, RER, and lactate) from pre- to post-intervention within IG men or IG women, except for a decrease in lactate in the IG women (-6.96±16.8%, $p \leq .05$) (Table 2).

Lung function measurements within-group changes (IG)

A six-month home-based HIIT program significantly increased MVV within the intervention group from the pre- to post-intervention (2.92±8.43%, $p \leq .05$) (Figure 2) (Table 3). There were no significant differences in FVC or FEV1 from pre- to post-intervention within the IG group (Figure 3) (Table 2). There were no significant differences in MVV, FVC, or FEV1 from pre- to post-intervention in either the IG men or the IG women within the IG, except for

a significant increase in MVV in the IG men (4.73±8.07%, p≤.05 (Figure 2 and Figure 3) (Table 2).

VO_{2peak} within-group changes (CG)

There was no significant difference in VO_{2peak} from pre- to post-intervention in the CG (Table 3) (Figure 1). There were no significant changes in end criteria measurements (Borg RPE scale, RER, and lactate) except for a decrease in RER (-1.86±5.16%, p≤.05) and lactate (-6.73±14.45%, p≤.001) from baseline within in the CG (Table 3). There was no significant difference in VO_{2peak} from pre- to post-intervention in either the CG men or the CG women (Table 2) (Figure 1). There were no significant changes in end criteria measurements (Borg RPE scale, RER, and lactate) from pre- to post-intervention, except for a significant decrease in RER in the CG women (-2.25±5.35%, p≤.05) and a significant decrease in lactate in both the CG men (-8.3±12.98%, p≤.05) and the CG women (5.66±15.44%, p≤.05) (Table 2).

Lung function measurements within-group changes (CG)

There were no significant differences in lung function measurements (MVV, FVC, and FEV1) within the CG from pre- to post-intervention, except for a significant decrease in FEV1 (2.38±7.86%, p≤.05) (Table 3) (Figure 3). There were no significant differences in lung function measurements (MVV, FVC, and FEV1) from pre- to post-intervention within the CG men or the CG women (Figure 2 and Figure 3) (Table 2).

Between-groups pre- to post changes

VO_{2peak} between-group changes (IG versus CG)

The IG group significantly increased VO_{2peak} compared to the CG group pre- to post-intervention (6.22±7.84% versus -1.29±7.07%, $p \leq .001$) (Table 3) (Figure 1). There were no differences in end criteria measurements (Borg RPE scale, RER, and lactate) between the groups from pre- to post-intervention (Table 3). Comparison within sexes showed that the IG men significantly increased VO_{2peak} compared to the CG men (5.03±9.6% versus -1.03±7.95%, $p \leq .05$). The IG women also had a significant increase in VO_{2peak} compared to the CG women (7.05±6.38% versus -1.46±6.51%, $p < .001$) from pre- to post-intervention. There were no differences within the sex (IG men versus CG men and IG women versus CG women) in end criteria measurements pre- to postintervention (Borg RPE scale, RER, and lactate) (Table 2).

Lung function measurements between-group changes (IG versus CG)

There were no significant differences between IG and CG in lung function measurements (MVV, FVC, and FEV1) after a six-month intervention period (Figure 2 and Figure 3) (Table 3). Comparison within sex showed no significant difference in the lung function measurements between the IG men versus the CG men and the IG women versus the CG women after completing the intervention (Figure 2 and Figure 3) (Table 2).

Table 1 Descriptive statistics at baseline for IG and CG, including main characteristics, aerobic fitness measurements, Borg RPE scale, and lung function measurements.

		IG			CG		
		All (n = 73)	Men (n = 33)	Women (n = 40)	All (n = 66)	Men (n = 26)	Women (n = 40)
Characteristics	***Age (years)***	68.88 ± 6.3	70.06 ± 6.8	67.9 ± 5.7	68.08 ± 5	67.96 ± 4.5	68.15 ± 5.3
	Height (cm)	172.12 ± 9.3	179.39 ± 7.6	166.13 ± 5.7	171.59 ± 9.7	180.31 ± 8.1	165.93 ± 5.7
	Weight (kg)	81.48 ± 13.3	86.96 ± 13.8	76.97 ± 11.2	79.37 ± 13.3	88.13 ± 12.1	73.68 ± 10.8
Aerobic fitness measurements	VO_{2peak} ***(ml/kg/min)***	27.52 ± 5.3	30.21 ± 5.2	25.31 ± 4.3	28.09 ± 5.2	31.26 ± 5.21	26.03 ± 4.2
	RER VCO_2/VO_2	1.11 ± 0.06	1.12 ± 0.58	1.10 ± 0.07	1.10 ± 0.73	1.12 ± 0.07	1.10 ± 0.73
	Lactate (mmol/L)	8.25 ± 2.15	8.54 ± 2.23	8.01 ± 2.07	7.74 ± 2.02	8.41 ± 2.21	7.30 ± 1.78
Perceived exertion	***Borg RPE (6-20)***	18.81 ± 0.98	18.82 ± 1.04	18.8 ± 0.039	18.88 ± 1.06	18.96 ± 0.91	18.83 ± 1.15
Lung function measurements	***MVV (L/min)***	110.06 ± 30.6	131.97 ± 25.7	91.98 ± 21.04	110.24 ± 34.1	137.43 ± 31.7	92.57 ± 21.9
	FVC (Liters)	3.31 ± 0.88	4.1 ± 0.67	2.79 ± 0.55	3.54 ± 0.84	4.15 ± 0.76	3.13 ± 0.61*
	FEV1 (Liters)	2.51 ± 0.61	2.99 ± 0.53	2.2 ± 0.44	2.74 ± 0.63*	3.15 ± 0.6	2.47 ± 0.49*

Values are presented as mean with standard deviation. *$p \leq .05$ for significant difference between groups (IG versus CG) at baseline.

Table 2 Changes from pre- to post-intervention in the Aerobic fitness measurements, lung function measurements, Borg RPE scale and bodyweight in the IG men and IG women and CG men and CG women.

	IG						CG					
	Men			Women			Men			Women		
	Pre (n=23)	Post (n=23)	Change	Pre (n=33)	Post (n=33)	Change	Pre (n=25)	Post (n=25)	Change	Pre (n=37)	Post (n=37)	Change
VO_{2peak} (mL/kg/min)	30.62 (28.33; 32.92)	32.05 (29.7; 34.39)	1.42 (0.31; 2.52) #*	25.43 (23.78; 27.09)	27.15 (25.42; 28.88)	1.75 (1.2; 2.2) #*	31.11 (28.93; 33.28)	30.7 (28.42; 33.13)	-0.33 (-1.35; 0.68)	25.73 (24.3; 27.1)	25.34 (23.94; 26.73)	-0.39 (-0.93; 0.15)
RER **VCO_2/VO_2**	1.12 (1.09; 1.14)	1.11 (1.07; 1.14)	-0.01 (-0.03; 0.015)	1.1 (1.07; 1.13)	1.09 (1.06; 1.11)	-0.01 (-0.03; 0.005)	1.12 (1.09; 1.15)	1.1 (1.07; 1.13)	-0.01 (-0.03; 0.006)	1.09 (1.07; 1.12)	1.07 (1.05; 1.09)	-0.02 (-0.04; -0.007) #
Lactate (mmol/L)	8.7 (7.76; 9.64)	8.49 (7.38; 9.59)	-0.21 (-0.81; 0.39)	8.1 (7.39; 8.81)	7.44 (6.77; 8.12)	-0.65 (-1.11; -0.19) #	8.4 (7.46; 9.33)	7.7 (6.79; 8.62)	-0.69 (-1.1; -0.28)#	7.34 (6.74; 7.94)	6.91 (6.27; 7.55)	-0.43 (-0.77; -0.08) #
Borg RPE **(6-20)**	18.69 (18.27; 19.12)	18.95 (18.6; 19.31)	0.26 (-0.23: 0.75)	18.87 (18.57; 19.18)	19.15 (18.83; 19.47)	1.008 (-0.08; 0.63)	18.96 (18.57; 19.35)	18.84 (18.43; 19.25)	-0.12 (-0.46; 0.22)	18.78 (18.4; 19.22)	18.89 (18.56; 19.22)	0.108 (-0.25; 0.46)
MVV (L/min)	132.36 (122.83; 141.11)	138.04 (127.5; 148.5)	5.67 (1.26; 10.09) #	92.23 (84.17; 100.29)	93.69 (85.15; 102.23)	1.46 (-1.2; 4.13)	136.3 (123.15; 150.26)	139.4 (124.3; 154.51)	3.1 (-0.43; 6.63)	93.06 (85.5; 100.57)	93.08 (84.2; 101.93)	0.02 (-3.41; 3.46)
FVC (Liters)	4.20 (3.9; 4.5)	4.21 (3.9; 4.5)	0.11 (-0.11; 0.14)	2.80 (2.6; 2.99)	2.8 (2.61; 3.01)	0.009 (-0.3; 0.05)	4.1 (3.75; 4.44)	4.02 (3.65; 4.39)	-0.1 (-0.21; 0.01)	3.1 (2.88; 3.31)	3.09 (2.88; 3.3)	-0.006 (-0.08; 0.07)
FEV1 (Liters)	3.02 (2.77; 3.27)	3.04 (2.79; 3.29)	0.02 (-0.05; 0.99)	2.22 (2.06; 2.38)	2.21 (2.04; 2.37)	-0.008 (-0.05; 0.3)	3.11 (2.84; 3.38)	3.06 (2.78; 3.33)	-0.06 (-0.13; 0.012)	2.45 (2.27; 2.62)	2.4 (2.2;2.57)	-0.04 (-0.12; 0.02)
Weight (kg)	88.03 (79.93; 90.93)	85.26 (82.07; 93.99)	-2.76 (-4.5; -1.02) #*	77.33 (73.37; 80.56)	76.18 (73.23; 81.43)	-1.14 (-2.04; 0.24) #*	87.82 (82.76; 92.88)	87.5 (82.26; 92.9)	-0.22 (-1.19; 0.73)	73.7 (70.1; 77.44)	73.8 (70.34; 77.4)	0.08 (-0.58; 0.76)

Values presented as mean with 95% CI. #p≤.05 for significant changes from pre- to post-intervention within groups (IG men, IG women, CG men, and CG women). *p≤.05 for significant change between groups from pre- to post-intervention (IG men versus CG men and IG women versus CG women).

Table 3 Changes from pre- to post-intervention in Aerobic fitness measurements, lung function measurements, Borg RPE scale and body weight in the intervention group and control group.

	Pre (n=56)	Post (n=56)	Change	Pre (n=62)	Post (n=62)	Change
VO_{2peak} (ml/kg/min)	27.56 (26.08; 29.05)	29,16 (27.66; 30.66)	1.59 (1.07; 2.11) #*	27.9 (26.79; 29.39)	27.53 (26.55; 29.24)	-0.36 (0.87; 0.13)
RER VCO_2/VO_2	1.11 (1.09; 1.13)	1.09 (1.07; 1.11)	-0.01 (-0.03; 0.002)	1.1 (1.08; 1.12)	1.08 (1.06; 1.1)	-0.02 (-0.03; -0.007) #
Lactate (mmol/L)	8.34 (7.79; 8.9)	7.87 (7.27; 8.47)	-0.47 (-0.83; -0.11) #	7.77 (7.25; 8.29)	7.23 (6.7; 7.75)	-0.53 (-0.79; -0.27) #
***Borg RPE* (6-20)**	18.8 (18.56; 19.05)	19.07 (18.84; 19.3)	0.26 (-0.14; 0.55)	18.85 (18.58; 19.13)	18.87 (18.62; 19.12)	0.016 (-0.23; 0.26)
MVV (L/min)	108.71 (100.57; 116.86)	111.91 (103.20; 120.62)	3.19 (0.81; 5.57) #	110.51 (101.86; 119.51)	111.77 (102.05; 121.49)	1.26 (-1.19; 3.72)
***FVC* (Liters)**	3.33 (3.08; 3.58)	3.34 (3.09; 3.60)	0.01 (-0.44; 0.06)	3.49 (3.27; 3.71)	3.44 (3.22; 3.67)	-0.04 (-0.1; 0.02)
***FEV1* (Liters)**	2.52 (2.35; 2.69)	2.53 (2.35; 2,70)	0.003 (-0.03; 0.04)	2.71 (2.54; 2.88)	2.65 (2.48; 2.82)	-0.05 (-0.1; -0.004) #
Weight (kg)	81.72 (78.11; 85.3)	79.91 (76.53; 83.29)	-1.81 (-2.69; -0.92) #*	79.44(76.05; 82.66)	79.40 (76.02; 82.84)	-0.03 (-0.58; 0.5)

Values presented as mean with 95% CI. *$p \leq .05$ for significant changes from pre- to post-intervention between groups (IG versus CG). # $p \leq .05$ for significant change within the group (IG and CG) from pre- to post-intervention.

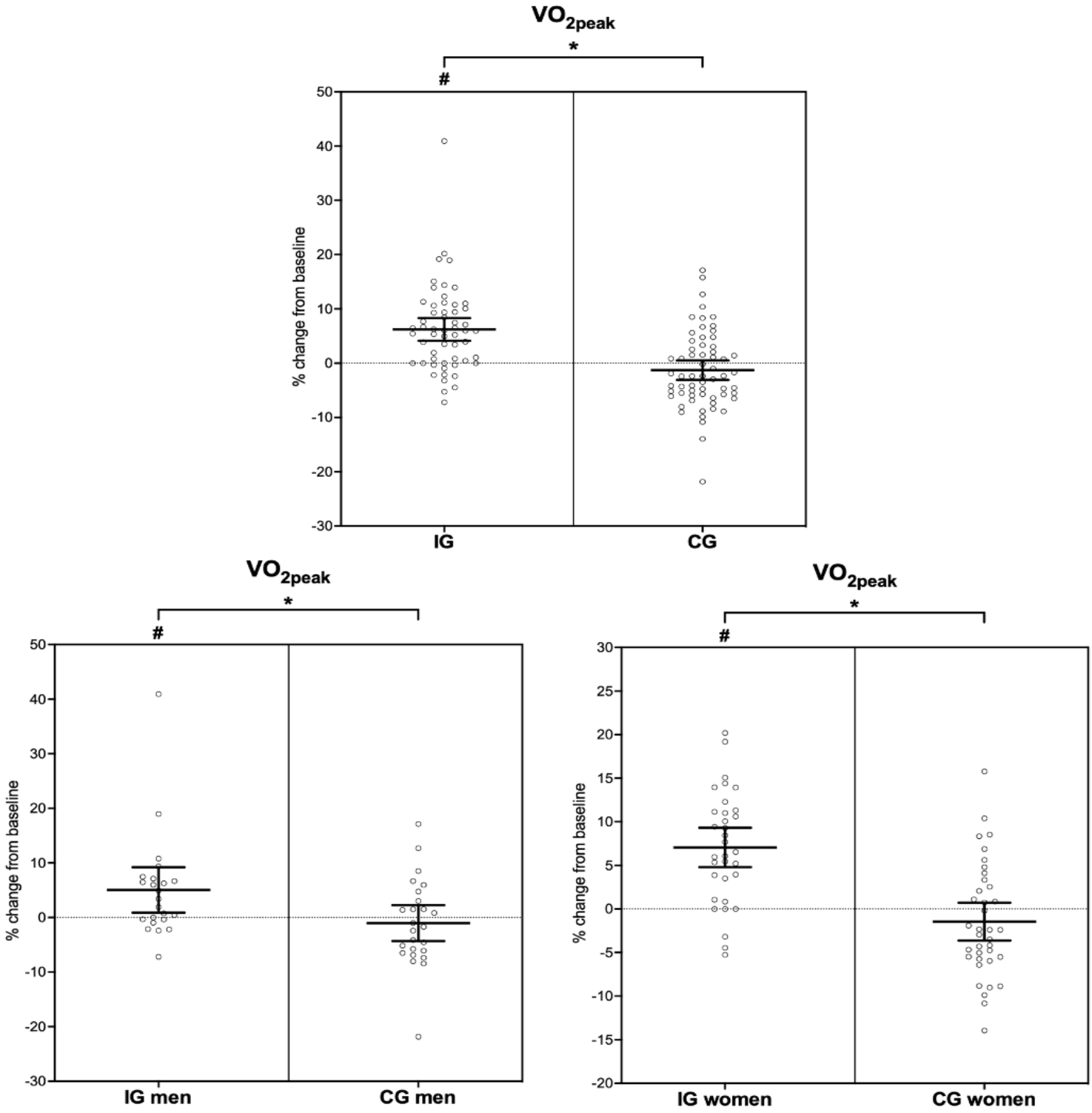

Figure 1*:* Percent change in VO_{2peak} (ml/kg/min) from pre- to post-intervention between the intervention group (IG) and the control group (CG), including comparison within sexes (IG men versus CG men and IG women versus CG women). Values are presented as mean and 95% CI. *p≤.05, significant change between groups from pre- to post-intervention. #p≤.05, significant change within groups from pre- to post-intervention.

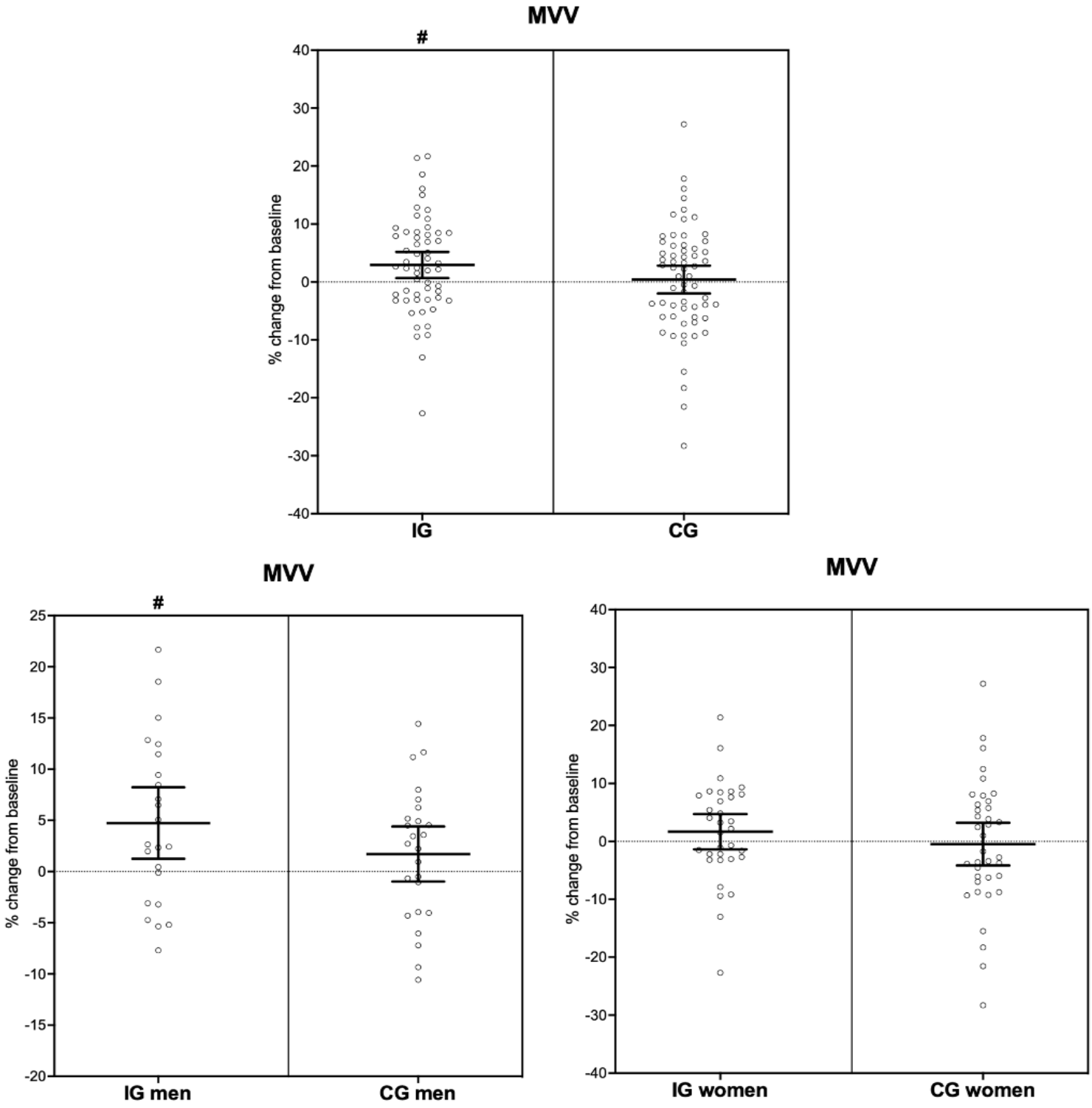

Figure 2*:* Percent change in MVV (L/min) from pre- to post-intervention between the intervention group (IG) and the control group (CG), including comparison within sexes (IG men versus CG men and IG women versus CG women). Values are presented as mean and 95% CI. *p≤.05, significant change between groups from pre- to post-intervention. #p≤.05, significant change within groups from pre- to post-intervention.

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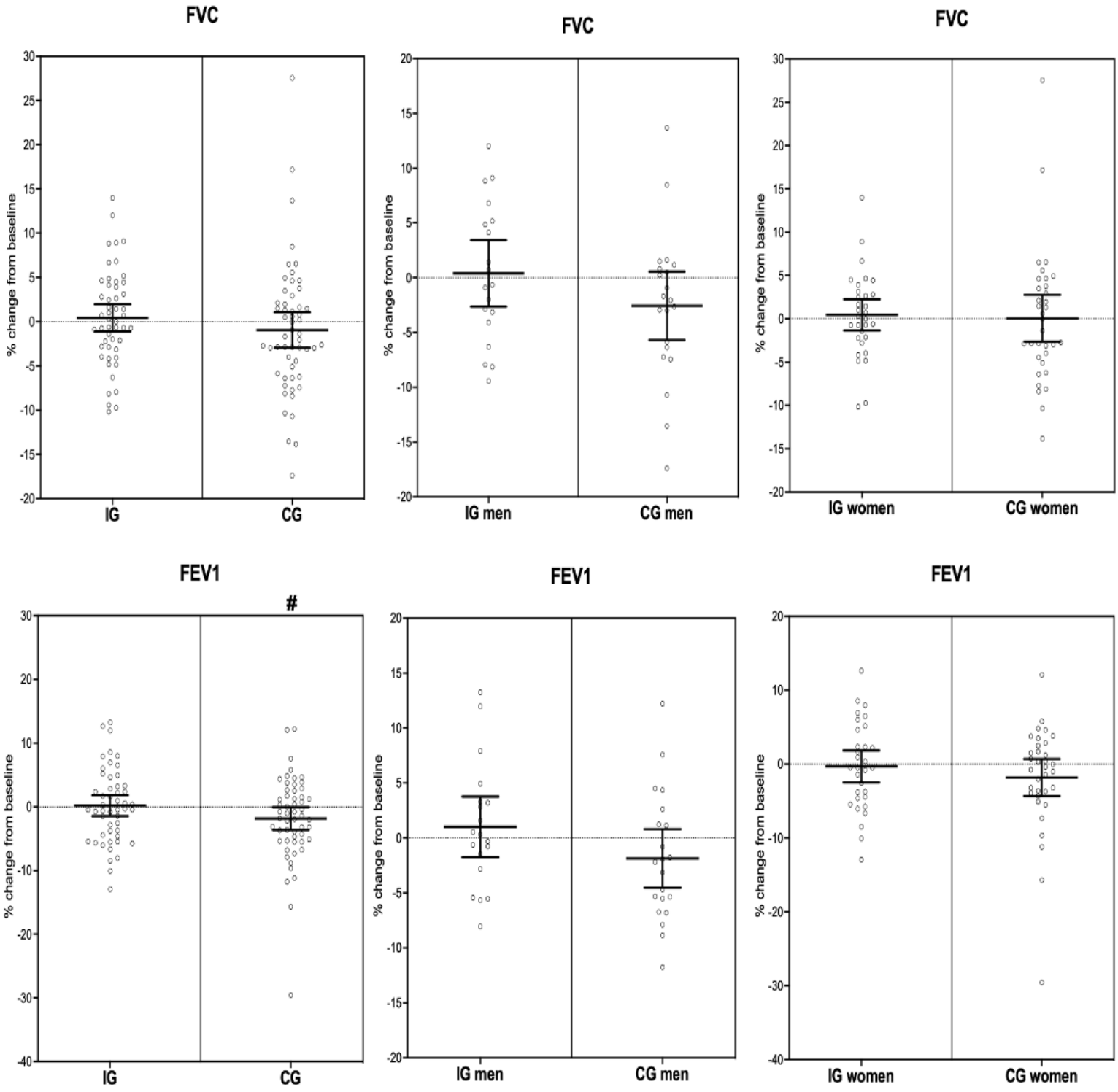

Figure 3: Percent change in FVC (Liter) and FEV1 (Liter) from pre- to post-intervention between the intervention group (IG) and the control group (CG), including comparison within sexes (IG men versus CG men and IG women versus CG women). Values are presented as mean and 95% CI. *p≤.05, significant change between groups from pre- to post-intervention. #p≤.05, significant change within groups from pre- to post-intervention.

1

Discussion

This current study aimed to experimentally test whether a home-based HIIT regimen could ameliorate cardiorespiratory fitness and lung function in healthy older adults. To the author's knowledge, there are few studies investigating home-based HIIT programs in older individuals outside of laboratory settings with a long-term intervention period (>12 weeks) (Gray et al., 2016; Keating et al., 2020; Vigorito & Giallauria, 2014).

The main findings of this present study showed a significant increase in VO_{2peak} within the intervention group from pre- to post-intervention. There was no difference in lung function measurements from pre- to post-intervention within the IG, except for a significant increase in MVV. Moreover, the IG significantly increased VO_{2peak} compared to the CG from pre- to post-intervention. There was no difference between the IG and the CG in lung function measurements from pre- to post-intervention. Additionally, sub-analysis showed a significant increase in VO_{2peak} within the IG men and the IG women from pre- to post-intervention. There were no differences in lung function measurements from pre- to post-intervention within the IG men or the IG women, except for a significant increase in MVV in the IG men. Moreover, a significant increase in VO_{2peak} was detected in the IG men compared to the CG men and the IG women compared to the CG women from pre- to post-intervention. No differences in lung function measurements were seen comparing the IG men and the CG men and the IG women and the CG women from pre- to post-intervention.

VO_{2peak} pre- to post changes

The intervention group significantly improved VO_{2peak} in aerobic fitness measurements from pre- to post-intervention following a six-month HIIT regime. In the current study, VO_{2peak} increased by 6.22±7.84% within the IG from pre- to post-intervention. Our data are comparable with previous research performed with similar HIIT regimes in healthy older

adults (55-79 years) (Hwang et al., 2016), cognitively healthy older adults (60-80 years) (Brown et al., 2021), older adults with metabolic syndrome (52.3±3.7 years) (Tjønna et al., 2008) and hypertensive older adults (52±7.8 years) (Molmen-Hansen et al., 2012). Moreover, a significant decrease in weight was detected within the IG from pre- to post-intervention in the present study and could potentially be a confounding factor for the increase in VO_{2peak} from pre- to post-intervention.

However, the resemblances between the abovementioned studies and the present study were the use of a HIIT regime compared to a passive control group and similarities in the age of the population (Brown et al., 2021; Hwang et al., 2016; Molmen-Hansen et al., 2012; Tjønna et al., 2008). Furthermore, the present study was different from the abovementioned studies regarding intervention type, participants, and sample sizes.

This present study had a higher number of participants in the HIIT group (n=73) compared to Hwang et al. (2016) (n=17), Brown et al. (2021) (n=33), Tjønna et al. (2008) (n=12), Molmen-Hansen et al. (2012) (n=31). According to the power analysis used for this present study, there was included more than 20 participants in each group to detect a 10% group difference in VO_{2peak} from pre- to post-intervention. Additionally, with the sample sizes in the current study, we were able to compare VO_{2peak} within sex in the IG and the CG and between the IG and the CG from pre- to post-intervention with >20 participants in all groups.

Additionally, the studies mentioned above did not use a home-based training regime and were conducted under direct supervision or in a laboratory-controlled fashion (Brown et al., 2021; Hwang et al., 2016; Molmen-Hansen et al., 2012; Tjønna et al., 2008). Moreover, the participants in Tjønna et al. (2008) and Molmen-Hansen et al. (2012) were not characterized as “healthy older adults” and could potentially be a limiting factor when comparing the results from the different studies.

Furthermore, the abovementioned studies indicated a larger increase in VO_{2peak} (>10% ml/kg/min) after a similar or shorter-term HIIT regime than in this present study (Brown et al., 2021; Hwang et al., 2016; Molmen-Hansen et al., 2012; Tjønna et al., 2008). However, it was difficult to state why there was a lower increase in VO_{2peak} in the present study, despite a long-term intervention period. The differences in the abovementioned studies regarding participant characteristics, training regimes, and sample sizes could explain the variances in increased VO_{2peak} from pre- to post-intervention (Brown et al., 2021; Hwang et al., 2016; Molmen-Hansen et al., 2012; Tjønna et al., 2008).

In addition, Williams et al. (2019) evaluated the trainability of VO_{2peak}, comparing interval training to moderate continuous training. Although HIIT seems more effective in influencing VO_{2peak}, the study implies a possibility for a difference in "responders" and "non-responders," with participants following the same exercise intervention (Williams et al., 2019). Despite the fact that a long-term intervention period with high loads of overall training should likely have more responders, it all depends on the total training load accumulated by each participant (Williams et al., 2019). Results from the present study showed a large spread in VO_{2peak} from pre- to post-intervention within the IG. Within the IG, 25% of the participants were unable to enhance their VO_{2peak} ($\leq$0 change ml/kg/min), and some had a decrease in VO_{2peak} from pre- to post-intervention and may be described as non-responders (Williams et al., 2019)

There could be various reasons for the spread in VO_{2peak} changes from pre- to post-intervention. As the participants had little experience with testing and adherence to a HIIT program, misperceptions of the aerobic fitness test and HIIT regime could be confounding factors in this study. The aerobic fitness measurements might have been affected by participants who did not reach maximal exertion due to fear of overexertion, low motivation, dyspnea, or muscle fatigue (Huggett et al., 2005). However, strict end criteria measurements

(RER, lactate, and Borg RPE scale) were utilized for each test to evaluate maximal exertion in the aerobic fitness test. Participants were well over the end criteria requirements recommended by Edvardsen et al. (2014) for older men and women to determine maximal exertion in VO_{2peak} tests.

Another limitation could appear due to the challenge of controlling the intensity, duration, and frequency of the participant's home-based HIIT sessions with limited supervision. As the participants were older adults, a concern could emerge due to the motivation and whether they were able to maintain the intended exercise intensity, duration, and frequency throughout the intervention period, even if they didn't feel an immediate physical benefit (Ory et al., 2006). However, participants were instructed to use the heart rate monitor and logbook for every session to register intensity, duration, and frequency. With the information from the heart rate monitor and logbook, we were able to give the participants feedback and motivation in frequent follow-up meetings on how to proceed in the program with the correct intensity and duration. Due to the submission deadline of this master's thesis, the data from the heart rate monitor and logbook were not completed and will not be presented.

Furthermore, Aamot et al. (2013) investigated the difference between home-based HIIT versus controlled hospital-based HIIT (treadmill group) in cardiac rehabilitation patients (57±8 years, 12 weeks). Similar to the current study, Aamot et al. (2013) used a heart rate monitor to objectively measure heart rate for each session within the home-based training group to reach the target HR. The study results showed a considerable difference in VO_{2peak} change in a controlled HIIT treadmill group compared to a home-based HIIT group (4.3±1.8 versus 2.8±2.9 ml/kg/min) with a 12-week HIIT intervention period (Aamot et al., 2013). Demonstrating a potential weakness when older individuals are supposed to conduct a HIIT training regime (>80% of HR_{peak}) under limited supervision. Although the VO_{2peak} values in

the present study and the home-based group in Aamot et al. (2013) substantially increased after a period with HIIT (1.59±1.95 and 2.8±2.9 ml/kg/min).

Nevertheless, maintaining or increasing VO_{2peak} with older age is associated with a lower risk of traditional cardiovascular diseases and health benefits (Bangsbo et al., 2019; Hamer et al., 2014; Letnes et al., 2020; Stensvold et al., 2015). The intervention group increased their VO_{2peak} compared to the control group after a six-month intervention period (6.22±7.84% versus -1.29±7.07%). Moreover, Letnes et al. (2020) investigated the age-related changes in VO_{2peak} and cardiovascular risk factors. The study implies a progressive decline in VO_{2peak} with age, but performing physical activity in leisure time slows the decline (Letnes et al., 2020). Higher-intensity training was suggested as a more favorable stimulus than lower-intensity training for maintaining or improving VO_{2peak} with older age (Letnes et al., 2020). However, HIIT has been demonstrated as a feasible method to enhance CRF, but as previously stated, the lack of "real-world effectiveness studies" could be a possible limitation in previous research investigating HIIT interventions (Biddle & Batterham, 2015; Gray et al., 2016).

The present study was comparable to the research of Reitlo et al. (2018), investigating older adults and the challenge of adhering to an extensive training regime with older age. The use of a long-term intervention period showed that even older individuals were able to maintain frequent HIIT sessions ($\geq$2 sessions per week) over a one-year period without strict supervision (Reitlo et al., 2018). Furthermore, the present study was similar to Reitlo et al. (2018) and shows the possibility of home-based HIIT programs for maintaining or increasing CRF in older age. Therefore, home-based HIIT programs may be a more feasible and time-efficient method for maintaining or potentially increasing CRF in older adults.

Lung function measurements pre- to post changes

Following a six-month home-based HIIT intervention, no differences in lung function measurements were detected within the IG, except for a significant increase in MVV within the IG and within the IG men from pre- to post-intervention. No difference in lung function measurements was seen between the IG and the CG from pre- to post-intervention. The results could relate to the study by McClaran et al. (1995), where the longitudinal effects of aging on lung function were evaluated among active older adults (67-73 years). The study implies that impaired lung function with increasing age does not seem to respond to exercise (McClaran et al., 1995). Further, a progressive decline in FVC, FEV1, and MVV was detected after a six-year period (McClaran et al., 1995).

Moreover, there are few studies regarding the effect of HIIT on lung function in a healthy older population. Studies that investigate the effect of HIIT on lung function in older adults have mainly comprised populations with health problems, such as chronic obstructive pulmonary disease (COPD) (Gao et al., 2022; Sawyer et al., 2020). A systematic review by Gao et al. (2022) summarizes the main outcomes of HIIT in older patients (62-74 years) with COPD on lung function measurements (FVC and FEV1). The study concludes that HIIT may be a sufficient way to rehabilitate and enhance lung function, exercise capacity, and quality of life in patients with COPD (Gao et al., 2022).

In addition, the effect of HIIT on lung function has also been investigated in younger populations. A study by Dunham and Harms (2012) investigated the effect of HIIT on lung function in healthy younger individuals (21.75±2.2 years). The findings from the study suggest that HIIT may enhance inspiratory muscle strength and could potentially reduce limitations in lung function on exercise performance (Dunham & Harms, 2012).

Moreover, the results from the abovementioned studies are not comparable to the current study due to the sample characteristics (younger individuals and older patients with

COPD). Speculative, there may be a reason to believe that few studies regarding the effect of HIIT on lung function in a healthy older population have been conducted due to the known age-related decline in lung function with advancing age.

Strengths and limitations of the study

The main strength of this current study was the use of an extensive intervention period and considerable population size compared to other similar research regarding HIIT in older adults (Ramos et al., 2015; Wu et al., 2021). In addition, further strengths of the present study are the representative population regarding baseline physical activity levels (Ramos et al., 2015; Vigorito & Giallauria, 2014), strict monitoring of training volume in the intervention group (intensity, duration, and frequency), frequent follow-up meetings to maintain the participant's motivation, direct measurements of VO_{2peak} performed to maximal exertion on an incremental treadmill (with strict end criteria requirements) and a home-based training intervention with low cost, was easily accessible, with pre-recorded exercises videos, written exercise instructions and were safe to use for older men and women. Additionally, the data from the logbook and HR monitor for each session would strengthen this present study. Nevertheless, as stated above, due to the submission deadline of this master's thesis, the data were not presented.

However, some limitations need to be addressed. Although the home-based intervention is presented as a strength, it can also be a limiting factor in the present study. There is often lower feasibility in home-based interventions. Meaning that it was difficult to determine whether the participants reached the intended stimuli (duration, intensity, and frequency) for each session with limited supervision. Moreover, the participants used a logbook and HR monitor for each session and were given feedback in the follow-up meetings

to minimize these possible limitations. The lack of these data regarding the frequency, duration, and intensity of the home-based HIIT sessions was a limitation in this current study.

Furthermore, a potential "selection bias" could be a limiting factor as the current study is part of a more extensive study, which only included participants with basic English skills. The inclusion criteria may contribute to a population with more highly educated subjects.

Conclusions

In conclusion, the current study revealed that a six-month home-based HIIT program could significantly increase CRF in healthy older adults. The intervention group significantly increased their VO_{2peak} compared to the passive control group. However, the intervention group did not improve lung function with a period of HIIT, and an age-related decrease in lung function may potentially impede the ability to enhance lung function in older men and women.

The main findings of the current study partially confirm my initial hypothesis: A home-based HIIT program could ameliorate CRF (VO_{2peak}) in older adults from 60-85 years. However, HIIT had no effect on lung function in older adults from pre- to post-intervention. Finally, older men and women were capable of enhancing their CRF with a home-based HIIT regime. Therefore, it may be a reason to believe that a home-based HIIT program could be a sufficient way to improve CRF in older adults.

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Appendix

Appendix 1

Information about the study:

Institutt for fremmedspråk og oversetting
Institutt for idrettsvitenskap og kroppsøving

DELTAKER INFORMASJON

Fysisk form, aldring og tospråklighet (FAB): Fordeler med regelmessig fysisk aktivitet for språkferdigheter ved sunn aldring
Vi vil invitere deg til å delta i en forskningsstudie ved Universitet i Agder. Før du bestemmer deg for om du vil delta, er det viktig at du forstår hvorfor forskningen utføres og hva den vil innebære. Ta deg tid til å lese nøye gjennom følgende informasjon og diskuter den gjerne med andre hvis du ønsker det. Spør forskerne hvis noe er uklart eller hvis du ønsker mer informasjon. Ta deg god tid med å bestemme om du ønsker å delta eller ikke.

Vi ser etter personer som har norsk som morsmål, men som også snakker engelsk, til å delta i en studie som undersøker forholdene mellom fysisk form og språk i aldring.

Hva er formålet med studien?
Når vi blir eldre, endres måten vi behandler informasjon på. I denne studien, som gjennomføres i Kristiansand, undersøker vi hvordan kognitive språkprosesser påvirkes av alder og tospråklighet, og om disse to faktorene er knyttet til fysisk form. Vi skal derfor teste språklige og kognitive ferdigheter hos en gruppe yngre og en gruppe eldre tospråklige voksne. Etterpå skal den eldre gruppen deles i to, i en aktiv gruppe og en kontrollgruppe. Den aktive gruppen skal delta i en treningsintervensjon (utholdenhetstrening). Etter treningsperioden skal vi teste språklige, kognitive og fysiske (fysisk form, lungefunksjon og fysisk funksjon) ferdigheter hos begge gruppene igjen, for å undersøke om fysisk trening har en effekt. For å teste effekten av å være tospråklig skal det utføres en lignende studie i Storbritannia på engelsktalende enspråklige voksne.

Hvorfor har jeg blitt invitert?
For å være kvalifisert til å delta må du ha norsk som morsmål og ikke snakke andre språk hjemme (bortsett fra engelsk). Du bør ha rimelige ferdigheter i engelsk som andrespråk. Dette betyr at du kan lese og forstå den engelske informasjonen på nettsiden vår (www.fab-study.com) og at du kan føre en samtale på engelsk (selv om du kanskje snakker litt feil). Du må ha syn og hørsel som er normalt eller tilnærmet normalt, og du kan ikke ha noen diagnoser som innebærer kognitiv svikt eller språkforstyrrelser som dysleksi eller stamming.

Du kan delta hvis du er mellom 18 og 35 år (yngre aldersgruppe) eller mellom 60 og 85 år(eldre aldersgruppe). Vi er interessert i å måle effekten av økt fysisk aktivitet hos eldre voksne. Er du i den eldre aldersgruppen (60–85 år), bør du derfor ikke ha mer enn totalt 150 minutter med moderat fysisk aktivitet per uke, og du bør generelt ha god helse.

Det vil være en del fysiske møtetidspunkter i Kristiansand, som du må ha mulighet til å møte opp på.

Hva blir jeg bedt om å gjøre?

A. Screening

Under det første besøket vil alle deltakerne først bli bedt om å signere et samtykkeskjema, slik at vi kan være sikre på at du ønsker å være med på forskningsprosjektet. Deretter blir du bedt om å fylle ut flere spørreskjemaer og tester: et språkprofilskjema, et generelt spørreskjema om helse og et spørreskjema om fysisk aktivitetsnivå.

Vi vil også be om legeattest fra våre **eldre deltakere**. Disse screeningmålingene gjør det mulig for oss å avgjøre om det er trygt for deg å delta i resten av studien. Eksklusjonskriterier for eldre i studien vår er: hjertesykdom, høyt blodtrykk, diabetes eller annen metabolsk sykdom, astma eller luftveissykdom, anemi, nåværende røyking, influensa den siste måneden, nevrologiske sykdommer som hindrer frivillige bevegelser. Du bør heller ikke allerede delta i spesifikke utholdenhetstreningsprogrammer eller studier.

B. Hovedstudie og treningsprogram

Hvis du oppfyller kriteriene våre, vil vi invitere deg til å delta i hovedstudien. Hovedstudien består av flere testdager, som vi kan planlegge når det passer deg. I disse øktene blir du bedt om å gjøre noen oppgaver på datamaskin. For eksempel vil vi be deg om å lytte til setninger for å finne bestemte ord, eller vi vil vise deg bilder av gjenstander og be deg om å navngi objektene. Du skal gjøre disse oppgavene på både norsk og engelsk. Disse oppgavene tar inntil tre timer totalt å gjennomføre for den yngre aldersgruppen, som kun skal gjøre oppgavene en gang.

Eldre deltakere vil også bli invitert til å fullføre en treningstest for å bestemme din nåværende aerobe kapasitet (dvs. VO2max). Dette er en progressiv treningstest, som gjennomføres gående på en tredemølle der skråningen på tredemøllen økes trinnvis (f.eks. hvert 4. minutt) til du ikke kan fortsette. Data om pustefunksjon og hjerterytme registreres, og i tillegg tas det en blodprøve i fingeren for å måle laktatkonsentrasjon i blodet.

Treningstesten skal ikke vare i mer enn 30 minutter, inkludert en aktiv nedtrappingsperiode. Før du gjennomfører denne testen, ber vi deg om å unngå tung fysisk trening og alkohol i 24 timer. Du vil også bli bedt om å ikke spise mat inntil 2 timer før testen begynner. I tillegg til denne kondisjonstesten vil vi gjerne at du skal gjennomføre flere tester som involverer fysisk funksjon. Dette kan for eksempel være test av håndstyrke, test av å reise seg og gå, test av å sitte og stå samt en balansetest og en test av fleksibiliteten i leddene. Disse testene viser oss hvordan treningsintervensjonen kan ha forbedret den generelle fysiske funksjonen din.

For eldre voksne vil det ta ca. 8 timer å fylle ut alle spørreskjemaer og gjennomføre datatester og kondisjonstest, fordelt på minst fire dager – både før og etter et seks måneders fysisk treningsprogram. Halvparten av de eldre voksne tilordnes tilfeldig til det fysiske treningsprogrammet (aktiv gruppe), mens den andre halvparten vil bli bedt om ikke å endre sitt vanlige aktivitetsmønster i samme seksmånedersperiode (kontrollgruppen).

Det seks måneder lange treningsprogrammet har fokus på aerob utholdenhetstrening som består av et opplegg som du utfører hjemme. Vi gir deg treningsøkter på nettet som du kan gjennomføre hjemme eller utendørs. Du vil bli bedt om å gjennomføre minst 3 økter per uke, og vi gir deg en pulsklokke og en aktivitetsklokke for å registrere både treningsøkter og generell fysisk aktivitet i løpet av denne seksmånedersperioden. En gang i måneden vil du møte testansvarlig som laster ned data fra pulsklokken. Hver treningsøkt registreres med

pulsklokken. Både før prosjektstart, midt i prosjektet og etter at prosjektet er slutt, skal det generelle fysiske aktivitetsnivået måles med en aktivitetsklokke.

Hvis du tilordnes til kontrollgruppen, gir vi deg en aktivitetsmåler slik at du kan overvåke det normale aktivitetsnivået ditt. Du vil derimot måtte vente med å få pulsklokken og tilgang til treningsøktene på nett. Dette vil du få utdelt etter at din seks måneder lange deltakelse i prosjektet er over.

Hvis du bestemmer deg for at du vil delta i denne studien, skal vi gå nærmere gjennom det som skal skje og du får mulighet til å stille spørsmål. Vi oppfordrer deg til å stille spørsmål både før og underveis.

Må jeg delta, og kan jeg trekke tilbake samtykke?
Det er frivillig å delta i prosjektet. Hvis du ønsker å delta, må du signere samtykkeerklæringen på siste side. Du kan trekke deg når som helst og uten grunn. Hvis du ønsker å trekke deg fra prosjektet, kan du også kreve at testene dine og helserelaterte personopplysninger blir slettet, med mindre de helserelaterte personopplysningene og testene allerede har blitt analysert eller brukt i vitenskapelige publikasjoner. Hvis du på et senere tidspunkt ønsker å trekke tilbake samtykke eller har spørsmål angående prosjektet, kan du kontakte Dr. Eunice Fernandes (eunice.fernandes@uia.no) eller professor Linda Wheeldon (linda.r.wheeldon@uia.no).

Kan jeg delta konfidensielt?
Alle helserelaterte personopplysninger som er registrert om deg, vil bare bli brukt som beskrevet i formålet med prosjektet. Du har krav på å få tilgang til informasjon som er registrert om deg, og du har rett til å be om at eventuelle feil i den registrerte informasjonen blir korrigert. Du har også rett til å få vite hvilke sikkerhetstiltak som er/blir iverksatt når helserelaterte personopplysninger behandles.

All informasjon vil bli behandlet anonymt, uten bruk av verken navn, fødselsnummer eller annen informasjon som kan identifisere deg. En kode knytter sammen deg og de helserelaterte personopplysningene dine via en identifikasjonsliste. Kun forskere på UiA på prosjektet som står oppført nedenfor, har tilgang til denne listen. Informasjon om deg blir anonymisert eller slettet fem år etter at prosjektet er avsluttet. Anonymiserte data blir lagret i minst 10 år etter at studien er avsluttet.

Deling av data i utlandet
Ved å delta i studien samtykker du også til at anonymiserte data kan overføres til våre samarbeidspartnere ved University of Birmingham i Storbritannia som en del av forskningssamarbeidet og publiseringen. Storbritannia kan ha lover som ikke oppfyller kravene i den europeiske databeskyttelsesloven. Prosjektlederen vil derfor sørge for at dine helserelaterte personopplysninger oppbevares på en trygg måte. Koden som knytter sammen deg og de helserelaterte personopplysningene dine, vil ikke gis videre.

Får jeg kompensasjon for å delta?
Yngre deltakere som deltar på alle screeninger og tester vil få kompensasjon i form av et gavekort på 300 kr. Eldre deltakere i intervensjonsgruppen får kompensasjon i form av en hjertemonitor og elektroniske treningsressurser som er en del av intervensjonen. Eldre deltakere i kontrollgruppen får samme kompensasjon som intervensjonsgruppen, men etter at de har fullført andre fase av testingen (dvs. rett etter at du har fullført prosjektet). Hvis du

trekker deg før eksperimentet starter, får du ingen kompensasjon. Hvis du trekker deg under selve eksperimentet, vil kompensasjonen være basert på hvor lenge du har deltatt. Hvis du trekker deg etter at du har deltatt, får dette ingen innvirkning på kompensasjonen.

Hva er de mulige fordelene ved å delta?
Ditt bidrag kan gi oss mer kunnskap om kognitive evner og språkbehandlingsevner, og om forholdet mellom disse og det å være i fysisk form under aldring.

Hva er den potensielle risikoen ved å delta? Moderat eller kraftig trening medfører visse typer risiko. Vi mener det er viktig at du gjøres oppmerksom på disse, og hva vi gjør for å minimere dem:
• Følelse av tretthet og fysisk utmattelse – dette vil være kortvarig og avta i løpet av få minutter etter at treningen avsluttes.
• Besvimelse – ofte knyttet til fysisk utmattelse og ved plutselig stans i treningen, men dette kan reduseres med en nedtrappingsperiode umiddelbart etter at den formelle treningstesten er fullført, slik at du gradvis kommer tilbake til normal tilstand.
• Kardiovaskulære problemer (f.eks. hjerteinfarkt eller hjerteattakk) – det er liten risiko for dette, spesielt hos friske mennesker. Dessuten vil alle som er i risikogruppen, sannsynligvis vil bli ekskludert fra studien etter første screening. Vi vil også sørge for at du varmes opp og trapper ned på riktig måte i forbindelse med treningsøktene. En forsker eller trener med godkjent førstehjelpskurs vil alltid være til stede, og dersom det mot formodning skulle oppstå en medisinsk nødssituasjon, følger vi standardprotokoller for å sikre at det blir gitt nødvendig medisinsk hjelp umiddelbart. Medisinsk ekspertise er tilgjengelige på sykehuset. Institutt for idrettsvitenskap og kroppsøving ved Universitetet i Agder (der de fysiske kondisjonstestene foregår) ligger i nærheten av sykehuset.

Hva skjer med svarene jeg gir?
Resultatene kan gi publiserbar forskning som er av interesse for et bredere forskningsmiljø, og som kan føre til nye tilskuddssøknader og samarbeid. Dataene dine lagres anonymt. Du kan ikke identifiseres i noen rapporter eller publikasjoner.

Hvem organiserer forskningen?
Denne studien organiseres av Institutt for fremmedspråk og oversettelse og Institutt for idrettsvitenskap og kroppsøving ved Universitetet i Agder og har godkjenning fra den regionale komiteen for medisinsk og helsefaglig forskningsetikk (16.12.2020 ref: 163931) og Norsk senter for forskningsdata (referanse). I samsvar med EUs personvernforordning (GDPR) har behandlingsansvarlig [UiA] og prosjektleder [Linda Wheeldon] uavhengig av hverandre et ansvar for å sikre dine helserelaterte personopplysninger behandles på lovfestet grunnlag. NSD har vurdert at behandling av dine personopplysninger er i samsvar med EUs personvernforordning (GDPR), og vi behandler personopplysningene dine basert på ditt samtykke. Du har rett til å klage på behandlingen av dine helserelaterte personopplysninger til Datatilsynet.

Hva hvis noe går galt? Hvem kan jeg klage til?
Hvis du vil klage på behandlingen du har fått av et medlem av forskerteamet (se kontaktinformasjon nedenfor) eller på noe som har med studien å gjøre, kan du henvende deg til en av personene som er oppført nederst på denne siden. Skulle du mot formodning oppleve å bli skadet eller få skader på eiendeler som følge av at du deltar i denne studien, vil universitetet dekke skader som oppstår på grunn av feil i utformingen av studien.

Hvor kan jeg finne mer informasjon om studien?
Denne forskningen er finansiert av Norges forskningsråd og ledes av et team av akademikere ved Universitetet i Agder: Professor Linda Wheeldon (linda.r.wheeldon@uia.no), professor Allison Wetterlin (Allison.wetterlin@uia.no), Dr. Hilde Lohne- Seiler (hilde.l.seiler@uia.no), og professor Sveinung Berntsen Stølevik (sveinung.berntsen@uia.no), og ved University of Birmingham (Dr. Katrien Segaert: k.segaert@bham .ac.uk; Dr. Sam Lucas: (sjelucas@bham.ac.uk) og Dr. Foyzul Rahman (F.Rahman@bham.ac.uk). Studien ved UiA er drevet av postdoktor Eunice Fernandes (eunice.fernandes@uia.no) og PHD-student Sindre Fosstveit (sindre.fosstveit@uia.no). Ta kontakt med dem hvis du har spørsmål om studien. Du kan også ta kontakt med UiAs personvernombud (ina.danielsen@uia.no) hvis du har spørsmål om hvordan dine helserelaterte personopplysninger brukes i forskningsprosjektet.

Ta kontakt med et hvilket som helst medlem av teamet hvis du har spørsmål om studien.

Takk for at du leser dette informasjonsarket.

Appendix 2

Participant consent form

Fitness, Ageing and Bilingualism (FAB): The benefits of regular physical activity for language abilities in healthy ageing

Participant Identification Number for this study

ID#

1) I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.
2) I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason. I understand that I can withdraw my data at any time during the experiment and for the duration of one month after my completion of the study.
3) I understand that data collected during the study will be looked at by researchers from the University of Agder and the University of Birmingham. I give permission for these individuals to have access to my data. Upon completion of the study, the data may be placed on an appropriate repository for data-sharing and be accessed by researchers not affiliated with these Universities. I understand that all my data will be stored anonymously.
4) I agree that I can be contacted after the study regarding follow-up information and future studies.
5) I agree to take part in the study.

Name of Participant (BLOCK LETTERS)	Date	Signature
Name of Researcher (BLOCK LETTERS)	Date	Signature

Date Participant`s signature

Appendix 3

Consent forms from participants photographed during the Aerobic fitness test, MVV maneuver, and FVC maneuver

UiA Fakultet for helse- og idrettsvitenskap

Samtykkeerklæring

Jeg samtykker i at det tas bilder/video/lydopptak og at dette materialet kan brukes i forbindelse med masteroppgave i prosjektet Fitness, Ageing and Bilingualism.

Navn: Oddvar Espegren

ODDVAR ESPEGREN

UiA Fakultet for helse- og idrettsvitenskap

Samtykkeerklæring

Jeg samtykker i at det tas bilder/video/lydopptak og at dette materialet kan brukes i forbindelse med masteroppgave i prosjektet Fitness, Ageing and Bilingualism.

Navn: Kirsti R. Espegren

Appendix 4

Approval from The Norwegian Center for Research Data

Sent from Linda Wheeldon 26.03.2021

Behandlingen av personopplysninger er vurdert av NSD. Vurderingen er: BACKGROUND The Regional Committees for Medical and Health Research Ethics (REC) have evaluated and approved of the project in accordance with The Health Research Act (hfl.) § 10, on (16.12.2020), their reference 163931.

Our assessment is that the processing of personal data in this project will also comply with the data protection legislation, so long as it is carried out in accordance with what is documented in the Notification Form and attachments, dated 26.03.2021, as well as in correspondence with NSD. Everything is in place for the processing to begin. NOTIFY CHANGES If you intend to make changes to the processing of personal data in this project it may be necessary to notify NSD. This is done by updating the Notification Form. On our website we explain which changes must be notified. Wait until you receive an answer from us before you carry out the changes. TYPE OF DATA AND DURATION The project will be processing special categories of personal data about health, and general categories of personal data, until 31.12.2023. The will then be stored for 5 years (until 31.12.2028) for documentation requirements/conditons set by Regional comittees for medical and health Research ethics (REC). LEGAL BASIS The project will gain consent from data subjects to process their personal data. We find that consent will meet the necessary requirements under art. 4 (11) and 7, in that it will be a freely given, specific, informed and unambiguous statement or action, which will be documented and can be withdrawn. The legal basis for processing special categories of personal data is therefore explicit consent given by the data subject, cf. the General Data Protection Regulation art. 6.1 a), cf. art. 9.2 a), cf. the Personal Data Act § 10, cf. § 9 (2). PRINCIPLES RELATING TO PROCESSING PERSONAL DATA NSD finds that the planned processing of personal data will be in accordance with the principles under the General Data Protection Regulation regarding: - lawfulness, fairness and transparency (art. 5.1 a), in that data subjects will receive sufficient information about the processing and will give their consent - purpose limitation (art. 5.1 b), in that personal data will be collected for specified, explicit and legitimate purposes, and will not be processed for new, incompatible purposes - data minimisation (art. 5.1 c), in that only personal data which are adequate, relevant and necessary for the purpose of the project will be processed - storage limitation (art. 5.1 e), in that personal data will not be stored for longer than is necessary to fulfil the project's purpose THE RIGHTS OF DATA SUBJECTS Data subjects will have the following rights in this project: transparency (art. 12), information (art. 13), access (art. 15), rectification (art. 16), erasure (art. 17), restriction of processing (art. 18), notification (art. 19), data portability (art. 20). These rights apply so long as the data subject can be identified in the collected data. In general, the data subjects have the right to obtain from the controller the erasure of personal data concerning him or her without undue delay. In the Health Research Act, however, the right to erasure of health data does not apply if the material or data have been anonymized, if the material has been processed and is now part of another biological product, or if the data have already been included in completed analyses, cf. § 16 paragraph 3. The paragraph refers to the idea that deletion in such situations can prevent the purpose of the research being achieved. In art. 17.3 d of the General Data Protection Regulation, the right to erasure will not apply if the processing is necessary for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes in accordance with Article 89(1) in so far as the right referred to in paragraph 1 is likely to render impossible or seriously impair the achievement of the objectives of that processing. NSD therefore finds that the study can make an exemption to the right to erasure when the material has already been included in completed

analysis, cf. § 16 paragraph 3 in the Health Research Act and art. 17.3 d in the General Data Protection Regulation. We specify that health data is included in completed analysis if they are compiled or linked to other data or test answers. Please note that any other personal data not related to health must be deleted and no further data can be obtained from the participant. NSD finds that the information that will be given to data subjects about the processing of their personal data will meet the legal requirements for form and content, cf. art. 12.1 and art. 13. We remind you

that if a data subject contacts you about their rights, the data controller has a duty to reply within a month. FOLLOW YOUR INSTITUTION'S GUIDELINES NSD presupposes that the project will meet the requirements of accuracy (art. 5.1 d), integrity and confidentiality (art. 5.1 f) and security (art. 32) when processing personal data. University of Birminham is a joint data controller, but will not have access to personal data gathered by UiA. NSD presupposes that processing meets the requirements of joint data controllers under the General Data Protection Regulation art. 26. To ensure that these requirements are met you must follow your institution's internal guidelines and/or consult with your institution (i.e. the institution responsible for the project). FOLLOW-UP OF THE PROJECT NSD will follow up the progress of the project underway (every other year) and at the planned end date in order to determine whether the processing of personal data has been concluded/is being carried out in accordance with what is documented. Good luck with the project! Contact person at NSD: Jørgen Wincentsen Data Protection Services for Research: +47 55 58 21 17 (press 1)

Appendix 5

Ethical approval by The Regional Ethical Committee at the University of Agder

Lars Daniel
Rønquist Erichsen

Besøksadresse:
Universitetsveien 25
Kristiansand

Ref: [object Object]

Tidspunkt for godkjenning: : 03/01/2023

Søknad om etisk godkjenning av forskningsprosjekt - Effekten av hjemmebasert aerob trening på fysisk form og lungefunksjon, hos tospråklige eldre voksne - RITM0193703

Vi informerer om at din søknad er ferdig behandlet og godkjent.

Kommentar fra godkjenner:
FEK registrer at søknaden er godkjent i REK. Derfor er det ikke nødvendig med godkjenning av FEK.

Hilsen
Forskningsetisk komite
Fakultet for helse - og idrettsvitenskap
Universitetet i Agder

UNIVERSITETET I AGDER
POSTBOKS 422 4604 KRISTIANSAND
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ORG. NR 970 546 200 MVA - post@uia.no -
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FAKTURAADRESSE:
UNIVERSITETET I AGDER,
FAKTURAMOTTAK
POSTBOKS 383 ALNABRU 0614 OSLO

Appendix 6

Approval from the Regional Committees for Medical and Health research ethics (REK South-East C)

Region:	Saksbehandler:	Telefon:	Vår dato:	Vår referanse:
REK sør-øst C	Øyvind Grønlie Olsen		16.12.2020	163931
			Deres referanse:	

Linda Ruth Wheeldon

163931 Fitness, Ageing and Bilingualism (FAB)

Forskningsansvarlig: Universitetet i Agder

Søker: Linda Ruth Wheeldon

Søkers beskrivelse av formål:

This project will determine the benefit of being bilingual and of regular physical activity for the amelioration of language decline in older age. Our project focuses on language because it is a core aspect of human cognition, which has received surprisingly little attention in ageing research given its tremendous impact on well-being. Our own previous research has demonstrated that healthy older adults experience a decline in language function, which is characterized by word finding difficulties, slower and more disfluent sentence production, and slower and less accurate sentence comprehension. Such language problems impact older adults' functioning and can lead to social withdrawal and loneliness.
Our project therefore investigates factors that might ameliorate such language problems, as well as other forms of cognitive decline in healthy ageing. Two ameliorating factors that have received a lot of attention are bilingualism and regular physical activity. Both have been shown to reduce the structural and functional brain decline associated with healthy ageing and to confer cognitive reserve, i.e. resilient cognitive performance. Currently however, it has only been established that bilingualism and regular physical activity provide benefits for nonlinguistic aspects of cognition, such as executive functioning, working memory and processing speed. What is currently lacking is knowledge about the effects of exercise and bilingualism on language abilities in healthy ageing. Many language processes are isolated from, and independent of, other cognitive faculties. For example, word finding difficulties are not failures of long-term memory, as word knowledge increases with age, but the ability to successfully access words decreases.

We will study language and cognitive function is older and younger groups of monolinguals and bilinguals. All bilinguals will be tested in Norway; all monolinguals will be tested in the UK. We will also test the effects of increased fitness in our older participants by running a randomized-controlled 26-week intervention, with the intervention group participating in an endurance-based exercise program.
Our first objective is to build a detailed picture of the costs and benefits of bilingualism across the lifespan, which will test competing psycholinguistic theories of the bilingual disadvantage, and identify those variables of bilingualism that serve to protect against decline in ageing. Our second objective is to establish whether there are causal benefits of exercise for linguistic and nonlinguistic abilities in an aerobic exercise intervention study with monolinguals and bilinguals, to inform theory on the relative benefits of bilingualism and exercise in ageing. Our third objective is to track the physiological, physical and perceived wellbeing gains throughout a aerobic exercise intervention study, to generate the knowledge needed to optimize naturalistic, easily accessible, yet effective interventions for the public. Our fourth objective is to extend knowledge of the neural changes caused by regular exercise, by investigating (using MRI) the functional and structural brain changes underlying language benefits caused by an exercise intervention in older monolinguals. We limit the fMRI study to monolinguals to avoid dependence between studies: our previous research has already established a link between language and fitness for monolinguals, thus for this group investigating underlying neural changes is a logical next step. Our study will thus provide new knowledge about how best to maintain language abilities across the lifespan.

REK sør-øst C
Besøksadresse: Gullhaugveien 1-3, 0484 Oslo
Telefon:22 84 55 11 | **E-post**:rek-sorost@medisin.uio.no
Web:https://rekportalen.no

REKs vurdering

Vi viser til søknad om forhåndsgodkjenning av ovennevnte forskningsprosjekt. Søknaden ble behandlet av Regional komité for medisinsk og helsefaglig forskningsetikk (REK sør-øst C) i møtet 03.12.2020. Vurderingen er gjort med hjemmel i helseforskningsloven (hfl.) § 10.

Språkferdigheter, som andre kognitive ferdigheter, reduseres med alder, og kan oppleves som et helseproblem for eldre. Det er kjent at det finnes faktorer som kan ha positiv effekt på språket når man eldes, det vil si som forhindrer eller reduserer degenerering av språk. I denne studien skal en undersøke effekten av mosjon og tospråklighet på språkferdigheter under en normal aldringsprosess.

Normalt friske menn og kvinner 18-35 år og 65-85 år inviteres til å delta. Det skal gjennomføres spørreskjemaundersøkelser, språktester, kognisjonstester, måling av lungefunksjon, gripetest og andre tester av fysisk form.

Komiteen har ingen forskningsetiske innvendinger til at studien gjennomføres.

Vedtak

Godkjent

Komiteen har gjort en helhetlig forskningsetisk vurdering av alle prosjektets sider. Prosjektet godkjennes med hjemmel i helseforskningsloven § 10.

Komiteen gjør samtidig oppmerksom på at etter ny personopplysningslov må det også foreligge et behandlingsgrunnlag etter personvernforordningen. Det må forankres i egen institusjon.

Godkjenningen innebærer at opplysninger innsamlet i helsetjenesten kan utleveres i tråd med det som angis i søknad og protokoll, uten hinder av taushetsplikt, med hjemmel i helseforskningslovens § 35.

Tillatelsen er gitt under forutsetning av at prosjektet gjennomføres slik det er beskrevet i søknaden og protokollen, og de bestemmelser som følger av helseforskningsloven med forskrifter.

Tillatelsen gjelder til 30.09.2025. Av dokumentasjons- og oppfølgingshensyn skal opplysningene likevel bevares inntil 30.09.2030. Opplysningene skal lagres avidentifisert, dvs. atskilt i en nøkkel- og en opplysningsfil. Opplysningene skal deretter slettes eller anonymiseres, senest innen et halvt år fra denne dato.

Komiteens avgjørelse var enstemmig.

Komiteens vedtak kan påklages til Den nasjonale forskningsetiske komité for medisin og helsefag, jfr. helseforskningsloven § 10, tredje ledd og forvaltningsloven § 28. En eventuell klage sendes til REK sør- øst C. Klagefristen er tre uker fra mottak av dette brevet, jfr. forvaltningsloven § 29.

Med vennlig hilsen

Britt Ingjerd Nesheim Prof. dr. med.
Leder REK sør-øst C

Øyvind Grønlie Olsen Seniorrådgiver REK sør-øst

Dokumentet er elektronisk signert

Kopi av vedtak: Forskningsansvarlig institusjon.

Sluttmelding

Søker skal sende sluttmelding til REK sør-øst C på eget skjema senest seks måneder etter godkjenningsperioden er utløpt, jf. hfl. § 12. Dersom prosjektet ikke igangsettes eller gjennomføres skal prosjektleder også sende melding om dette via sluttmeldingsskjemaet.

Søknad om å foreta vesentlige endringer

Dersom man ønsker å foreta vesentlige endringer i forhold til formål, metode, tidsløp eller organisering, skal søknad sendes til den regionale komiteen for medisinsk og helsefaglig forskningsetikk som har gitt forhåndsgodkjenning. Søknaden skal beskrive hvilke endringer som ønskes foretatt og begrunnelsen for disse, jf. hfl. § 11.