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Doctoral thesis

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Effekten av pragmatisk styrketrening hos eldre som mottar hjemmetjenester

Økende alder kjennetegnes blant annet av redusert muskelstyrke, muskelmasse og aktivitetsnivå. I tillegg reduseres den fysiske funksjonen, slik som evnen til å gå, reise seg fra en stol og gå trapp. Disse aldersrelaterte endringene gir store konsekvenser både for individet og samfunnet. Vi blir stadig flere eldre og vi lever lenger, og behovet for å holde flest mulig eldre selvstendige og hjemmeboende så lenge som mulig øker.

Jeg har undersøkt 107 eldre med hjemmetjenester (median alder 86 år). Dette er en lite studert, men aktuell gruppe eldre som befinner seg på terskelen mellom å bo selvstendig hjemme og å ha behov for insitusjonsplass. Først har jeg undersøkt sammenhengen mellom muskelstyrke og fysisk funksjon. Videre har jeg undersøkt effekten av et pragmatisk styrketreningsprogram sammenliknet med generelle råd om fysisk aktivitet. Styrketreningen ble gjennomført med lett tilgjengelig utstyr, slik som strikk, vannkanner og egen kroppsvekt. Fysisk funksjon, maksimal- og eksplosiv muskestyrke, kroppssamennsetning og aktivitetsnivå ble kartlagt.

Resultatene viser at det er en sammenheng mellom muskelstyrke i beina og fysisk funksjon; høyere maksimal- og eksplosiv styrke gir bedre evne til å reise seg fra stolen og raskere ganghastighet. Videre viser resultatene at styrketrening to ganger i uka over åtte måneder er mer effektivt enn generelle råd om fysisk aktivitet. Styrketreningsgruppa opplevde bedret maksimal beinstyrke (16% økning), samt fysisk funksjon målt som evnen til å reise seg fra en stol, gå og gå trapper (9-24% økning). Det var ingen forskjell mellom gruppene i eksplosiv styrke, kroppssammensetning eller aktivitetsnivå.

Denne studien har bidratt med ny kunnskap rundt betydningen av å se muskelstyrke og fysisk funksjon i sammenheng. Pragmatisk styrketrening kan være et godt alternativ for å redusere eller motvirke flere aldersrelaterte endringer hos eldre som mottar hjemmetjenester.

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English summary

The number and proportion of older adults is increasing with the most rapid rise projected for individuals above 80 years. Old age is accompanied by reduced muscle strength and mass, impaired physical function, high levels of sedentary behavior, and low levels of physical activity (PA). These changes may influence the ability to live independently, which imposes a major burden for the individual and the society. Evidence suggest that muscle strength is related to physical function, and that resistance training may be an effective strategy to counteract the age-related decline in muscle strength, muscle mass, physical function, and PA levels. This thesis is based on the recognition that there is a need for an effective resistance training program that can be incorporated into older adults' key settings, such as at home or the health care centers. Pragmatic resistance training programs utilizing easily available, low-cost equipment (e.g., elastic bands, water canes, body weight) may be a viable alternative for the oldest old (>80 years).

This thesis aims to increase the knowledge about the relationship between muscle strength and physical function, and about the effectiveness of a pragmatic resistance training program among community-dwelling older adults receiving home care. Accordingly, one paper examines the cross-sectional association between muscle strength and physical function. The second paper examined the effectiveness of pragmatic resistance training compared to PA counselling on physical function, muscle strength, and body composition. The third paper examined the effectiveness of pragmatic resistance training compared to PA counselling on PA levels.

This thesis was based on data from the Independent, Self-reliant, Active Elderly (ISRAE) study, a cluster-randomized controlled trial. A total of 107 community-dwelling older adults receiving home care (median age 86 years) from 12 clusters were included. The participants were randomized to either a resistance training group or a control group. The training group (n=64) were offered eight months of supervised resistance training twice a week using elastic bands, water canes, and body weight as external resistance. The control group (n=43) received PA counselling. Maximal- and explosive muscle strength were tested through an isometric contraction of the leg extensors. Physical function was evaluated through a test battery assessing the ability to rise from a chair, climb stairs, and walk. Body composition was estimated using bioelectrical impedance analysis. PA levels were estimated objectively by ActiGraph GT3X+ accelerometers over 14 consecutive days.

The results of the research presented in this thesis show that higher maximal- and explosive strength are related to better physical function among community-dwelling older adults receiving home care. Furthermore, in the same sample, eight months of pragmatic resistance training resulted in improved physical function and maximal strength when compared to PA counseling. However, the resistance training program did not result in improved explosive strength, body composition, or PA levels when compared to receiving PA counseling. Thus, pragmatic resistance training may be a viable strategy that holds great potential for slowing down or counteracting several unfavorable age-related changes. Older adults, including those of poor muscle strength, poor physical function, and the oldest old, should be encouraged to implement a structured resistance training program into their weekly routines.

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First, thank you to my main supervisor Atle Hole Sæterbakken for giving me the opportunity to work with data from ISRAE. Thank you for all your appreciated input and feedback, and for allowing me to "leave my mark" on the project. I am also very grateful to my co-supervisors: Vidar Andersen for always answering my emails within a blink of an eye and for all your valuable input and knowledge. Truls Raastad for sharing your expertise. Last, but not least, thank you to you Marius Steiro Fimland for always having an open door, contributing with constructive feedback, and for making me believe in myself and my work. You have been an invaluable support and this journey would not have been possible without you.

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List of papers

I. **Bårdstu HB, Andersen V, Fimland MS, Raastad T, and Saeterbakken AH.** Muscle strength is associated with physical function in community-dwelling older adults receiving home care. A cross-sectional study. *Frontiers in Public Health.* [Internet]. 2022; 10:856632

II. **Bårdstu HB, Andersen V, Fimland MS, Aasdahl L, Raastad T, Cumming KT, and Saeterbakken AH.** Effectiveness of a resistance training program on physical function, muscle strength, and body composition in community-dwelling older adults receiving home care: A cluster-randomized controlled trial. *European Review of Aging and Physical Activity.* 2020; 17:11.

III. **Bårdstu HB, Andersen V, Fimland MS, Aasdahl L, Raastad T, Lohne-Seiler H, and Saeterbakken AH.** Physical activity level following resistance training in community-dwelling older adults receiving home care: Results from a cluster-randomized controlled trial. *International Journal of Environmental Research and Public Health (IJERPH)* 2021; 18(13):6682

Abbreviations

TUG-8ft	Timed 8-feet-up-and-go
BMI	Body mass index
CG	Control group
CI	Confidence interval
CPM	Counts per minute
ICC	Intracluster correlation coefficient
IQR	Interquartile range
ISRAE	The Independent, Self-reliant, Active Elderly Study
ITT	Intention to treat
LPA	Light physical activity
MU	Motor unit
MVC	Maximal voluntary isometric contraction
MVPA	Moderate-to-vigorous physical activity
PA	Physical activity
RCT	Randomized controlled trial
RFD	Rate of force development
RM	Repetition maximum
RTG	Resistance training group
SB	Sedentary behavior
SD	Standard deviation
TPA	Total physical activity
VM	Vector magnitude
WHO	World health organization

Clarification of concepts

Body composition: The percentage or amount of muscle, bone, and fat in the human body.

Community-dwelling: Older adults living in the community on their own as opposed to living in an institution.

Explosive resistance training: In this thesis, this is used as an umbrella term for resistance training performed with high intentional velocity in the concentric phase of the movement. Often, an intensity of 40-60% of 1 repetition maximum (RM) has been used.

Explosive strength: In this thesis, this is used as an umbrella term including different parameters that measure the ability to produce force rapidly or apply the maximum amount of force as fast as possible, such as power (force×velocity) and rate of force development ($\Delta force/\Delta time$).

Heavy resistance training: In this thesis, this is used as an umbrella term for resistance training of high intensity, often carried slowly and controlled in the concentric phase of the movement. Traditionally, an intensity of 70-85% of 1RM has been used.

Home care: Home care is services delivered to individuals in their own home and includes assistance in daily living, home health services (e.g., home nurse), user-controlled personal assistance, and care benefits from volunteers.

Institutionalized care (institutionalized): Long-term stay or short-term stay in nursing homes, retirement homes, or relief institutions.

Maximal strength: In this thesis, this is used as an umbrella term including several parameters that measure the ability to generate maximal force, such as 1 RM, maximal/peak torque, and maximal voluntary isometric contraction (MVC).

Maximal voluntary isometric contraction (MVC): The maximal capacity of a muscle or muscle group to generate force, derived from an isometric contraction.

Mobility devices: In this thesis, mobility devices are understood as devices designed to help older adults to move around independently, reduce lower limb load and pain, improve balance and stability. This includes walkers, rollators, and canes. Other terms that are often used synonymously are walking aids, walking devices, assistive devices, geriatric assistive devices, ambulatory devices, among others.

Physical activity: Any bodily movement produced by skeletal muscles that results in energy expenditure.

Physical function: Understood in this thesis as the measurement of different physiological domains that reflect an individual's ability to perform functional tasks such as walking, rising from a chair, and climbing stairs

Pragmatic resistance training: In this thesis, this is understood as resistance training utilizing elastic bands alone or in combination with other easily available equipment (e.g., chairs, water canes, ankle weights), which can be implemented in community- and/or home-based settings.

Rate of force development (RFD): The neuromuscular systems capability to increase contractile force in situations where the contraction is performed with high intentional velocity (as fast as possible). RFD can be derived from the slope of the force-time curve (Δforce/Δtime) during an isometric contraction.

Resistance training: Exercise that causes the muscles to contract against an external resistance (e.g., weight machines, dumbbells, elastic bands, body weight), designed to increase muscle strength, muscle mass, and fitness.

Sedentary behavior: Periods of waking activity that do not increase energy expenditure substantially above the resting level.

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Introduction

The number and proportion of older adults is increasing globally. A similar trend is seen in Norway with estimates showing that the number of individuals above 70 years will double within three decades, from 600 000 to approximately 1.2 million (1). The most rapid rise is projected for individuals above 80 years and they are projected to make up ~8% of the Norwegian population in 2040 as compared to ~4% in 2018. This aging society is due to improvements in health care (e.g., medicine and diagnostics) and lifestyle during the entire life span which has led to increased life expectancy, as well as the post-world-war-two birth cohorts now becoming the oldest (1,2).

Unfortunately, additional years gained from increased life expectancy does not necessarily mean additional years spent in good health and physical function as projections indicate that life expectancy increases faster than number of healthy life years (2). Aging is associated with several unavoidable age-related changes, such as reduced muscle strength and mass, aerobic capacity, and physical activity (PA) level, increased fat mass, and increased risk of chronic- and acute disease (3). These changes may have great individual costs as they impact an individual's perseverance of physical function and independence (3). Additionally, the costs for the society imposes a major challenge as a change in the global population reduces the ratio of workforce to the overall population (1,2). Thus, the increased demand for health- and long-term care puts substantial pressure on our health care system.

The abovementioned challenges arising from an aging population emerges as a substantial global health concern as more older adults will have to live functionally and independently in their own homes into even older ages. Clearly, developing and implementing effective strategies aiming to counteract some of the age-related physical deteriorations affecting older adults is crucial (4). To make such strategies easily accessible they should be implemented into older adults' key settings, such as at the health care centers or at home (5). In this thesis, older adults receiving home care were examined, as they represent a key population at the threshold between living independently in their own home and the need for institutionalized care. In general, home care recipients are characterized by reduced overall health and physical function which may result in challenges in coping with everyday life (6,7), independent of chronological age. Still, the need for health care services is highest among the oldest old (i.e., >80 years) (8). Appropriately tailored strategies such as resistance training aiming to maintain or improve muscle strength, physical function, and PA level in this group could reduce or delay the need for health and care services and institutionalized care. This may have large implications on individual level and for the society. Despite this, older adults receiving home care are still underrepresented in clinical research.

Background

Impact of aging

Muscle strength

One of the hallmarks of the physiological aging process is the gradual loss of maximal muscle strength (3,9). This loss becomes apparent around the age of 60 years (10) with an annual reduction of approximately 1.0-2.5% (10,11). Healthy older adults in their 60-s and 70-s show on average 20-40% lower strength when compared to young adults (10,12). These differences become even more apparent in the oldest old (>80 years) (10). Similarly, an age-related, progressive decline in explosive strength has been shown (9,13,14) and several studies indicate that explosive strength starts to decline earlier in the lifespan than maximal strength does (9,14). Furthermore, studies show that explosive strength declines at a faster rate than maximal strength with an annual reduction of approximately 1.7-3.5% after the age of 65 years (9,13,14)

Traditionally, cross-sectional studies have linked reductions in muscle strength to *muscular factors*, such as a gradual loss of muscle mass and reduced muscle fiber size (12). However, longitudinal studies have shown that the rate of decline in muscle strength is 2-5 times greater than declines in muscle mass (11,15,16). This has led to suggestions that *neural factors* may play an important role in the age-related loss of muscle strength (17–19). In the following section, some of the *muscular factors* and *neural factors* that may contribute to age-related muscle weakness will be discussed briefly.

One of the most researched *muscular factors* is the gradual reduction in whole muscle mass (20,21). By the age of 50 years approximately 10% of muscle mass is lost (18) and from there on the reduction accelerates with an annual loss of approximately 1.0-1.4 percent (11,20). Loss of muscle mass may be explained by the aging process per se, but also by disuse due to high levels of sedentary behavior (SB). Substantial evidence show a reduction in muscle fiber size with increasing age (20,22). However, the size reductions are only moderate compared to the total reduction in muscle mass, which can be explained by a coincident loss in muscle fiber number (20). The greater loss of type II versus type I fiber size may explain the faster decline in explosive strength (23) and the age-related impairments in physical function (21). Furthermore, increased intramuscular fat and overall body fat mass are seen at old age (15) as well as increased connective tissue (21). Consequently, older muscles have reduced muscle quality, thus, they produce less force relative to muscle mass

(22). The age-related loss of muscle mass accompanied by increased fat mass may affect weight maintenance and contribute to the alterations seen in body composition with aging (23,24). In addition, several *neurological factors* may play an important role. Advancing age has been related to loss of motor neurons from the spinal cord and degeneration of their axons (17,21). The denervation of muscle fibers and the following reinnervation have been linked to increased motor unit (MU) size and reduced number of functioning MUs (17,21). Consequently, remodeling of remaining MUs leads to increased fiber type grouping, which indicates a neuropathological process (17,21,22). Furthermore, the reduction in descending drive from the motor cortex compromises voluntary muscle activation and reduces MU recruitment and firing rate (17). There is substantial evidence that several of the abovementioned factors can be counteracted by regular resistance training. For example, muscle fiber hypertrophy (especially type II fibers), increased contractile material, reduced fat mass, increased MU recruitment and firing frequency, and increased central activation have been shown (21,25,26). The effectiveness of resistance training on the potential mechanisms (i.e., muscular and/or neural factors) is not the focus in this thesis and will not be discussed in more detail.

Physical function

Physical function is a broad term and there is no consensus on how to define it. Physical function can be described as the ability to perform activities of daily life in order to live independently. This includes, but are not limited to, being able to cook food, do one's own shopping, getting dressed, getting up from a chair or the bed, walking, and cleaning oneself (27). In this thesis, physical function is understood as the measurement of different physiological domains that reflect an individual's ability to perform functional tasks such as walking, rising from a chair, and climbing stairs (28).

Physical function declines with increasing age (29) and often emerges as walking disability and slow gait speed, trouble rising from a chair, poor balance, and difficulties with walking up and down stairs (30,31). These abilities are even poorer among those above 80 years than in 60–79-year-olds (31). For example, in older adults above 80 years a maximal gait speed of 1.08-1.23 m/s has been shown, further declining to 0.88-0.93 m/s in those using mobility devices (e.g., rollator, cane) (31). For comparison, a gait speed of approximately 1.2 m/s is required to cross a street on a green light (32). Thus, it is safe to say that many older adults will have great difficulties with getting safely across a street. Furthermore, poor physical function is a major risk factor for activities of daily life disability (33), falls (34), need of home care (35), institutionalized care (35), and mortality (36). Therefore, the age-related decline in physical function such as the ability to walk, climb stairs, and rise from a chair, may have a major impact on older adults' ability to take an active part in their own daily life.

The relationship between muscle strength and physical function

Substantial evidence points towards loss of muscle strength being an important determinant for loss of physical function at old age (13,37–47). A minimum amount of muscle strength is needed to be able to carry your own body weight through tasks of daily life, such as rising from a chair, walking, and climbing stairs. Especially for low functioning, very old individuals muscle strength may be a limiting factor. For example, Young and colleagues concluded that healthy 80-year-old women were at or very close to the threshold for strength necessary to rise from a chair (48). Despite this, few studies have investigated the relationship between muscle strength and physical function among the oldest old (>80 years). Barbat-Artigas and co-workers showed that women (mean age 80.4 years) in the lowest maximal strength quartile were 12-25-fold more likely to have impaired ability to rise from a chair and walk compared to those in the highest strength quartile (42). Furthermore, Casas-Herrero and co-workers found moderate correlations between maximal leg strength and the ability to rise from a chair and walk among frail older adults (mean age 93.4 years) (45).

Explosive strength has emerged as an important determinant for older adults' physical function (49). Studies have shown that power is correlated with physical function (13,50) and systematic reviews have consistently demonstrated that power explains marginally more of the variance in physical function than what measures of maximal strength does (49,51). However, few studies have examined the relationship between explosive strength and physical function among the oldest old (>80 years) (43–45). Casas-Herrero and colleagues showed a stronger correlation for power with gait speed and chair rise (r=-0.64 and r=0-66, respectively) as compared to maximal leg strength (r=-0.51 and r=0.54, respectively) among institutionalized individuals (45). However, the sample size was low, especially for the power measurements (n=15). Considering the benefits of both muscle strength and physical function for older adults' independence, a clear understanding of the relationship between these variables is relevant for future health and for designing effective preventive- and treatment strategies. Especially, studies examining explosive strength and targeting the oldest old (>80 years) and/or older individuals with poor physical function or strength are warranted.

Physical activity

According to the WHO, inactivity is one of the leading risk factors for global mortality (5). Thus, low levels of physical activity (PA) and high levels of SB represent a major global health concern. PA can be defined as “any bodily movement produced by skeletal muscles that results in energy expenditure” (52), and SB as waking “activities that do not increase energy expenditure substantially above the resting level” (53). It is well known that high levels of PA and low levels of SB reduce the risk of several non-communicable diseases (e.g., heart disease, diabetes, and cancer), disability and falls, improves mental health and quality of life, and decreases the risk of mortality (3).

The Norwegian Directorate of Health recommends that older adults ≥65 years should do at least 150 min/week of moderate intensity PA or at least 75 min/week of vigorous intensity PA, or a combination (54). According to a recent Norwegian study including 1175 community-dwelling older adults (>65 years), only 30% meet the PA recommendations (55). PA further declines with increasing age (56,57) with only 5.6% of Norwegian individuals aged 80 years achieving the recommended level of PA (56). This pattern is consistent with findings from other countries such as Iceland (58), United Kingdom, France, and Italy (59), and United States (60). In addition, the Norwegian recommendation states that older adults should decrease their time spent in SB (54) as prolonged SB is an important risk factor for several health outcomes independent of PA (61,62). Despite this, community-dwelling older adults spend approximately 70-75% of awake time sedentary (58,63), further increasing to above 80% in institutionalized individuals (64). The low PA and high SB seen in older adults may be related to age-related changes in the cardiovascular system (3), muscle strength, muscle mass, and physical function (63–65). For example, poor muscle strength is related to lower walking speed (66) and low PA (67), and walking is found to contribute greatly to older adults’ daily PA (68). Thus, maintaining PA and limiting SB may be relevant for perseverance of muscle strength and physical function, and thereby independence, into old age.

To summarize this first chapter, many older adults find themselves in a vicious cycle where the age-related changes in muscle strength, muscle mass, physical function, and PA level all co-exist and influence each other. Therefore, strategies aiming to maintain and/or improve one or more of these changes are important. In the following chapter resistance training as a countermeasure to the age-related changes in muscle strength, physical function, body composition, and PA level will be described.

Resistance training for older adults

The first studies aiming to investigate the effectiveness of resistance training among older adults emerged around early 1990-s (63). From then on, resistance training has consistently been shown to be a safe and effective method to counteract several of the undesirable consequences of aging (4). The Norwegian Directorate of Health and the National Strength and Conditioning Association (NSCA) recommend that older adults perform resistance training involving all major muscle groups twice or more per week (4,54). The NSCA further recommends that a proper resistance training program should consist of 8-10 exercises with 2-3 sets of 8-12 repetitions at a moderate to high intensity (i.e., 40-85% of one repetition maximum (RM)) (4). The intensity and volume should be tailored to the individual and increased progressively (4,71). Despite its benefits, the NSCA reports that just ~9% of older adults include resistance training in their leisure time (4).

Resistance training has traditionally been carried out in fitness centers using weight machines and/or free weights (4). However, lack of availability, training experience, and affordability may limit older adults' accessibility to such facilities and equipment (72,73). According to the WHO it is important to create active people. One of the recommended actions towards this is to provide appropriately tailored programs which can be implemented into older adults' key settings such as at home, at local and community venues, and in health, social and long-term care settings (5). Easily available, low-cost equipment such as elastic bands, body weight, and other equipment (e.g., ankle weights, water canes, chairs) can be used as external resistance in these settings (74–76). In this thesis, interventions utilizing elastic bands alone or in combination with other easily available equipment and that can be implemented in community- and/or home based settings will be referred to as "pragmatic resistance training" (51)

Effect of resistance training on muscle strength

Systematic reviews and meta-analyses have shown small to large effects of resistance training on muscle strength in older adults with a variety of health- and functional statuses (71,75–78). Furthermore, strength gains can be compared to those of younger adults (20-35 years) (79). One study even found that resistance training once a week over a 9-week period was enough to improve muscle strength in older adults (65-79 years) (80). However, several studies have pointed towards a clear dose-response relationship (71,78,80). Traditionally, resistance training has been carried out using high intensity (e.g., 70-85% 1RM) and with a slow, controlled concentric phase and it often aims to increase older adults' maximal strength (4,81). From here on this is referred to as "heavy resistance training". A 2009-Cochrane meta-analysis found a moderate to large beneficial effect on maximal leg strength, with most of the included studies using resistance training machines and/or free weights at a high intensity performed 2-3 times per week, and examining 60- and 70-year-olds (78). Although less frequently studied, substantial maximal strength gains (e.g., 113% increase) has been shown following heavy resistance training even among the oldest old (>80 years) (69).

Over the last decades, more attention has been directed towards resistance training where the concentric phase of the movement is performed with high intentional velocity and often with an intensity of 40-60% of 1RM (4,81–83). From here on this is referred to as "explosive resistance training". Heavy- and explosive resistance training have demonstrated comparable gains in maximal strength (81), but explosive resistance training may seem more beneficial for improving explosive strength (81). It should be noted that explosive resistance training appears to be effective despite often operating at a lower absolute load compared to heavy resistance training (81). Accordingly, the NSCA recommends that older adults include explosive resistance training in their exercise routines (4).

Systematic reviews and meta-analyses point towards pragmatic resistance training interventions being effective for increasing muscle strength among both healthy- and functionally limited older adults, showing small to large effects (75,76,84). A meta-analysis including older adults (60-79 years) stated that the strength gains following elastic band resistance training was larger than what had been reported previously with machines and/or free weights (75). It should be noted that the lack of a quantitative measure of intensity when using elastic bands makes comparisons with more traditional interventions challenging (75). In the following section, findings from randomized controlled trials (RTCs) examining whether pragmatic resistance training improves muscle strength will be highlighted.

A study from the 90-s examined the effectiveness of a pragmatic resistance training intervention and showed positive effects of 12 weeks of training on muscle strength in healthy women (mean age 79.5 years) (85). From there on, several studies have investigated the effectiveness of pragmatic interventions on muscle strength (70,86–99). Westhoff and colleagues (91) found improvements in maximal knee-extensor torque following 10 weeks of pragmatic resistance training among frail, institutionalized older adults (mean age 76.7 years). The large gain in strength was explained by the participants' low initial strength level, which has been discussed in other studies as well (90). In contrast, Fahlman and co-workers failed to improve maximal torque following 16 weeks of pragmatic resistance training (mean age 75.2 years) (86) and Oesen and colleagues did not demonstrate gains in peak torque following six months training among institutionalized older adults (mean age 82.7 years) (87). To our knowledge, only a few studies have examined the effectiveness of pragmatic resistance training using an explosive approach (89,90,100). One study compared heavy- and explosive pragmatic resistance training and found similar, positive effects on lower limb peak torque and power, with a trend towards greater improvements in the explosive training group (100). Furthermore, Hruda and colleagues encouraged their participants to perform exercises with gradually higher velocity and demonstrated improvements in both peak torque and power in institutionalized older adults (76-94 years) (90). In contrast, in community-dwelling older adults receiving home care (mean age 85 years), pragmatic resistance training focusing on a fast concentric phase did not improve isometric maximal strength or RFD (89).Thus, more research is needed to clarify the effectiveness of pragmatic resistance training on muscle strength as these studies are inconclusive. Especially, more studies examining an explosive approach is warranted. Lastly, home care recipients represent a group of older adults where one can expect poor muscle strength and/or high age (>80 years). A special focus on these individuals therefore seems important.

Effect of resistance training on physical function

Systematic reviews and meta-analyses have shown that resistance training is effective for improving older adults' physical function (78,101). A Cochrane meta-analysis from 2009 concluded that resistance training had a small to moderate effect on gait speed, stair climb, and timed-up-and-go (TUG), and a moderate to large effect on chair rise in healthy-, chronically diseased-, and functionally limited participants (78). The same meta-analysis emphasized the large variance between studies regarding choice of tests for physical function, design of the intervention (e.g., exercises, duration, frequency, intensity, equipment), and characteristics of the participants (e.g., age, health- and functional status). This heterogeneity may explain the inconsistencies between studies with respect to the effectiveness of resistance training (3). It should also be mentioned that many studies have examined heavy resistance training programs (78,102,103). However, many of the physical tasks of daily life operate with a high movement velocity (103). A meta-analysis from 2022 found a small effect favoring power training (i.e., explosive resistance training) over traditional, heavy resistance training for physical function (101). However, the same meta-analysis pointed out that most studies examined younger (i.e., 60-s and 70-s) and more functional older adults.

Pragmatic resistance training interventions may hold great potential for improving physical function as it may facilitate the inclusion of movement patterns that resemble those of functional tasks (76,97). In general, systematic reviews have shown that such interventions may improve physical function, but that the improvements are small (76,84). In the following sections, findings from RCTs will be assessed, focusing on studies examining the oldest old (mean age >80 years) or frail (e.g., functionally limited, receiving health care services).

Most studies include a variety test that assess different functional abilities, such as the ability walk, rise from a chair, and climb stairs. In a study from 2021, 12 weeks of pragmatic resistance training improved several aspects of physical function, including chair rise ability and TUG performance, in women living in geriatric centers (104). However, many studies demonstrate improvements in one or a few tests, and not all. Oesen and colleagues examined a 6 months intervention and showed better chair rise ability, but not walking ability among institutionalized individuals (mean age 82.7 years) (87). Another study found an effect on TUG, but not on gait speed in frail, institutionalized individuals (mean age 76.7 years) (91). It should be noted that improvements often have been found in tests that resemble the movement patterns of the exercises (3) and that many studies included squats or a chair rise exercise (86,87,90,91,105). The training programs may also have been ineffective due to low intensity, short duration (mostly 8-16 weeks), and lack of strength improvements.

The combination of pragmatic- and explosive resistance training for improving physical function has gained little attention (101). In home care recipients (mean age 85 years), 10 weeks pragmatic resistance training using high intentional velocity did not improve chair rise, gait speed, or stair climb compared to a control group (89). On the other hand, TUG, gait speed, and chair rise ability improved as compared to a control group following 10 weeks of training in institutionalized individuals (mean age 82.8 years) (90). It should be noted that the latter study, but not the first, demonstrated increased maximal- and explosive strength as well. Thus, despite being well researched, the existing evidence for the effectiveness of pragmatic resistance training on physical function is still unclear and divergent. Furthermore, studies examining the effectiveness of explosive pragmatic resistance training on physical function are needed.

Effect of resistance training on body composition

It has been suggested that resistance training may alter older adults body composition through a shift from fat mass to muscle mass (23). Hunter and co-workers found an increase in fat free mass of 2 kg and a loss of fat mass of 2.7 kg following resistance training using weight machines (106). However, results from meta-analyses examining the effectiveness of resistance training on different measures of body composition are conflicting. A recent meta-analysis found no effect on muscle mass, but a moderate effect on body fat in sarcopenic older adults above 65 years (26). In contrast, Peterson and colleagues found a significant 1.1 kg increase in lean body mass among older adults (mean age 65.5 years) (24). It should be noted that most of the studies in the latter meta-analysis included healthy individuals and there were some differences between the meta-analyses with respect to the outcome measures.

A recent systematic review reports unclear findings with respect to the effectiveness of pragmatic resistance training on measures of body composition (84). Vikberg and colleagues found lower body fat and higher lean mass in older adults with pre-sarcopenia (mean age 70.9 years) following pragmatic resistance training compared to a control condition (107). Similar findings have been shown in older adults with sarcopenic obesity (mean age 67.3 years) (108). In contrast, in healthy older adults in their 60-s no effect was found on fat free mass (88). It should be noted that the existing studies have used a variety of outcome measures and assessment methods for body composition (e.g., dual energy X-ray versus bioelectrical impedance analysis), and that none of the studies investigated the oldest old (>80 years). Interestingly, Yoon and co-workers suggested that training with high velocity (i.e., explosive) may be more effective for improving body composition (e.g., body fat, muscle mass, fat free mass) as compared to using lower velocity (100). However, more research is needed to examine the effectiveness of a combined pragmatic and explosive approach on body composition among older adults. Especially, most previous research has targeted healthy older adults, and studies including the oldest old (>80 years) are currently lacking.

Effect of resistance training on physical activity

In a meta-analysis from 2019, Sansano-Nadal and co-workers examined the effectiveness of exercise interventions on PA levels among community-dwelling older adults (>65 years). The meta-analysis concluded that exercise interventions had a small benefit on PA, although results were inconclusive when exercise was compared to active controls (109). Among frail older adults, a meta-analysis found that an exercise intervention alone was not enough to stimulate frail older adults to increase their PA (110). In both abovementioned meta-analyses, any type of exercise intervention was included and most of the studies investigated a multi-modal exercise program (i.e., combining strength, mobility, flexibility, endurance, tai chi etc.). This makes it difficult to separate the specific effect of resistance training alone on PA and highlights the limited knowledge base on whether resistance training alone can be beneficial for PA levels. However, a few studies do exist, and these will be addressed in the following paragraphs.

In a pioneer study from the early 90-s, Fiatarone and colleagues examined the effectiveness of 10 weeks of high intensity resistance training using weight machines in institutionalized individuals (mean age 87.1 years). They found that PA increased, as did muscle strength and physical function (69). In contrast, 6 months of resistance training using weight machines or functional exercises failed to increase total PA in institutionalized older adults (mean age 81.7 years) (111). The lack of effect on PA is in line with the results from other studies for a variety of ages, and health- and functional statuses (87,89,112). Furthermore, no effect on PA has been found following pragmatic resistance training, although studies are sparse (87,89). Interestingly, none of the studies that failed to increase PA demonstrated, or included findings of, both improved muscle strength and physical function. The age-related decline in PA is related to both muscle strength (67) and physical function (64). Accordingly, one can speculate that increased muscle strength and physical function are important for a concurrent increase in PA, as shown by Fiatarone and colleagues (69).

Over the past decades, the importance of reducing older adults time spent sedentary has emerged as an important public health concern and focusing on breaking up SB have proven effective (113). Furthermore, older adults spend much time in light intensity PA (LPA) such as walking and housework (114), and higher levels of LPA is associated with better health (115) and reduced mortality (116). Resistance training may have the potential to break up SB by strengthening the lower body and making it easier to rise from a seated to a standing position. Possibly, the level of LPA may also increase as a consequence of spending more time upraised. However, whether resistance training is effective for reducing SB and increasing LPA is often overlooked. No change in time spent in SB or LPA was found among community-dwelling older adults (mean age 85 years) receiving home care following pragmatic resistance training (89). It should be mentioned that the intervention was of short duration (10 weeks) and failed to increase both muscle strength and physical function as well. Clearly, there is limited research on the effectiveness of resistance training on the PA levels of older adults. Thus, more research is needed to fully understand the potential effect, especially of pragmatic resistance training. Furthermore, studies assessing the entire intensity spectrum ranging from SB to moderate-to-vigorous PA (MVPA) are warranted.

Rationale for the thesis

One major consequence of the aging society is that a substantial proportion of older adults will need to be able to live functionally and independently in their own home for as long as possible. This is also highlighted in the Norwegian Government's Quality Reform for Older Persons, "A full life – all your life" (117). Therefore, effective interventions aiming to improve and/or maintain muscle strength, physical function, muscle mass, and PA level are needed. Resistance training has been recommended as one of the "best buys". Especially, development of resistance training programs that can be implemented into older adults' key settings, such as at home or in community environments is warranted. For this to be accomplished, the interventions should utilize low-cost, easily available equipment such as elastic bands, chairs, water canes, and/or body weight. Despite this, there is a gap in the research literature regarding the effectiveness of resistance training interventions meeting the abovementioned criteria.

One interesting, but highly understudied group is community-dwelling older adults receiving home care. These older adults need help due to functional- and/or medical reasons. Thus, it is reasonable to believe that the majority will have low initial physical function, muscle strength, muscle mass, and/or PA levels. Furthermore, although the chronological age-range will vary, many can be expected to be among the oldest old (>80 years). Here, we see a window of opportunity as these older adults may represent a breaking point between living functionally and independently in their own home and the need for institutionalized care. Despite this, home care recipients are underrepresented in studies examining the effectiveness of resistance training interventions. A special focus on these individuals therefore seems warranted.

Aims of the thesis

The overall aim of this thesis was to increase the knowledge about the cross-sectional relationship between muscle strength and physical function, and about the effectiveness of a pragmatic resistance training program in community-dwelling older adults receiving home care.

Aims of the papers

The main aim of each specific paper (I-III) is described below.

- The aim of Paper I was to explore the cross-sectional associations between muscle strength (maximal- and explosive) and physical function among older adults receiving home care.
- The aim of Paper II was to examine the effectiveness of a pragmatic resistance training program on physical function, muscle strength, and body composition among older adults receiving home care. The resistance training program was compared to receiving standard PA counselling.
- The aim of Paper III was to examine the effectiveness of a pragmatic resistance training program on PA levels, compared to receiving standard PA counselling among older adults receiving home care.

Materials and methods

Trial design

This thesis is based on data from the Independent Self-Reliant Active Elderly (ISRAE) study, an open label, two-armed, parallel group, cluster-randomized controlled trial (cluster-RCT). In cluster-RCTs, groups of participants, and not individuals, are randomized into the study arms (118) and in ISRAE the participants were randomized in clusters based on geographical residency. Cluster randomization was chosen to avoid contamination as members of groups often interact and may share information and to increase adherence (118).

The ISRAE study consisted of an eight-month intervention which examined the effect of resistance training by comparing a resistance training group (RTG) to a control group (CG). Paper I is based on cross-sectional data from the baseline measurement. Paper II and III examine the effectiveness of the eight-month intervention using the baseline data and data from the four- and eight months measurements.

Participants

ISRAE was carried out in three municipalities (Sogndal, Luster and Leikanger) in Western Norway and participants were recruited in co-operation with the health and care services in these three municipalities. We contacted the municipalities and those with practical- and executive responsibility for delivering home care services were informed about the project (e.g., timeline, intervention, follow up, eligibility criteria). To be included participants had to be above 70 years, community-dwelling, and receive home care due to functional and/or medical disabilities. In Norway, home care is organized, managed, and financed according to the local demands of the municipality. Home care is services delivered to individuals in their own home and includes assistance in daily living, home health services (e.g., home nurse), user-controlled personal assistance, and care benefits from volunteers (119). Older adults who receive home care report poor physical function, quality of life, higher fall risk, and challenges with activities of daily life (119). In 2020, approximately 30% of Norwegian citizens above 80 years received home care (120). The exclusion criterions were serious cognitive disease (e.g., Alzheimer's disease, dementia), physical diagnoses/conditions that could affect testing and/or training, and/or disapproval from a medical doctor due to contraindications for training. Based on these inclusion and exclusion criteria, those working in the health and care services provided us with a list of eligible participants, and potential participants were then approached based on this information. An amendment was made to the inclusion criteria during participant recruitment; seven older adults otherwise meeting the eligibility criteria, but who were below 70 years (median age 67 (range 63-69) years) were included in the study to increase the sample size.

The flow of participants is presented in Figure 1. In total, 123 older adults were invited to participate, and 104 met for baseline testing. A total of 12 clusters were identified based on geographical residency. After randomization, an additional six participants were included and allocated to the cluster representing their geographical residency. Furthermore, three participants in wheelchair who could not perform testing were excluded from analysis. Table 1 presents participant characteristics.

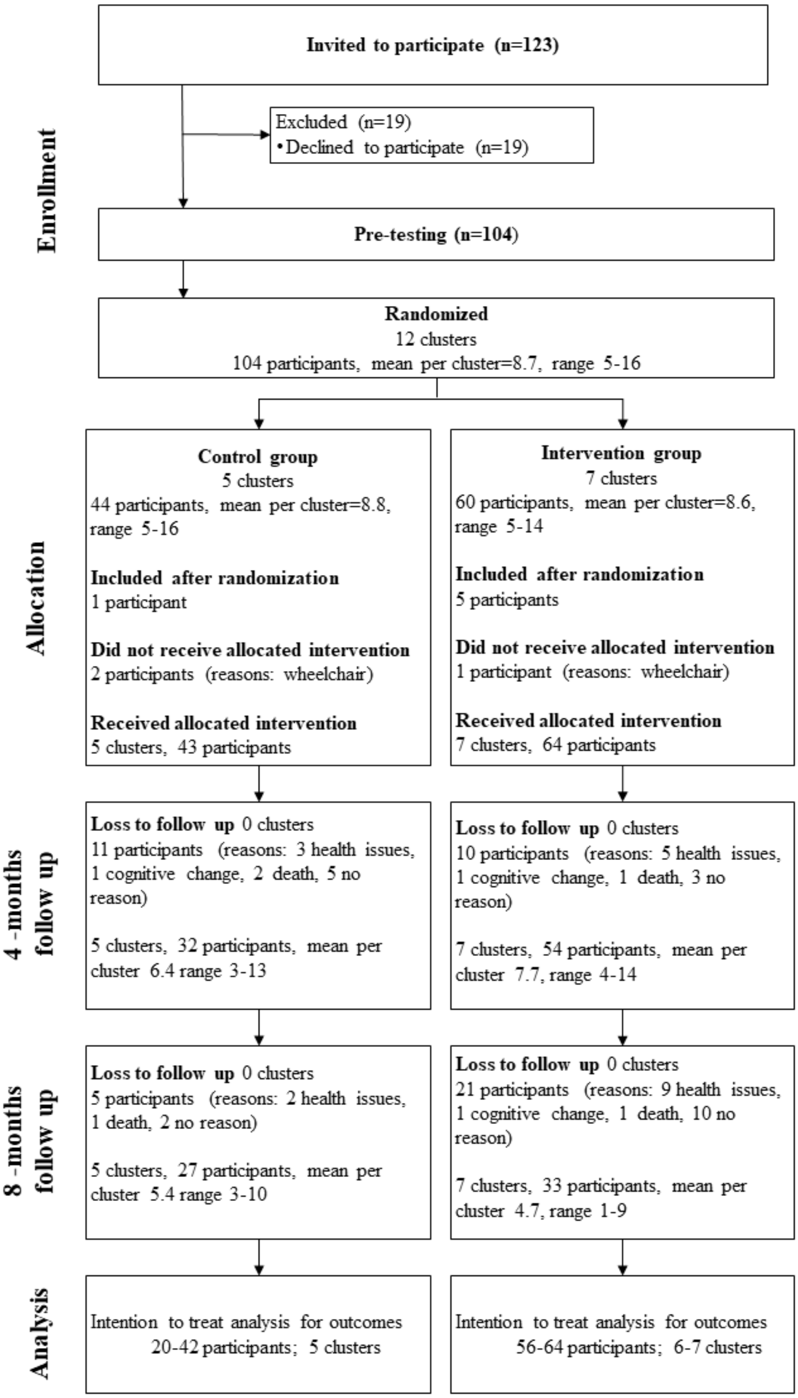

Figure 1. CONSORT (Consolidated Standards of Reporting Trials) flow chart of participant recruitment.

Table 1 Baseline characteristics of the participants.

	RTG (*n*=64)	CG (*n*=43)	Total (*n*=107)
Age (years) median (IQR)	87 (80-90)	86 (80-90)	86 (80-90)
Females n (%)	42 (66)	22 (51)	64 (60)
Use of mobility devices n (%) *	33 (52)	31 (72)	64 (60)
Height (cm) mean (SD)	160 (9)	164 (9)	162 (9)
Body mass (kg) mean (SD)	67.6 (17.5) [a]	74.3 (18.0) [b]	70.2 (17.9) [c]
Fat mass (%) mean (SD)	30.3 (8.5) [d]	29.7 (10.2) [e]	30.1 (9.1) [f]
Fat free mass (kg) mean (SD)	46.4 (11.8) [g]	51.5 (10.3) [h]	48.2 (11.5) [i]
Body mass index (kg/m^2) mean (SD)	26.0 (5.3) [a]	27.7 (5.7) [b]	26.7 (5.5) [c]
Chair rise (s) mean (SD)	19.1 (11.4) [a]	21.1 (6.5) [j]	19.9 (9.7) [k]
TUG-8ft (s) mean (SD)	14.6 (8.1) [l]	16.1 (6.2) [m]	15.2 (7.4) [c]
Stair climb (s) median (IQR)	18.8 (12.7-29.3) [n]	23.1 (19.0-33.6) [o]	20.1 (13.5-31.5) [p]
Preferred gait speed (m/s) mean (SD)	0.78 (0.28) [a]	0.66 (0.18) [m]	0.73 (0.25) [q]
Maximal gait speed (m/s) mean (SD)	1.10 (0.42) [a]	0.90 (0.28) [m]	1.01 (0.39) [q]
Leg MVC (N) mean (SD) **	185 (82) [a]	175 (67) [j]	181.2 (76.0) [k]
Relative MVC (N/kg) mean (SD) **	2.8 (1.0) [l]	2.3 (0.8) [r]	2.6 (1.0) [s]
Leg RFD (N/s) mean (SD) **	406 (32) [a]	448 (279) [j]	423 (306) [k]
Relative RFD (N/s/kg) mean (SD)**	6.0 (3.9) [l]	5.8 (3.7) [r]	5.9 (3.8)
Grip strength (kg) mean (SD)	25.4 (8.1) 64	28.0 (7.8) 42	26.4 (8.1) [s]
SB (min/day) mean (SD)	600 (100) [t]	643 (86) [r]	617 (96) [u]
LPA (min/day) mean (SD)	170 (73) [t]	145 (64) [r]	160 (70) [u]
MVPA (min/day) mean (SD)	35 (35) [t]	29 (30) [r]	33 (33) [u]
TPA (cpm) mean (SD)	278 (165) [t]	224 (138) [r]	256 (157) [u]
Steps (number/day) mean (SD)	6623 (3258) [t]	5223 (2623) [r]	6072 (3087) [u]

RTG, resistance training group; CG, control group; IQR, interquartile range as 25 and 75 percentiles; SD, standard deviation; TUG-8ft, timed 8-feet-up-and-go; MVC, maximal voluntary isomeric contraction; RFD, rate of force development; N, Newton; SB, sedentary behavior; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; TPA, total physical activity; cpm, counts per minute.

*Includes walker, canes, or crutches. One participant in CG with missing data. ** Tested in isometric leg extension.

[a] *n*=63 [b] *n*=40 [c] *n*=103 [d] *n*=59 [e] *n*=36 [f] *n*=95 [g] *n*=58 [h] *n*=31 [i] *n*=89 [j] *n*=42 [k] *n*=105 [l] *n*=62 [m] *n*=41 [n] *n*=55 [o] *n*=20 [p] *n*=75 [q] *n*=104 [r] *n*=39 [s] *n*=101 [t] *n*=60 [u] *n*=99

Randomization and blinding

As previously mentioned, 12 clusters (range 5-16 participants) were identified based on the geographical residency of the participants, meaning that participants living nearby belonged to the same cluster. The clusters were randomly allocated in a 3:2 ratio to the RTG or the CG using Microsoft Excel and a random numbers generator (RANDOM.ORG, Randomness and Integrity Services Ltd., Ireland). The randomization process was performed by the project leader using the following procedure: (i) a number (1-12) was assigned to each cluster and large clusters (≥10 participants) were weighted with two numbers, (ii) 60% of the participants (i.e., seven clusters) were allocated to RTG using a random numbers table and (iii) the remaining participants (i.e., five clusters) were allocated to CG.

Blinding of participants and exercise instructors is difficult in studies applying exercise interventions and consequently these were not blinded in ISRAE. Furthermore, those collecting and/or analyzing data were not blinded. The reasons for this were practical and economical concerns; the ISRAE project group was small and all researchers, instructors, and data collectors participated in all the phases of carrying out the study. Importantly, the exercise instructors were trained and instructed to follow the protocol.

Intervention

Paper II and III are based on data from the intervention, which will be described in detail in the following paragraphs. The intervention lasted for eight months from the end of September 2016 to the end of May 2017. Although a cluster randomized design was used, the intervention was targeted at the participant level.

Intervention group

Participants in the intervention group performed a resistance training program consisting of two 30-45 minutes long group-based sessions per week. The training sessions were held at the local health care centers and were led by trained exercise instructors. The resistance training program included exercises targeting the major muscle groups which are most important for daily living activities, and included rowing, chest press, squat, biceps curl, knee extension, shoulder press, and up-and-go. A detailed description of the progression and content of the resistance training program is presented in Table 2 and the exercises are illustrated in Figure 2. The exercises were performed using elastic bands (ROPES a/s, Aasgardstrand, Norway). The intensity and load were tailored to the individual by performing exercises seated or standing according to ability, and by adding water canes and/or changing the thickness and tension (level of pre-stench) of the elastic band. The up-and-go exercise was performed either with an elastic band or without and by walking and turning around a cone (Figure 3). Furthermore, the number of series and repetitions were manipulated, and new exercises were introduced to ensure progression (Table 2). After the baseline testing, a five-week introductory phase was conducted, focusing on proper execution of the exercises without going to fatigue. After this, volume and intensity were increased progressively, and participants were encouraged to perform each exercise to fatigue – i.e., they were unable to complete more repetitions with proper technique. The exercises were to be performed with high intentional velocity during the concentric phase (to increase explosive strength) and with slower controlled velocity in the eccentric phase (to increase the hypertrophic stimulus). Additionally, participants were encouraged to continue their normal daily activity.

Attendance to the exercise program was registered and defined as percentage of sessions met of sessions offered.

Table 2. Progression of the resistance training program.

Phase	Length (Weeks)	Number of exercises	Description of exercises	Series	Target repetitions
1	5	5	Rowing, chest press, squats, biceps curl, knee extension	2	10-12[a]
2	10	5	Same as phase 1	3	10-12
3	10	6	Same as phase 1 + shoulder press	3	8-10
4	10	7	Same as phase 3 + up-and-go	4	8-10

[a] Introductory phase, repetitions not performed until fatigue.
Table slightly modified from Bårdstu et al. 2020 (Paper II).

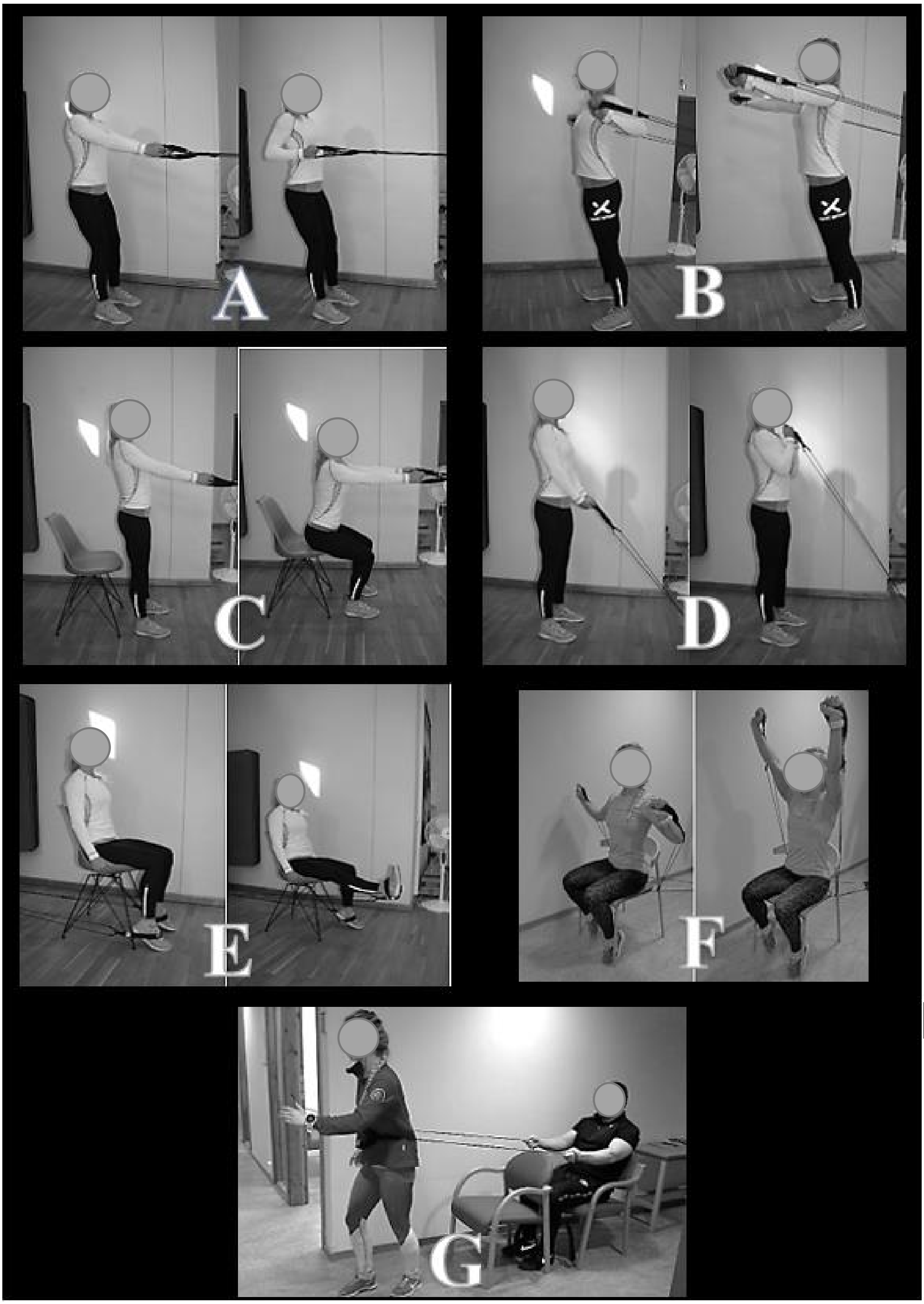

Figure 2. Illustration of the exercises: (A) rowing, (B) chest press, (C) squat, (D) biceps curl, (E) knee extension, (F) shoulder press, and (G) up-and-go.

Control group

Participants in the CG received PA counselling based on the national guidelines (54), as well as a physical education booklet from the Ministry of Health and Care Services. Furthermore, a researcher or research assistant contacted them every 6th week. This conversation was to remind them about the importance of achieving the national recommendations of PA and to motivate them to stay active. This conversation was conducted either as a visit or by phone.

Measurements

All measurements were performed at the participant level and assessed at baseline and after four- and eight months. Mainly, one test-day was organized at each health care center in the municipalities. However, if many participants were unable to attend the test-day, an attempt was made to gather these individuals for a second test-day or go for a home-visit for those in need of such. The data collection was organized and performed by trained researchers and research assistants. Paper I used only data from the baseline assessment, while Paper II and III used data from baseline, four-, and eight months.

Muscle strength

To assess muscle strength (Paper I-II) participants performed a maximal isometric contraction the leg extensors. A custom-made flexi-bench (Pivot 430 Flexi-bench, Sportsmaster, Norway) and a non-elastic band (ROPES a/s, Aasgardstrand, Norway) attached to a force cell (Ergotest innovation AS, Langesund, Norway) were used. Force data was recorded and analyzed using Musclelab Software (v10.5, Ergotest Technology AS, Langesund, Norway) using a frequency of 200 Hz and a range of 0-500 kg. The participants were seated, the knee was fixed at a 90-degree angle, and the non-elastic band was placed around the participants' preferred ankle. The instruction was to contract "as fast and forcefully as possible" and to hold the contraction for at least five seconds, and verbal encouragement was given. We aimed to perform three trials, but this was adjusted based on the individual's capacity. A 1-min resting period was carried out between each trial and the best trial was used in the analyses. Maximal strength was assessed as maximal voluntary contraction (MVC) and was defined as the highest average force output over a 3-second window. RFD was used to assess explosive strength and was calculated at the steepest vertical force generation as the mean tangential slope of the force-time curve over a 200-millisecond window. Weaker, very old individuals often use a longer time to peak force from onset of force as compared to younger and/or stronger individuals, which is one reason for choosing longer time-interval, such as 200-miliseconds. Furthermore, previous experience from a pilot study including a similar sample of older adults was taken into consideration regarding what to expect from the force-time curves, the individuals' ability to understand the task (e.g., generating force as fast and forcefully as possible), and their fear of pain and/or movement. MVC was analyzed as absolute MVC and absolute RFD (Paper II). Furthermore, we analyzed relative muscle strength normalized to body mass as relative MVC (Paper I and II) and relative RFD (Paper I).

Grip strength (Paper II) was measured using a hand-held dynamometer (Baseline® Hydraulic Hand Dynamometer, Elmsford, NY, USA). The participants were instructed to squeeze as hard as they could for three to five seconds using the preferred arm. Verbal encouragement was given. As for leg extension strength, we aimed to perform three trials, but adjusted this based on the individual. The best of trials was used for analyses.

Physical function

We included five physical tests to assess physical function. We aimed to perform three trials per test, but adjusted this according to the individual's ability. A stopwatch was used to register time. The participants were allowed to use mobility devices, handrails of chairs, and/or the rails of the stairs if necessary.

Chair rise (Paper I and II) was measured as the time taken to finish five sit-to-stand cycles (30). The participants were instructed to perform the test as fast, but controlled as possible. A straight backrest chair with armrests was used and the participants were told to fully extend their legs in the upright position. The best trial was used for analyses.

For the timed 8-feet-up-and-go (TUG-8ft, Paper I and II) the participants were instructed to rise from a chair, walk 2.4 meters (8 feet), turn around a cone, and walk back to the chair and sit down (121). The test was to be performed as fast, but controlled as possible. A straight backrest chair with armrests was used and the best trial was included in the analyses.

Preferred- and maximal gait speed (Paper I and II) were assessed over 20-meters, with a one-meter acceleration- and retardation phase before and after the 20-meter course (122). For preferred gait speed, the participants were told to walk in a comfortable pace, and the average of the trials was included in analysis. For maximal gait speed, the participants were instructed to walk as fast as possible without running and with proper control and the best trial was included in the analyses.

Stair climb (Paper II) was measured as the time needed to walk up a flight of stairs. As testing was conducted at the different health care centers the same staircase was not used for all participants. However, each participant walked the same staircase at the baseline, four-, and eight months assessment. The number of steps ranged from 16 to 24, with a vertical climb of 2.7 to 4.0 meters. The participants were instructed to ascend the staircase in the same way as they normally would. The best trial was used for analyses. One cluster (CG n=15) did not have access to stairs at their health center and was not included in analyses. Due to the low number of participants with valid stair climb data, this test was not included in paper I which examined the association between muscle strength and physical function.

Physical activity levels

To assess PA levels (Paper III) the ActiGraph GT3X+ triaxial accelerometer (ActiGraph, LLC, Pensacola, FL, USA) was used. An accelerometer detects the acceleration of the body segment of which it is attached to. The ActiGraph is a small, lightweight device able to record and store free-living accelerometer data for several days and weeks. The participants were asked to wear the accelerometer in a belt attached over their right hip for at least 14 consecutive days and only to remove it while sleeping or during showering/bathing. The accelerometers were initialized with a sampling rate of 30 Hz and analyzed using 10-second epochs using the ActiLife v.6.11 software (ActiGraph, LLC, Pensacola, FL, USA).

At date, there is no clear consensus on protocols and analytical approaches for using accelerometers to assess PA levels (123). The methodological choices made in this thesis (Paper III) have been made based on the population of interest, which are older adults. First, tri-axial accelerometers collect acceleration in three directions (gravitational-, anteroposterior-, and mediolateral axis) and are sensitive to both gravitational- and dynamic acceleration (124). Vector magnitude (VM) incorporates data from all three axes (i.e., square root of the sum of the squares of each axis of data) (125) and was used for analyses. Furthermore, the ActiGraph low frequency extension (LFE) filter was applied. The LFE filter sets a lower frequency threshold for detecting accelerations, capturing slower movements often seen in older adults (126). Non-wear time was defined as at least 90 consecutive min of zero counts, allowing for a 2 min interval of non-zero counts if accompanied by 30 min of consecutive zero up- or downstream as suggested for older adults using VM (125). The first day of wearing the accelerometer was excluded due to the risk of reactivity (127). Files with at least 10 hours of data for at least 4 days were considered valid (128) and data between midnight and 6:00 am were excluded.

The included outcomes were total PA (TPA, counts per minute (cpm)), SB (min/day), LPA (min/day), MVPA (min/day), and steps (steps/day). The cut points chosen to assess time spent in different intensity zones were developed and validated in older adults and by using VM and are presented in Table 3. The number of steps was registered using the embedded pedometer function in the GT3X+ device.

Table 3. Cut points used to assess time spent in different intensity zones.

Intensity	Cut points
Sedentary behavior (SB)	0-199 cpm (129)
Light physical activity (LPA)	200-1923 cpm (129,130)
Moderate-to-vigorous physical activity (MVPA)	≥1924 cpm (130)

Body composition

Body composition (Paper II) was assessed with bioelectrical impedance analysis using a Tanita weight (Tanita MC 780MA S, Illinois, USA). A small electrical signal is sent from the metal electrodes on the handles of the Tanita weight through the body. This electrical signal passes quickly through water (hydrated muscle tissue), and slower in fat tissue. Based on this, equations from the manufacturer calculates the different body composition measures (Tanita MC 780MS S, Illinois, USA). The participants were instructed to be barefooted and wear light clothing. Participants with a pacemaker were told not to perform the bioelectrical impedance analysis. Furthermore, height was measured without shoes using a stadiometer. Body composition was assessed using the outcomes body mass index (BMI), percentage body fat, and fat free mass.

Ethics

The Regional Committee for Medical and Health Research Ethics South-East and the Norwegian Centre for Research Data evaluated the study (2016/51 and 49361/s/AGH, respectively), and it was conducted in accordance with the Declaration of Helsinki and Norwegian laws and regulations. ISRAE was registered in the ISRCTN registry (1067873). We registered ISRAE retrospectively due to miscommunication within the research group. The results are presented according to the CONSORT statement extension to cluster randomized trials (131). All participants received oral and written information about the study before signing a written, informed consent-form.

Statistical analyses

All statistical analyses were performed using STATA (Version 15.0-17.0, StataCorp. 2017-2021. Stata Statistical Software: Release 15.0-17.0. College Station, TX: StataCorp LLC). Figures were made in SigmaPlot 14.0 (Systat Software, Inc., San Jose, CA, USA) or GraphPad Prism 8.0 (GraphPad Software, San Diego, California USA). To assess normality of the data, Q-Q plots of the residuals were visually inspected. Normally distributed descriptive data was presented as mean and standard deviation (SD). For non-normal variables, descriptive data was presented as median and 25-75 percentile (interquartile range, IQR). A p-value of < 0.05 was considered statistically significant in all studies and for all analyses.

Paper I

In Paper I linear regression was used for analyses. The dependent variables were the continuous variables of physical function, and the independent variables were the muscle strength variables. Analyses were conducted for each combination of the physical function and muscle strength variables. Standardized regression coefficients (β) and 95% confidence intervals (95% CI) were calculated to show the strength of each independent variable to the dependent variable. All analyses were adjusted for gender.

Paper II and III

In Paper II and III linear mixed models were used to assess the between-group effects, according to the intention to treat principle. To obtain the baseline level the two groups were merged (132). The interaction between group (RTG and CG) and time (baseline, four and eight months) was included, and cluster and participant-id were entered as random effects accounting for cluster randomization and dependency of repeated measures. Furthermore, the intra-cluster correlation coefficient (ICC) was calculated for all outcomes as between cluster variation divided by total variation (133). Figure 3 shows the levels included in the analysis of Paper II and III.

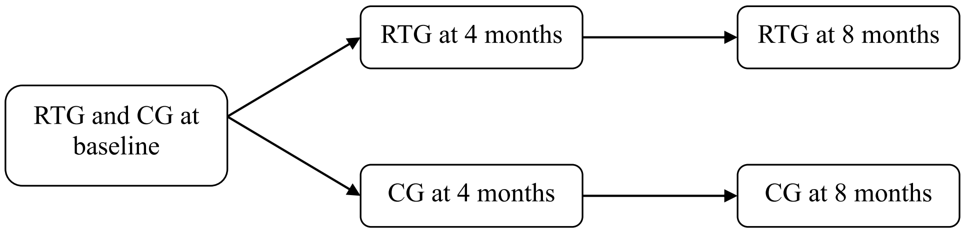

Figure 3. Levels included in the analysis of Paper II and III.

After examination of normality using Q-Q plots, chair rise, TUG-8ft, stair climb, BMI, fat mass, and fat free mass was transformed using the natural logarithmic scale in Paper II. The outcomes were back transformed using the formula $exp.(\mu + \frac{\sigma^2}{2})$. The estimated mean difference between the two groups is presented as ratios and 95% CI. For the other outcomes (i.e., muscle strength), results are presented as mean and 95% CI. In Paper II some sensitivity analyses were performed: (1) per-protocol analyses of participants with ≥ 60% attendance to the exercise sessions, (2) analyses of participants meeting the original inclusion criteria (≥ 70 years), (3) analyses adjusting for the baseline value of the outcome without using combined baseline, and (4) analyses of stair climb adjusted for vertical climb and number of steps in two separate analyses.

In Paper III the results were presented as mean and 95% CI. Furthermore, we performed some sensitivity analyses for Paper III: (1) per-protocol analyses of participants with ≥ 60% attendance to the exercise sessions, (2) analyses of participants meeting the original inclusion criteria (≥ 70 years), (3) analyses adjusting for the baseline value of the outcome without using combined baseline, and (4) analyses adjusting for wear time, age, and BMI.

Loss to follow up

Some extra analyses which were not included in the papers were performed for this thesis. First, an examination of potential differences in the baseline characteristics between those lost to follow up and those remaining in the study was conducted. Second, analyses were performed to examine whether there were some differences in the baseline characteristics between those lost to follow up in RTG versus CG. An independent samples t-test was used, except for the analysis of age and stair climb where the Wilcoxon rank-sum test was used.

Summary of results

In this section, a summary of the results from the three papers will be presented. For more details, see Paper I-III. Furthermore, some additional analyses on loss to follow up, which were not included in the papers, will be presented.

Paper I

The aim of the paper was to examine the cross-sectional associations between muscle strength and physical function among community-dwelling older adults receiving home care.

Table 4 show the standardized regression coefficients (β) with 95% CI and p-values for the associations between muscle strength and physical function, adjusted for gender. Higher relative MVC was significantly associated with improved chair rise ability, TUG-8ft performance, preferred-, and maximal gait speed ($p < 0.01$ for all, β -0.26 to 0.45). Similarly, higher relative RFD was significantly associated with improved chair rise ability, TUG-8ft performance, preferred-, and maximal gait speed ($p < 0.01$ for all, β -0.35 to 0.48).

Sensitivity analyses without extreme values (n=93-96 participants analyzed) showed no major changes, except for a higher β indicating a stronger association between relative MVC and chair rise (-0.40 [-0.59, -0.21] and a lower β indicating a weaker association between relative RFD and chair rise (-0.29 [-0.49, -0.09]).

Table 4. Regression analyses showing the association between muscle strength and physical function.

	n	**Standardized regression coefficient** ß	95% CI	**p-value**
Chair rise				
Relative MVC	100	-0.26	-0.45, -0.06	0.009
Relative RFD	100	-0.35	-0.54, -0.17	<0.001
TUG-8ft				
Relative MVC	99	-0.36	-0.53, -0.19	<0.001
Relative RFD	99	-0.43	-0.60, -0.27	<0.001
Preferred gait speed				
Relative MVC	99	0.39	0.22, 0.57	<0.001
Relative RFD	99	0.40	0.22, 0.57	<0.001
Maximal gait speed				
Relative MVC	99	0.45	0.27, 0.62	<0.001
Relative RFD	99	0.48	0.31, 0.66	<0.001

MVC, maximal voluntary isometric contraction; RFD, rate of force development; TUG-8ft, timed 8-feet-up-and-go; CI, confidence interval; ß, standardized regression coefficient. MVC and RFD tested in isometric leg extension. Adjusted for gender. Table modified from Bårdstu et al. 2022 (Paper I).

Paper II and III

The aim of Paper II was to assess the effectiveness of a pragmatic resistance training program compared with a control condition on physical function, muscle strength, and body composition among community-dwelling older adults receiving home care. Using the same sample, the aim of Paper III was to assess the effectiveness of the same pragmatic resistance training program on PA levels.

Of the 107 participants that initiated the intervention 86 were followed up at 4 months and 60 after 8 months (Figure 1). The number of participants analyzed ranged from 76-106.

Paper II

From baseline to eight months, statistically significant between-group differences were found for all physical function tests (9-24%, p=0.01-0.03, Figure 4) and absolute- and relative MVC (16-18%, p=0.01-0.03) all in favor of RTG. There were no differences in the between-group changes for RFD, grip strength, or body composition after eight months. Furthermore, after four months the RTG had improved more than CG in stair climb (18%, p=0.03) and maximal gait speed (8%, p=0.01) (Figure 4).

A per-protocol analyses of participants attending ≥ 60% of training sessions showed that the difference between the groups in TUG-8ft after eight months was smaller and no longer statistically significant (10%, p=0.06). A sensitivity analysis removing participants under 70 years showed smaller and no longer statistically significant between-group differences for stair climb after four months (17%, p=0.06), and maximal gait speed (7%, p=0.11) and absolute MVC (13%, p=0.05) after eight months.

Paper III

There were no significant between-group differences in any of the PA outcomes from baseline to eight months (Figure 5 A-E). From an estimated baseline mean of 261 (95% CI 217-306) cpm the estimated mean difference between RTG and CG was 20 (95% CI -16-37) cpm after eight months. The estimated mean SB at baseline was 616 (95% CI 593-639) min/day and the mean difference between the groups after eight months was 9 (95% CI -42–23) min/day. Estimated mean LPA at baseline was 161 (95% CI 144-178) min/day with a mean difference between RTG and CG of 8 (95% CI -13-29) min/day after eight months. For MVPA the estimated mean at baseline was 34 (95% CI 24-43) min/day, and after eight months the mean difference between the groups were 3 (95% CI -3-10) min/day. The estimated mean steps per day was 6105 (95% CI 5247-6964) at baseline, with a mean difference between the groups of -90 (95% CI -896-716) steps/day in favor of CG after eight months.

There was no additional benefit in RTG when more than 60% of the training sessions had been completed. Similarly, there were no changes in the conclusions following the other sensitivity analyses.

Loss to follow up

Overall, we experienced a 44% loss to follow up from baseline to eight months. Those lost to follow up were older than those remaining (median (IQR) age 88 (8) versus 85 (10), p=0.011). Furthermore, those remaining in the study performed better on chair rise (mean (SD) 17 (6) sec versus 23 (13) sec, p=0.001) and stair climb (median (IQR) 19 (13-27) sec versus 24 (18-40) sec, p=0.026) at baseline.

Loss to follow up was higher in RTG (48%) versus CG (37%). Grip strength was higher among those lost to follow up in CG than RTG (mean (SD) 29 (9) kg versus 23 (7) kg, respectively, p=0.014). Fat mass (%) was higher in those lost to follow up in RTG than CG (mean (SD) 32 (8) versus 25 (10) respectively, p=0.041).

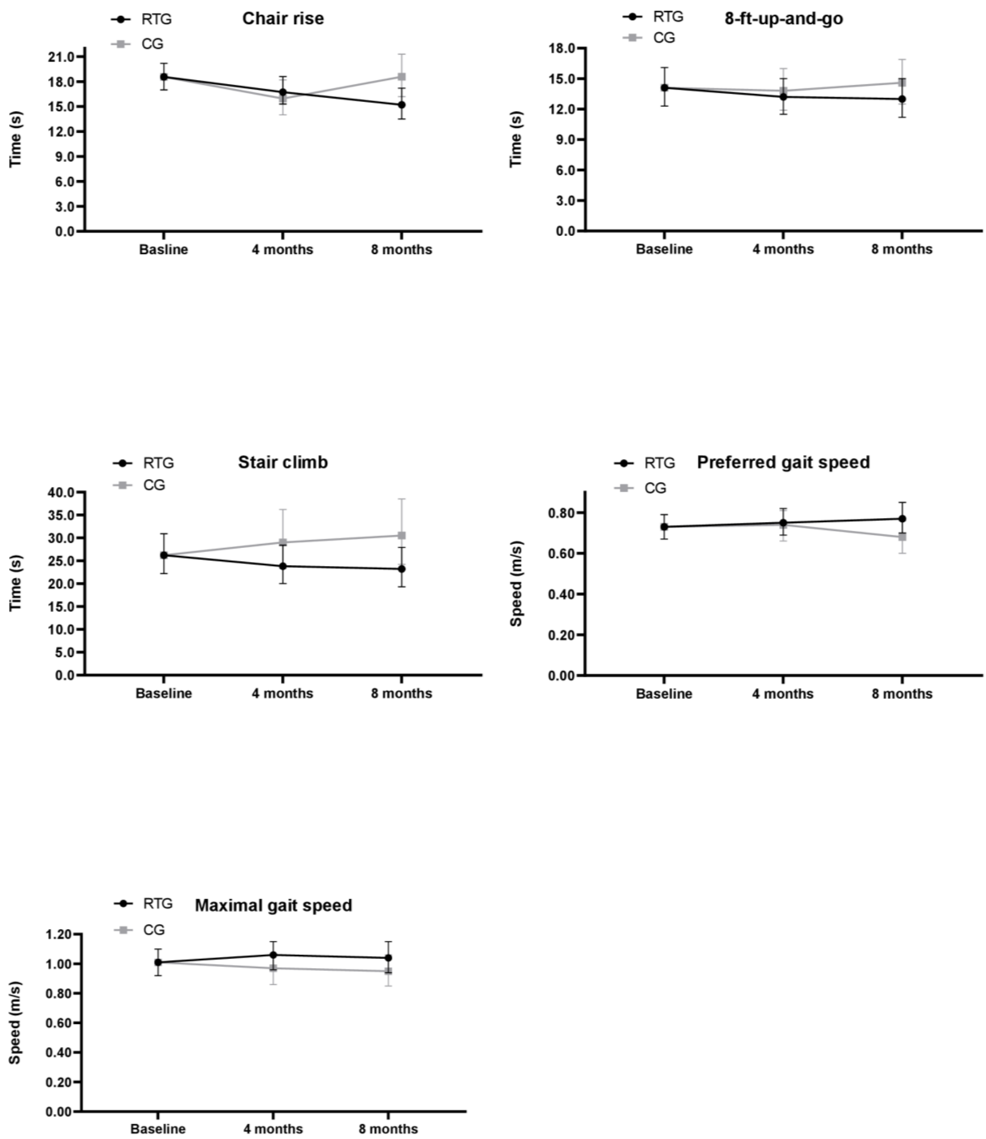

Figure 4. Changes in physical function from baseline to four- and eight months. Values are estimated means and 95% confidence intervals. Figure from Bårdstu et al. 2020 (Paper II).

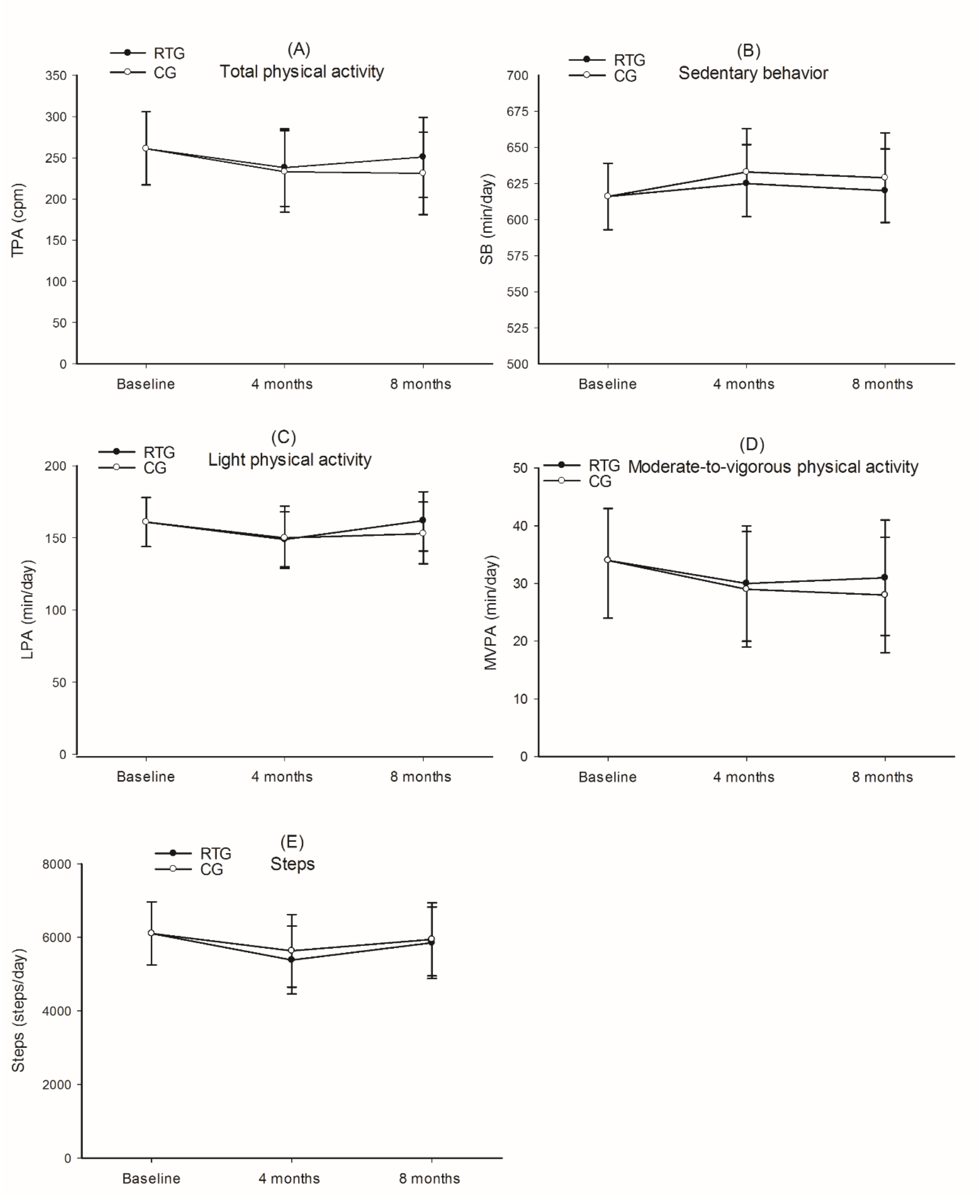

Figure 5. Changes in physical activity levels from baseline to four- and eight months. Values are estimated means and 95% confidence intervals. RTG, resistance training group; CG, control group; Total PA, total physical activity; cpm, counts per minute; SB, sedentary behavior; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity. Figure from Bårdstu et al. 2021 (Paper III).

Discussion

A detailed discussion of the specific results is presented in Paper I-III. In the following discussion the main findings will be summarized briefly and the findings across the different studies will be reflected upon. Thereafter, methodological- and ethical considerations will be addressed, followed by perspectives and suggestions for future research.

Main findings

A short summary of the main findings from the three papers that this thesis consists of is presented below.

In *Paper I* we showed that both maximal (i.e., MVC)- and explosive (i.e., RFD) muscle strength were associated with physical function, measured using chair rise, TUG-8ft, preferred-, and maximal gait speed among older adults receiving home care.

Paper II showed that the eight-month pragmatic resistance training program was more effective than PA counselling for improving maximal muscle strength (i.e., MVC) and physical function (i.e., chair rise, TUG-8ft, preferred- and maximal gait speed, and stair walk) among older adults receiving home care. We found no between-group differences for explosive strength or body composition.

Paper III demonstrated that eight-months pragmatic resistance training was not a more effective approach than PA counselling for improving PA levels in older adults receiving home care. However, the resistance training group showed a smaller decline in MVPA and total PA, stable LPA levels, and less increase in time spent sedentary compared to the control condition.

Discussion of the results

The relationship between muscle strength and physical function

The participants examined in the research for this thesis can be classified as low functioning individuals due to their high age, home care, and mobility device use. It has been suggested that there exists a function threshold above which an improvement in maximal- and/or explosive strength only leads to marginal or no improvements in physical function (134). Above this threshold, muscle strength is not a limiting factor for the ability to for example walk or rise from a chair (Part B in Figure 6). However, below this threshold, muscle strength may be the limiting factor and even small improvements in muscle strength may translate into large improvements in physical function (Part A in Figure 6) (134,135). Thus, most likely the participants examined in the research for this thesis falls within part A of Figure 6, indicating that muscle strength plays an important role for physical function. Despite this, there is limited research on the relationship between muscle strength and physical function among the oldest old (>80 years) (42–45).

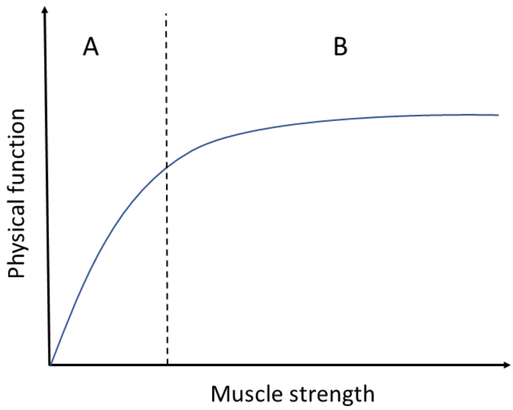

Figure 6. Illustration of a potential theoretical curvilinear relationship between muscle strength and physical function. (A) muscle strength may be a limiting factor for physical function. (B) muscle strength most likely not a limiting factor for physical function. Figure inspired by Buchner and colleagues (1996) (134).

Paper I was an exploratory cross-sectional study, and the findings are supportive of previous studies by indicating that higher maximal- and explosive strength is related to better physical function among the oldest old (>80 years) (42–45). This finding suggests that maintaining and/or improving muscle strength into old age is important for perseverance of physical function also among the oldest old who receive home care and where the majority is dependent on mobility devices (60%). Furthermore, although previous research indicate that explosive strength is more important for physical function than maximal strength, few have examined this relationship among the oldest old (>80 years) (45) and/or those receiving home care. We examined measures of both maximal- and explosive strength in the same population. Although we cannot conclude on the independent contribution of MVC versus RFD based on our analyzes, some interesting reflections can be made. The standardized regression coefficients (β) give an indication of the strength of the relationships. Overall, both MVC and RFD were associated with all measures of physical function. The β values were somewhat higher for RFD than MVC for all physical function measures. Similarly, although we did not publish the explained variance (r^2) it ranged from 7-22% for MVC and 13-25% for RFD (unpublished results). This is in the same range as what has been reported in a systematic review including mainly older adults in their 60-s and 70-s (51). Despite what may be assumed with respect to the relative importance of the two strength measures, our findings do emphasize the importance of maintaining and/or improving both maximal- and explosive strength for perseverance of physical function into old age. Knowledge about the relationship between muscle strength and physical function is important for those designing and implementing preventive- and treatment strategies. However, cross-sectional results do not state causality or temporality. To establish and clarify the role of muscle strength for physical function, RCTs designed to examine the effectiveness of resistance training are needed.

The resistance training intervention

Based on a substantial body of evidence, it has been proposed that resistance training is effective to counteract the age-related changes in muscle strength, physical function, and body composition (24,26,75–78,84). Less is known about the impact of resistance training on PA levels (110). The findings of the present thesis suggest that this pragmatic resistance training program had a small to moderate effect on maximal strength and physical function. However, we were not able to demonstrate between-group differences in explosive strength, body composition, or PA levels. To understand the findings of Paper II and III, it is important to relate them to the design and implementation of the pragmatic resistance training intervention. The design was in accordance with recommendations for older adults (4) and based on experiences from a pilot study investigating a comparable sample (89).

Specificity and transferability between training and testing could explain some of our findings. For example, participants performed the squat to a chair and an “up and go” exercise, which are transferrable to chair rise ability, TUG-8ft, and in some ways, gait. Furthermore, leg extension was included as a training exercise and was also used to assess muscle strength. Importantly, we tested muscle strength in an isometric contraction while the training was dynamic. This indicates a training effect on maximal strength (i.e., MVC) and not just a learning effect. However, even greater improvements could have been expected using dynamic testing after dynamic resistance training (3,4). It should also be mentioned that most of the exercises targeted the upper body and that a larger volume and load targeting the lower body may have led to greater improvements (136).

Lack of specificity could further explain why we failed to demonstrate significant between-group differences for PA levels. We hypothesized that an increase in PA would result from strength gains and better physical function as these are related in older adults (64,67). Furthermore, resistance training could make movement easier. This could also have broken up SB thereby reduced time spent sitting. However, we were not able to demonstrate changes in SB, LPA, MVPA, total PA, or steps, which is in accordance with most previous studies (87,89,111,112). Fiatarone and colleagues found increased PA along with strength gains and better physical function (69), but their strength- and muscle mass gains were larger than what we demonstrated. Furthermore, they assessed PA over a 72-hour window, which is rather shorth. Thus, their finding may be a results of a spontaneous increase due to the individuals knowing that they were being measured, a phenomenon called measurement reactivity (127). It should be mentioned that our training group maintained their LPA at the same level as at baseline and that the reduction in MVPA and total PA was smaller than in the controls. Thus, we may have been able to counteract some of the age-related decline over the eight months, which is very important for this group of individuals. This was despite of the fact that many of the participants probably experienced increased total stress due to regular participation in resistance training sessions which none of the participants were accustomed to. Importantly, the resistance training program did not specifically aim to improve PA levels. A potential solution could be to include walking exercises and/or behavioral strategies (e.g., goal setting, attitude change, social support) which may heighten the potential to increase PA and decrease SB (137–139). However, this would have changed the main aim of ISRAE and would not have answered whether the current pragmatic resistance training program alone was effective for changing the PA levels.

Our pragmatic approach involved designing a resistance training program using low-cost, easily available equipment and we used elastic bands, chairs, water canes, and body weight as resistance. The literature comparing elastic bands with traditional equipment such as weight machines and/or free weights among older adults are sparse, but suggest that elastic bands are a viable alternative for improving strength, function, body composition in older adults (140,141). Studies examining the effectiveness of pragmatic resistance training on PA levels are still lacking. To ensure safety and effectiveness of exercise it is important to control the intensity and resistance, but quantification of intensity and resistance using elastic bands have been problematized previously (75,88). We used a combination of exercising to fatigue and volume (target number of repetitions and sets) to control the intensity, and used elastic bands of different thickness and tension to ensure progressive overload. However, the intensity and resistance were still subjectively based and there is a chance that some participants trained at a lower intensity and/or resistance than what they were able to due to for example fear of pain or a misunderstanding of what it meant to train to fatigue. Overall, we are confident that the combination of ways to monitor intensity and resistance as well as the supervised sessions ensured adequate stimuli for as many participants as possible. This may also explain why we were able to demonstrate improvements in all measures of physical function, which targeted the ability to walk, rise from a chair, and climb stairs.

The pragmatic resistance training program was designed as a "heavy explosive resistance training program" as the participants were instructed to train with high intensity and high intentional velocity. After eight months, a between-group difference was observed for maximal- (i.e., MVC), but not explosive strength (i.e., RFD). We may have been able to ensure a high intensity during training, but unable to control and ensure that the exercises were carried out with high intentional velocity. In practice perhaps the training could be described more as heavy than as explosive. Although studies on adults have shown increased velocity with variable resistance (e.g., using elastic bands) compared to weight machines and/or free weights (142), elastic bands provide variable resistance that increases at the end of the range of motion (74). This could have affected the ability to maintain a high intentional velocity during the last haft of the concentric phase where the force generated is higher. Furthermore, some of the participants may not have understood the term "as fast as possible" or not been able to create a high enough velocity to improve explosive strength. Interestingly, both MVC and RFD was cross-sectionally related to physical function (Paper I), with indications of a marginally stronger relationship for RFD. However, there were no between-group differences for RFD despite increased physical function (Paper II). It should be mentioned that the high variability seen in RFD may have influenced our ability to detect an intervention effect, as could the choice of window length (143). The improvements in maximal strength along with the specificity discussed previously may have been a sufficient stimulus for improvements in physical function to occur in our sample.

We experienced low attendance (51%) to the training sessions. Poor health and physical function are associated with low exercise attendance (144), which is relevant for the sample examined in this thesis. A meta-analysis reported high (>75%) attendance rate to resistance training programs among older adults, but stated that these data are difficult to interpret due to different definitions of attendance (78). For example, we calculated attendance taking loss to follow up (e.g., drop outs) into consideration, while others report these data with these individuals excluded (78). Thus, the low attendance is partially related to the large proportion of loss to follow up, which will be discussed more in detail in the methodical considerations chapter. When those lost to follow up were excluded, we experienced a 69% attendance rate for those remaining in the study, which is more comparable to other studies (78). Regardless, the high loss to follow up, low attendance, and number of offered sessions (two per week) may indicate that the training volume and frequency could have been too low in some cases, which could explain our small-to-moderate- and lack of effects. Especially, sufficient volume and frequency has been found to be important for muscle growth (4,24,71) which may explain why we were unable to demonstrate alternations in body composition. Furthermore, it has been indicated that the oldest old experience less gains in muscle mass (21,24), which is relevant for our participants. Furthermore, the first five weeks of ISRAE served as an introductory phase with low intensity and volume progressing from there on, which may explain the lack of between-group differences for most of the outcomes after four months. On the other hands, although older adults are recommended to perform resistance training twice or more per week (4), our findings may suggest that the oldest old, receiving home care may even benefit from resistance training for 30-45 minutes only once or twice a week. This may be related to the low initial level of muscle strength and physical function in our sample. Such groups of individuals often demonstrate greater improvements in physical function following resistance training as compared to more functional older adults (47). This may be explained by the nature of the relationship between muscle strength and physical function (Figure 6) as discussed previously. Furthermore, it may be an important aspect to ensure that the training period is adequately long. Thus, it seems reasonable to advise older adults to engage in structured resistance training in a long-term perspective. Furthermore, even a small weekly volume, which may be manageable for most individuals of very old age and home care services, may be beneficial.

The participants in CG were offered PA guidance in accordance with the Norwegian recommendations (54). Furthermore, they were informed about the importance of an active lifestyle and given regular motivational talks. We cannot exclude the possibility that some of the participants in CG were more active during the intervention than they had been previously or would have been without receiving this information. Thus, the age-related decline seen in CG may have been underestimated as compared to allowing nature to take its course.

Older adults receiving home care

Older adults receiving home care is a relatively new group to study and they are underrepresented in clinical research. One reason for this may be that it is a very heterogenous group when it comes to chronological age, as well as their health- and functional status. This could make it difficult to develop strategies targeting the entire spectrum of conditions. Furthermore, many of these individuals use mobility devices, such as walkers, rollators, or canes. This makes it more challenging to perform training and testing in terms of individual tailoring and/or monitoring. Several studies have excluded older adults with mobility devices (37,46,100,135) and many studies do not state whether mobility devices are allowed during testing and/or training (70,85,86,88,91–93,107,108). However, mobility devices are common among the oldest old (7,145) as they may help compensate for lower limb weakness and help maintain mobility (145,146). Consequently, it is reasonable to believe that these individuals 1) are of low initial strength and function, and 2) may have much to gain from improving these aspects. Lusardi and colleagues published reference values for healthy older adults from 80 to 89 years where 30% used mobility devices (31). Our participants had poorer performance on chair rise (19.9 sec versus 17.1 sec), TUG (15.2 sec versus 13.6 sec), comfortable- (0.7 m/s versus 0.8 m/s), and maximal gait speed (1.0 m/s versus 1.2 m/s). It should be mentioned that in our sample 60% used mobility devices. Nonetheless, this emphasizes the large potential for improvement in these individuals. Therefore, we argue that it is important to include older adults in need of mobility devices and allow them to use their devices during training and/or testing because this is the reality for many older adults in their daily life. Although it in some cases will be at the expense of the quality of testing and/or training and increase variance it may also increase the generalizability of the study.

Although we included individuals of poor strength and function, their time spent in MVPA and daily number of steps were higher compared to previous estimates for older adults (55,56,89). This may come as a surprise, however, we used age-relative intensity thresholds and not absolute thresholds to estimate MVPA (147). Zisko and colleagues examined a sample of Norwegian older adults (mean age 72.5 years) and found that a substantially higher proportion met the recommendations for time spent in MVPA when relative intensity thresholds were compared to absolute thresholds (75% versus 30%, respectively) (148). Furthermore, we applied the LFE filter and used all three axes (VM) in the estimations. This has been suggested for older adults, but may influence the estimations. Although we cannot exclude the possibility that we have overestimated time spent in active and underestimated time spent inactive, we stress the importance of choosing as age-appropriate thresholds as possible since the reduction in basal metabolic rate and increase in fat free mass seen with aging causes the energy expenditure to decrease (149). It should be noted that our aim was not to describe the participants level of PA, but examine the between-group differences which should not be influenced by these methodological choices.

Methodological considerations

The RCT is regarded the gold standard for evaluating the effectiveness of interventions (150). The aim of a RCT is to draw inferences from findings observed in the study sample and apply these to a real-world setting (151). The validity of a RCT is an important quality indicator (150). Internal validity is related to what happened in the study (i.e., design, conduction, and reporting) and external validity is related to the study's generalizability, meaning to what extent the study's finding can be applied to the general population (151). Violation of validity is related to bias, which is defined as the tendency of an estimate to systematically deviate in one direction from the true value (151). In the following sections the methodological aspects that may have affected the validity of the ISRAE and the papers included in this thesis will be discussed.

Sampling and participants

In ISRAE, we used a convenience sample which means that individuals that meet the eligibility criteria, are easily available, and willing to join are invited to participate (151). Such samples are not always representative of the accessible population, which affects the ability to generalize the findings from our sample to the population of interest (151). However, all the older adults living in Sogndal, Luster, or Leikanger and who met the eligibility criteria were invited and we included all those willing to participate. We do not see any reason why older adults living in these three municipalities should be very different from those from the rest of Norway.

Although we invited all eligible individuals, participant bias may have occurred. Participant bias is a type of selection bias which is observed when those who chose to participate in a study differ from those choosing not to (151). In an intervention study aiming to evaluate the effect of a resistance training program there is a chance that those who chose to participate are familiar with exercise, take good care of their health, and/or are more motivated as compared to those not choosing to participate. Potentially, this could have led to healthy-participant bias (151). Unfortunately, we did not include a reference group consisting of those who declined to participate, and we do not have any information about non-responders. Thus, we cannot exclude the possibility for selection bias affecting the representativeness of our sample.

Cluster randomization and sample size

Cluster-RCTs randomize groups of participants, and not individuals, into the study arms (118). Participants in one cluster tend to be more like each other and respond more similar than to those in another cluster due to common exposures. Consequently, observations within a cluster tend to be correlated, which reduces the effective sample size (118). The reduction in effective sample size is dependent on the degree of similarity of outcomes among members of the same cluster, known as the Intracluster Correlation Coefficient (ICC). An ICC of 1 means that all responses within a cluster are identical (152) and the ICC can be used to calculate the sample size needed while taking clustering into account (152). As previously mentioned, we aimed to include as many participants as possible based on our resources and did not plan the sample size taking clustering into account. We chose to calculate the ICC for our outcomes afterwards and include them in the papers (Paper II and III) for two reasons: 1) they allow the reader to interpret our findings based on the ICC and 2) they may be of relevance for future studies aiming to carry out a cluster RCT using a similar sample and similar outcomes. Preferably, we should have included more municipalities, but in Western Norway the travel distances are long, and the municipalities have few inhabitants. Our resources did not allow us to extend the project. However, we cannot exclude the risk of type 2 error, which are defined as failing to reject a null hypothesis that is actually false (151), especially for RFD (Paper II) and PA level (Paper III) as they had the largest ICC.

Proper randomization is one of the cornerstones of a well-designed RCT and ensures that prognostic baseline factors (e.g., age, gender) that could confound the observed effect are evenly balanced between the study groups and minimizes selection bias (151). However, selection bias can occur if the randomization process is not performed properly. For example, those recruiting participants may do so based upon knowledge of the upcoming treatment allocation if a study has improper allocation concealment (151,153). In ISRAE, randomization was carried out by the study leader, who also were involved in recruitment and testing of eligible participants. Preferably, randomization should have been carried out through a third party to reduce possible selection bias. Furthermore, we did include some participants after randomization, who were allocated to the cluster representing their geographical belonging. This only concerned a small portion of participants and since clusters were identified prior to randomization the risk of post-randomization selection bias is most likely small (118).

Blinding

The investigator's or participant's assumptions about the benefits of one treatment over another can affect the outcomes, leading to performance bias (151,153). Thus, performance bias concerns differences between groups in how the intervention is provided and their exposure to factors other than the intervention (153) and is related to blinding of a study. The nature of the exercise intervention made blinding of participants and exercise instructors impossible. To avoid performance bias, the exercise instructors were thoroughly trained and instructed to follow the protocol, and regular meetings and discussions were held to refresh both skills and knowledge. Furthermore, we did not blind researchers involved in data collection and/or data analyzes due to practical concerns and limited resources. We acknowledge that this could have introduced detection bias, which is bias related to how outcomes are assessed (151,153). However, all those involved in the data collection received instructions and were properly trained to try to avoid bias.

Loss to follow up

Loss to follow (e.g., dropouts, deaths, worsening of health etc.) up is often a major issue in studies including older adults. Loss to follow up may introduce attrition bias, which is systematic differences in the number of participants dropping out from the study groups (153). We observed 44% loss to follow up from inclusion to 8 months. There were no major differences between those lost to follow up and those remaining, but significant differences were found for age, chair rise, and stair climb. Thus, the possibility that some of the missing data may be related to the outcomes can not be excluded (132). Some of the loss to follow ups were explained by death and worsening in health or cognitive status, which were anticipated (154). However, most of those lost to follow up were unexplained. This may be explained by the age, health-, and functional status of our participants. Loss to follow up and missing data will be a challenge and a consequence of conducting research on such a sample, especially when taken into consideration that we applied a long intervention (i.e., 8 months). We did experience some difficulty in contacting the participants to schedule testing as some never answered their phone, called back, or answered their door. This may be one explanation of the large proportion of unexplained cases. It should also be noted that the loss to follow up was higher in RTG than CG (48% vs 37%) and we cannot exclude the possibility that this was related to the exercise intervention. Importantly, the exercise sessions were supervised by trained instructors and designed in accordance with recommendations. We did not experience any adverse events other than some increased muscular- and/or joint pain, mostly due delayed onset of muscle soreness. If participants experienced pain or discomfort during training the exercises and load were modified. The difference in loss to follow up between the groups could introduce bias. However, except for percentage fat mass and grip strength there were no significant differences in characteristics among those dropping out in RTG versus CG, so the risk of bias is most likely small.

Loss to follow up could affect a study's results through reduction in statistical power and reduced precision of the estimates (132). There are several ways to try to compensate for bias related to loss to follow up. Our main analyses in Paper II and III were ITT analyses, which includes all randomized participants according to the group they were allocated to (153). Furthermore, attrition bias and missing data was to some extent accounted for in the linear mixed models which takes all available data into account and are less sensitive to missing data than other models (132). However, we cannot be sure that data were missing by random which mixed models rely on. Importantly, our findings are comparable to those of most previous studies.

Confounding

Confounding refers to when the association between an independent and a dependent variable is affected by a confounding variable (155). In RCTs that would transfer to a difference between treatment groups in the distribution of prognostic factors that influence the outcome. If a randomization process is successful, confounding is not considered a major concern in RCTs. We did not perform any significance tests of baseline differences in accordance with the CONSORT statement (131), but considered the previous knowledge of the prognostic strength of the variables measured (Paper II and III).

Confounding is more common in cross-sectional studies (Paper I). Based on results and knowledge obtained from previous studies we only adjusted the regression analyses for gender. Body weight was accounted for through relative muscle strength and age indirectly through the strength and function measures. However, we do acknowledge that there may be some residual confounding from variables that were not considered or from variables that we did not collect data on, such as socioeconomic status (e.g., education) and use of medications. Furthermore, a cross-sectional study is prone to reverse causation, which means that the association between an exposure (i.e., independent variable) and outcome (i.e., dependent variable) is not due to direct causality from exposure to outcome, but rather because the defined outcome results in a change in the exposure (155). For example, people with poor physical function are more likely to have poor muscle strength, thus, there is a risk of reverse causality in the cross-sectional paper (Paper I) and no possibility to assess temporality and causality.

Ethical considerations

In ISRAE, we included a control group who undertook the same tests as the training group without receiving the same benefits of the intervention. To compensate for this, participants in CG was offered elastic bands and information about the resistance training program (pictures and explanation of exercises) after the initial training period. Furthermore, the three municipalities were offered educational courses so that they could continue to offer the same training sessions on their own initiative if they wished to.

Taking part in resistance training always comes with a small risk of injury. Especially individuals who are unfamiliar with resistance training, sedentary, and/or functionally limited may have a higher risk of reporting adverse events (154). Furthermore, higher intensity comes with a greater risk of adverse events compared to lower intensity (154). However, previous research show that heavy resistance training can be safe and tolerable for the oldest old (156). Another important aspect is that lack of a familiarization period may increase the risk of adverse events (157). The first weeks of the training program served as an introductory phase to take this aspect into consideration. However, to minimize participant burden we chose not to include a familiarization period before the baseline measurements. As previously mentioned, all testing and training were supervised and tailored to the individual and we did not experience any adverse events.

Perspectives

Our findings show that very old individuals receiving home care may improve their maximal strength and physical function through participation in pragmatic resistance training. As little as one weekly sessions of 30-45 minutes may even be effective. Furthermore, pragmatic resistance training may be effective to counteract or slow down the age-related decline in PA level, which is important for this sample. However, based on our small-to-moderate effects we speculate that action should be made at an earlier stage; before older adults are at the threshold for institutionalized care. This may be especially important as making regular resistance training a lasting, sustainable habit is challenging in very old individuals who receive home care, as seen from the large dropout rate. The findings from the research conducted for this thesis alone cannot be used to demonstrate whether the improvements in muscle strength and function are transferrable to increased independence and ability to live in one's own home. However, this may be an important step along the way towards developing long-term sustainable habits that may transfer into improved independence, and by so achieving the goals of the Norwegian Government's Quality Reform for Older Persons "A full life – all your life" (117).

Although older adults receiving home care may be a challenging group to study, we would like to stress the importance of including these individuals in clinical research, as they represent what is the reality for many older adults. The individually based approach in this thesis allowed us to tailor the intervention and thereby examine this highly relevant and growing, yet understudied group of older adults. Lastly, we would like to encourage those working in the home care services and all significant others (e.g., family, friends) to encourage and remind older adults of the importance of implementing a structured resistance training program into their weekly routines. Under supervision and guidance, older adults can be recommended to take part in programs of high intensity and intentional velocity, and even small doses such as 30-45 minutes once or twice a week may be effective. A pragmatic approach such as the one in this thesis can be implemented into key settings, in line with the recommendations from WHO (5). Thus, this may be a viable alternative for those who do not want to or are not able to go to a fitness center.

Future work

The research of this thesis has answered some relevant questions and has filled a research gap related to an important, but understudied group of older adults. Furthermore, this thesis has opened for some important future research questions:

- As previously mentioned, this thesis itself does not provide knowledge on whether pragmatic resistance training improves independence and the ability to live in one's own home in a long-term perspective. Future studies should aim to investigate whether such a strategy reduces or delays the need for home care and/or institutionalized care among older adults.
- We experienced large loss to follow up which affected the overall attendance to the training program. Previous studies have shown that it is challenging to motivate older adults to maintain training following an intervention (158). Future research should aim to explore strategies that motivates older adults to adhere to training without close supervision and make sustainable habits in the long run.
- Our findings indicate that a low training volume, such as 30-45 minutes once or twice a week for eight months may be effective among older adults receiving home care. Future studies should aim to examine whether adding several sessions is achievable and more effective (i.e., dose-response relationship) in a comparable sample.
- The sample size in ISRAE was small. Thus, future research should aim to investigate the effectiveness of pragmatic resistance training in a larger sample of older adults receiving home care. This may also allow for pre-defined subgroup analyzes examining the impact of age, baseline levels of muscle strength and physical function, mobility device use, among others.

Conclusions

The research presented in this thesis highlights the relationship between muscle strength and physical function at very old age. Furthermore, the thesis describes and provides knowledge on the effectiveness of a pragmatic resistance training program for the community-dwelling oldest old receiving home care. The conclusions drawn from this research are:

- Greater muscle strength is related to better physical function among older adults receiving home care. Explosive strength may be marginally more important for physical function than maximal strength, but this was not verified through the cluster-RCT.
- Among older adults receiving home care, a pragmatic resistance training program performed twice weekly for eight months compared to receiving PA counselling was effective for improving physical function, measured with the chair rise test, TUG-8ft, stair climb, preferred, and maximal gait speed. Furthermore, the resistance training program was effective for increasing maximal strength.
- Among older adults receiving home care, a pragmatic resistance training program performed twice weekly for eight months was not effective for increasing explosive strength, improving body composition, or improving PA levels as compared to receiving PA counselling. However, pragmatic resistance training may counteract or slow down the unfavorable age-related changes in PA levels.

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Paper I

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Muscle Strength Is Associated With Physical Function in Community-Dwelling Older Adults Receiving Home Care. A Cross-Sectional Study

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Background: Higher maximal- and explosive strength is associated with better physical function among older adults. Although the relationship between isometric maximal strength and physical function has been examined, few studies have included measures of isometric rate of force development (RFD) as a measure of explosive strength. Furthermore, little is known about the oldest old (>80 years), especially individuals who receive home care and use mobility devices. Therefore, the aim of this study was to examine the association between maximal- and explosive muscle strength with physical function in community-dwelling older adults receiving home care.

Methods: An exploratory cross-sectional analysis including 107 (63 females and 43 males) community-dwelling older adults [median age 86 (interquartile range 80–90) years] receiving home care was conducted. Physical function was measured with five times sit-to-stand (5TSTS), timed 8-feet-up-and-go (TUG-8ft), preferred-, and maximal gait speed. Maximal strength was assessed as maximal isometric voluntary contraction (MVC) and explosive strength as RFD of the knee extensors. We used linear regression to examine the associations, with physical function as dependent variables and muscle strength (MVC and RFD) as independent variables.

Results: MVC was significantly associated with 5TSST [standardized regression coefficient β = −0.26 95% CI (−0.45, −0.06)], TUG-8ft [−0.6 (−0.54, −0.17)], preferred gait speed [0.39 (0.22, 0.57)], and maximal gait speed [0.45 (0.27, 0.62)]. RFD was significantly associated with 5TSST [−0.35 (−0.54, −0.17)], TUG-8ft [−0.43 (−0.60, −0.27)], preferred gait speed [0.40 (0.22, 0.57)], and maximal gait speed [0.48 (0.31, 0.66)].

Conclusions: Higher maximal- and explosive muscle strength was associated with better physical function in older adults receiving home care. Thus, maintaining and/or improving muscle strength is important for perseverance of physical function into old age and should be a priority.

Keywords: elderly, functional ability, independent living, muscular force, home healthcare services

INTRODUCTION

Increasing age is accompanied by a gradual decline in muscle strength (1) which may be explained by reduced muscle mass (e.g., loss of muscle fibers and reduced size of muscle fibers, especially type II fibers), inactivity, and neural factors (e.g., loss of motor neurons) (2, 3). This age-related loss of muscle strength may impair older adults' physical function (e.g., ability to walk, rise from a chair) (3, 4). The reduction of muscle strength and physical function are important components in both sarcopenia and frailty (5, 6) and increases the risk of dependency, institutionalization, and mortality among older adults (5–8). Thus, assessing these aspects is important to develop effective preventive- and treatment strategies especially among the oldest old (>80 years).

Previous cross-sectional studies show that higher muscle strength in the lower body is related to better physical function, such as walking and rising from a chair (9–20). Most previous studies examining the association between muscle strength and physical function have focused on healthy older adults in their 60-s and 70-s (9, 12, 14–18, 20, 21). However, as life expectancy increases worldwide, many live into their 80-s and 90-s and the age-related physiological changes affecting muscle strength and physical function become more prominent after the age of 80 years (1). Consequently, a higher proportion of the aging population will depend on mobility devices (e.g., rollator, walker, canes) and home care services (22, 23). Despite this, only a handful of studies have examined the oldest old (>80 years) (10, 11, 13, 19) and these studies are limited to healthy older adults (10, 19) and/or institutionalized participants able to walk independently (11, 13). Use of mobility devices could influence both muscle strength and physical function as such devices may compensate for lower extremity weakness and loss of mobility (24). This leaves a gap in the literature, and it is important to examine the association between muscle strength and physical function among very old (>80 years) frail individuals who receive home care services, where the need for mobility devices might be high (22, 23).

Most studies examining the association between muscle strength and physical function have measured muscle strength dynamically, especially explosive strength [i.e., power (force × velocity)] (11–13, 15, 16, 18–21, 25). However, evaluating dynamic strength can be challenging for older adults, as it may require high technical skills, sufficient balance and coordination, proper equipment and familiarization, and multiple attempts (26, 27). These challenges become even more apparent for the oldest old (>80 years) and/or those who depend on mobility devices. A possible alternative to overcome the abovementioned challenges is to measure muscle strength isometrically. This enables measurement of maximal strength as maximal voluntary contraction (MVC) and explosive strength as isometric rate of force development (RFD) with high level of control, making it safe, easy, and practical to perform for older adults (26, 27). Despite this, few studies on the oldest old (>80 years) have used isometric measures for muscle strength (13). Furthermore, RFD which is obtained from the slope of the force-time curve (Δforce/Δtime), has been proposed as an important determinant for daily life activities, maintaining postural balance, and avoiding falls among older adults (27–29). Although a few cross-sectional studies have shown that higher RFD is associated with better physical function in 60- and 70-year-olds (9, 14, 15, 17), more research is needed to understand the relationship between RFD and physical function, especially among the oldest old (>80 years). However, to our knowledge, this has not been reported in the existing literature. Finally, although studies indicate that explosive strength is more important for physical function than maximal strength (25), there is a lack of studies including the oldest old and examining explosive strength (i.e., isometric RFD). Thus, the aim of this cross-sectional study was to investigate the association between maximal- and explosive strength with physical function among very old community-dwelling individuals receiving home care.

MATERIALS AND METHODS

Study Design

This exploratory paper used cross-sectional baseline data from a cluster randomized controlled trial (RCT) conducted in three Norwegian municipalities (Sogndal, Luster, and Leikanger) in the period 2016–2019 (trial registration ISRCTN registry 1067873). The RCT was evaluated by The Regional Committee for Medical and Health Research Ethics South-East and the Norwegian Centre for Research Data (2016/51 and 49361/s/AGH, respectively), and was conducted in accordance with the Declaration of Helsinki and Norwegian laws and regulations. Participants received oral and written information about the study before signing a written consent-form. The results from the RCT have been published previously (30, 31).

Participants

The health care services in the three included municipalities identified potential participants. We used a convenience sample strategy, thus, all inhabitants in Sogndal, Luster, and Leikanger who fulfilled the inclusion/exclusion criteria were invited to participate in the study. We included those who were above 70 years old, community-dwelling, and received home care due to functional and/or medical disabilities. The exclusion criteria included serious cognitive impairments (e.g., Alzheimer's disease, dementia), diagnoses/conditions hindering testing or training, or disapproval from a medical doctor due to contraindications. We made an amendment to the inclusion criteria during participant recruitment; seven older adults otherwise meeting the eligibility criteria, but who were below 70 years [median age 67 (range 63–69) years] were included in the study to increase the sample size.

All inhabitants in the three municipalities who met the inclusion criteria were invited to participate in the study, and all those who accepted were included. Based on this, 123 older adults were initially invited to participate, and six individuals were invited after the initial recruitment. Of these, 19 declined to participate and three participants who were in a wheelchair were excluded as they could not perform testing and/or training. The final sample consisted of 107 participants (**Table 1**).

TABLE 1 | Participant's characteristics.

	N	Males[b]	Females[c]	Total
Age (years), median (IQR)	107	85 (80–90)	87 (81–90)	86 (80–90)
Mobility devices, *n* (%)[a]	104	27 (68)	35 (55)	62 (60)
Body Mass Index (kg/m^2), mean (SD)	103	27 (5)	26 (6)	27 (6)
5TSTS (s), mean (SD)	105	20.4 (8.4)	19.6 (10.6)	19.9 (9.7)
TUG-8ft (s), mean (SD)	103	16.0 (7.4)	14.7 (7.5)	15.2 (7.4)
Preferred gait speed (m/s), mean (SD)	104	0.7 (0.3)	0.8 (0.2)	0.7 (0.3)
Maximal gait speed (m/s), mean (SD)	104	1.0 (0.4)	1.0 (0.3)	1.0 (0.4)
Absolute MVC (N), mean (SD)	105	212.8 (92.6)	160.1 (53.8)	181.2 (76.0)
Relative MVC (N/kg), mean (SD)	101	2.7 (1.2)	2.5 (0.8)	2.6 (0.9)
Absolute RFD (N/s), mean (SD)	105	525.9 (385.6)	353.5 (215.0)	422.5 (305.6)
Relative RFD (N/s/kg), mean (SD)	101	6.7 (4.8)	5.4 (3.8)	5.9 (3.8)

SD, standard deviation; IQR, interquartile range; 5TSTS, five times sit-to-stand; TUG-8ft, timed 8-feet-up-and-go; MVC, maximal voluntary isometric contraction; RFD, rate of force development.
[a]*Mobility devices include rollator, walker, and cane(s).*
[b]*43 males in total.*
[c]*64 females in total.*

Procedures

Testing was conducted at the health care centers by qualified researchers and research assistants. The participants performed two to three trials depending on their individual physical capacity. Time was measured using a stopwatch. For tests of physical function, participants were allowed to use mobility devices and/or the handrails of the chair if necessary. Participants' age and gender was registered, and height was measured using a stadiometer. Body mass was measured in light clothes using a Tanita weight (Tanita MC 780MA S, Illinois, USA) and body mass index (BMI) was calculated as kg/m^2.

Dependent Variables

The ability to rise from a chair was measured as the time taken to finish five sit-to-stand cycles (5TSTS) as fast as possible (32). A straight back chair with armrests was used and participants were told to fully extend their legs in the upright position. The best trial was used for analyses. The 5TSTS test has shown high reliability with Intraclass Correlation Coefficients (ICCs) ranging from 0.64 to 0.96 (33).

For timed 8-feet-up-and-go (TUG-8ft) the participants were instructed to rise from a chair, walk 8 feet, turn around a cone, and walk back to the chair and sit down. The test was performed in a fast, but controlled manner (34). A straight back chair with armrests was used and the best trial was included in the analyses. An ICC of 0.79 has been reported for TUG-8ft (35).

To assess preferred- and maximal gait speed, participants walked a 20-m course (i) in their comfortable pace and (ii) as fast as possible without running (36). A one-meter acceleration- and retardation phase was included before and after the 20-meter course. For preferred gait speed we included the mean of three trials in the analyses, while for maximal gait speed the best trial was used. An ICC of $\geq$0.903 has been reported for preferred- and maximal 10-m gait speed (37).

Independent Variables

Muscle strength was measured during a maximal voluntary isometric contraction (MVC) of the knee extensors. A custom-made flexi-bench (Pivot 430 Flexi-bench, Sportsmaster, Norway) and a non-elastic band (ROPES A/S, Aasgardstrand, Norway) attached to a force cell (Ergotest Innovation AS, Langesund, Norway) was used. We used a frequency of 200 Hz and a range of 0–500 kg. The knee was fixed at a 90-degree angle and the band was placed around the preferred ankle. Participants were told to contract as "fast and forcefully" as possible for at least 5 s, with a 1-min resting period between trials. The best trial was used in analyses. As all the dependent variables were weight bearing, we calculated relative maximal- and explosive muscle strength (normalized to body mass). Maximal strength (i.e., MVC) was defined as the highest mean force output over a 3-second window. Explosive strength (i.e., RFD) was calculated at the steepest vertical force generation as the mean tangential slope of the force-time curve over a 200-ms window (see **Figure 1** for a typical example of a force-time curve) (38). A 200-ms interval was chosen for analysis because weaker, very old individuals might use a longer time to peak force from the onset of force than younger and/or stronger individuals (9, 27). Furthermore, we took into consideration our previous experience from a pilot study (39) when it comes to force-time curves, ability to understand the task (e.g., generating force as fast and forcefully as possible), and fear of pain and/or movement in this particular group of older adults, when choosing the window length. The correlation between MVC and RFD was $r = 0.67$.

Statistical Analysis

Demographic participant characteristics are presented as mean and SD or median and IQR. To assess normality, the Q-Q plots of the residuals were visually inspected. The associations were examined using linear regression with the continuous variables of physical function as dependent variables and the muscle strength measures (MVC and RFD) as independent variables. We conducted analyses for each combination of physical function- and muscle strength measure. Due to some extreme values, we performed sensitivity analyses without extreme values to assess the robustness of our results. Visual inspection of the entire data set was used to assess these extreme values. All analyses were adjusted for gender (40). Standardized beta coefficients (ß) and 95% confidence intervals (CI) was calculated to show the strength of the independent variable to the dependent variable. A *p*-value $\leq$ 0.05 was defined as statistically significant.

All analyses were conducted in STATA 16 (StataCorp. 2019. *Stata Statistical Software: Release 16.* College Station, TX: StataCorp LLC) and **Supplementary Figures 1–4** were made in SigmaPlot 14.0 (Systat Software, Inc., San Jose, CA, USA).

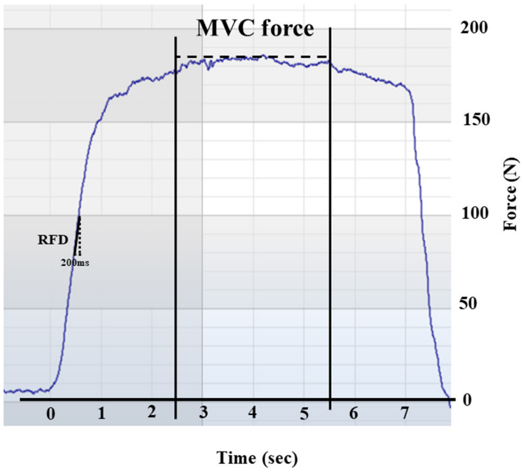

FIGURE 1 | Representative force-time curve obtained during a maximal isometric voluntary contraction (MVC) in a single subject. The figure illustrates the rate of force development (RFD) calculated over a 200-ms window and the MVC calculated over a 300-s window.

RESULTS

Baseline characteristics of the participants are presented in **Table 1**. The sample consisted of 64 females (60%, body mass 65.5 kg, height 157 cm) and 43 males (40%, body mass 77.4 kg, height 169 cm). The males were slightly younger (85 vs. 87 years), stronger, and had a higher percentage of mobility device usage (68 vs. 55%) than the women. Data for physical function were available in 97–98% of participants, while data on MVC and RFD was available in 94% of participants. The number of participants included in the analyses ranged from 99 to 100.

Associations Between Muscle Strength and Physical Function

The regression analyses showed that both MVC and RFD were significantly associated with all physical function measures ($p < 0.01$ for all). For MVC there were negative (favorable) associations with 5TSTS [$\beta = -0.26$ 95% CI (−0.45, −0.06)] and TUG-8ft [−0.36 (−0.53, −0.19)], and positive (favorable) associations with preferred- [0.39 (0.22, 0.57)] and maximal gait speed [0.45 (0.27, 0.62)]. For RFD there were negative (favorable) associations with 5TSTS [−0.35 (−0.54, −0.17)] and TUG-8ft [−0.43 (−0.60, −0.27)], and positive (favorable) associations with preferred- [0.40 (0.22, 0.57)] and maximal gait speed [0.48 (0.31, 0.66)]. **Supplementary Table S1** show the unstandardized regression coefficients.

Sensitivity Analysis

Supplementary Table S2 show the results from the sensitivity analysis after removing extreme values. The number of participants analyzed ranged from 93 to 96. MVC was associated with 5TSST [$\beta = -0.40$ 95% CI (−0.59, −0.21)], TUG-8ft [−0.39 (−0.81, −0.21)], preferred- [0.35 (0.18, 0.53)], and maximal gait speed [0.42 (0.24, 0.59)]. RFD was associated with 5TSST [−0.29 (−0.49, −0.09)], TUG-8ft [−0.43 (−0.61, −0.24)], preferred- [0.36 (0.18, 0.53)], and maximal gait speed [0.47 (0.30, 0.64)].

DISCUSSION

This cross-sectional study showed that higher maximal- and explosive strength were associated with better physical function in the oldest old who receive home care. These findings suggest that maintaining and/or improving muscle strength is important for perseverance of physical function into old age.

Some previous cross-sectional studies have investigated the relationship between muscle strength and physical function among the oldest old (>80 years) (10, 11, 13, 19). Barbat-Artigas et al. (10) showed that ambulatory women (mean age 80.4 years) in the lowest maximal leg-strength quartile was 12–25-fold more likely to have impairments in chair rise, preferred-, and maximal gait speed compared to those in the highest strength quartile. Likewise, Bassey et al. (11) found that explosive strength, measured as leg extension power, was related to chair rise, stair climb, and gait speed ($r = 0.65$–0.81) in residents of a rehabilitation center where 65% used mobility devices. These previous findings are in line with ours, however, direct comparisons between studies are difficult due to the focus on slightly different populations and aspects of physical function. Moreover, explosive strength has in previous studies been assessed by dynamic measures (i.e., power), especially among the oldest old (11, 19). Although Altubasi (9) showed that higher isometric rate of torque development (RTD) was moderately correlated with stair climb time ($r = -0.59$), correlations were weak for TUG, ramp up, and preferred gait speed ($r = -0.12$ to -0.29) in healthy older adults in their 60s and 70s. Similarly, Osawa et al. (17) found that RTD was important for some, but not all, measures of physical function among healthy older adults in their 60s. However, these results might not be entirely comparable to ours as the relationship between muscle strength and physical function is believed to be curvilinear, creating a threshold where muscle strength is less important for physical function, especially in younger, stronger older adults (12, 41). Thus, our results support those of previous studies showing that higher muscle strength is associated with better physical function in the oldest old and expand on the existing literature by including individuals who receive home care and with high mobility device dependency (60%), which is an important and increasing group of older adults.

Explosive strength has been found to be more important for physical function than maximal strength among older adults in their 60-s and 70-s (12, 18, 42). Although evidence suggest that explosive strength decreases more rapidly than maximal strength with increasing age (2) few of the previous studies have examined the oldest old (>80 years) have included measures of both maximal- and explosive strength (13). To indicate the strength of the associations, we calculated standardized regression coefficients which indicated a slightly stronger association for explosive strength (RFD) than maximal strength (MVC) with all measures of physical function. Rising from a chair as fast as possible involves repetitive acceleration of one's body mass and may demand less time to develop force and a higher level of explosive- than maximal strength (43). Similarly, the acceleration of body mass is also relevant for TUG-8ft performance and walking as fast as possible. It should be mentioned that the 95% CIs for the standardized regression coeffects overlap substantially, making it difficult to draw inferences regarding the importance of maximal- vs. explosive strength from our results. Furthermore, we used a 200-ms window to assess RFD, and RFD measured during the later phase of rising muscle force has been found to be closely related to MVC (44). Thus, there is most likely a relation between the two measures. However, a stronger association for explosive strength can be supported by the age-related degeneration in the muscle (e.g., atrophy of type II fibers, cross-sectional area, fewer motor units, and reduced motor unit firing rate) (45). We cannot exclude the possibility that some extreme values affected our findings. Therefore, we performed a sensitivity analysis to assess the influence of extreme values showing no major changes in the standardized regression coefficients. However, it should be noted that the standardized regression coefficient for MVC with 5TSTS increased from −0.26 to −0.40, possibly indicating that maximal strength is even more important for the ability to rise from a chair than initially found.

The progressive atrophy of muscle fibers reported with increasing age is greater for type II muscle fibers than for type I muscle fibers (46). Type II muscle fibers are especially important during fast movements and, consequently, explosive strength might be more impaired than maximal strength (27, 38). Resistance training using maximal intentional acceleration of load (i.e., explosive type) has shown superior effects on explosive strength and physical function when compared to traditional heavy load resistance training (47). However, heavy loads resistance training has shown to increase the size of type II muscle fibers and myosin heavy chain II A proportion in 85–97-year-olds (48), which might be effective for eliciting gains in explosive strength (27). Thus, designing heavy loads resistance training programs with maximal intentional acceleration of the load ("explosive heavy load type") (38, 48) could be the optimal combination for improving older adults' explosive strength, and consequently maintaining or improving physical function in old age. Additionally, such a training program would be beneficial for increasing maximal strength as well.

Isometric testing of older adults' muscle strength holds several advantages, as it requires less technical skills, balance, and coordination than dynamic strength testing (26, 27). Furthermore, isometric testing enables a high level of control, making it safe, easy, and practical to perform (26, 27). Although dynamic power has been measured previously in the oldest old during chair rise (11) and a facilitated jump test (19), these tests require higher technical skills and can be difficult to perform for older adults, especially for those who depend on mobility devices. Furthermore, many daily life movements (e.g., rapid walking, postural balance, preventing a fall) require rapid force production over a short time frame (e.g., 50–300 ms) (27–29). As RFD can be obtained from the force-time curve (27) it is a relevant measure of older adults' explosive strength. Thus, the present study show that isometric testing is a viable, practical, and safe alternative for assessment of muscle strength in older adults, also when the proportion of mobility device use is high.

Previous studies have suggested that the relationship between muscle strength and physical function is curvilinear, creating a threshold above which an increase in strength does not translate into improved physical function (12, 41, 49, 50). Identification of a specific threshold would be useful to target those with an increased risk of functional limitations who would most likely benefit from resistance training. We did not aim to statistically investigate non-linearity. Furthermore, our participants were very old with poor muscle strength and physical function (e.g., 60% used mobility devices), and identification of a clear threshold may not be possible in such a population (41, 49, 50). Nevertheless, visual inspection of the strength-function curves indicated that if a threshold (i.e., point of change in slope) exist, it is at the far range of our data, around 5.6–6.2 N/kg and 14.1–16.7 N/s/kg for MVC and RFD, respectively (**Supplementary Figures 1–4**). Importantly, there are very few data points above this, thus, the observed threshold may be due to random variation and should be interpreted with caution.

Reference estimates of older adults' physical function are often derived from apparently healthy populations (32, 51, 52), which excludes more frail individuals. However, as life expectancy increases, many older adults will live into their 80-s and 90-s, and many will be dependent on home care and mobility devices to function in their own home. Thus, healthy, younger older adults are not representative for the entire older population. In the present study, the participants were classified as the oldest old, all received home care, and 60% used mobility devices. Accordingly, their physical function was in line with or slightly lower than those reported by Lusardi et al. (22) for older adults (80–101 years) with- and without mobility devices. Furthermore, the maximal strength was low and comparable to those shown by Aas et al. (53) in a comparable sample, although direct comparison is difficult due to different methods used to assess maximal strength. Thus, our findings highlight the importance of obtaining knowledge about the level of, and association between, muscle strength and physical function in this rapidly growing group of older adults, and not only in younger, healthier, and more well-functioning individuals.

The strengths of our study include the choice of participants (i.e., oldest old, receiving home care, mobility devices) which allows for knowledge about an understudied, yet important group of older adults. Furthermore, we examined both maximal- and explosive muscle strength, and used isometric measures to assess muscle strength. Some study limitations should be addressed. First, this was an exploratory study and the cross-sectional design precludes determination of the temporal relationship between muscle strength and physical function, as well as causality. Second, the study may not have been powered to investigate the associations included in the current paper. Third, our data material showed large SDs and some extreme values. This was not surprising given the variation in age, strength, and functional status seen among older adults receiving home care. It may be that the differences in muscle strength between the genders influenced the distribution of the data, and hence, the results. However, we did use relative muscle strength which may take some of the gender differences into account. Fourth, we did not investigate whether the association between muscle strength and physical function differed according to use of mobility devices, as introducing mobility devices as a covariate in this regression analysis would introduce a collider bias (54). Future studies should examine the impact of mobility devices on the association between muscle strength and physical function. Lastly, although we included measures of both maximal- and explosive strength our analyses did not investigate their independent contributions, which should be examined in future studies. Based on the abovementioned limitations we advise reflective interpretation of the results.

In conclusion, the present study shows that higher maximal- and explosive muscle strength is associated with better physical function in the oldest old who receive home care. Our findings add knowledge about a rapidly growing yet understudied group of older adults and highlight the importance of prioritizing strategies aiming to maintain and/or improve muscle strength for perseverance of physical function into old age.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Regional Committee for Medical and Health Research Ethics (2016/51), Armauer Hansens Hus, nordre fløyel, 2. etasje, Haukelandsveien 28, Bergen; Norwegian Centre for Research Data (49361/s/AGH), Harald Hårfagres gate 29 N-5007, Bergen, Norway. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

HB oversaw the main writing of the manuscript and data analyses. AS, VA, MF, and TR contributed to planning the study, while AS and VA were in charge of running the study and collected data. AS, VA, MF, and TR reviewed the manuscript and gave valued input on revisions. All authors read and approved the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.856632/full#supplementary-material

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RESEARCH ARTICLE Open Access

Effectiveness of a resistance training program on physical function, muscle strength, and body composition in community-dwelling older adults receiving home care: a cluster-randomized controlled trial

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Abstract

Background: Aging is associated with reduced muscle mass and strength leading to impaired physical function. Resistance training programs incorporated into older adults' real-life settings may have the potential to counteract these changes. We evaluated the effectiveness of 8 months resistance training using easily available, low cost equipment compared to physical activity counselling on physical function, muscle strength, and body composition in community-dwelling older adults receiving home care.

Methods: This open label, two-armed, parallel group, cluster randomized trial recruited older adults above 70 years (median age 86.0 (Interquartile range 80–90) years) receiving home care. Participants were randomized at cluster level to the resistance training group (RTG) or the control group (CG). The RTG trained twice a week while the CG were informed about the national recommendations for physical activity and received a motivational talk every 6th week. Outcomes were assessed at participant level at baseline, after four, and 8 months and included tests of physical function (chair rise, 8 ft-up-and-go, preferred- and maximal gait speed, and stair climb), maximal strength, rate of force development, and body composition.

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Results: Twelve clusters were allocated to RTG (7 clusters, 60 participants) or CG (5 clusters, 44 participants). The number of participants analyzed was 56–64 (6–7 clusters) in RTG and 20–42 (5 clusters) in CG. After 8 months, multilevel linear mixed models showed that RTG improved in all tests of physical function and maximal leg strength (9–24%, $p = 0.01–0.03$) compared to CG. No effects were seen for rate of force development or body composition.

Conclusion: This study show that resistance training using easily available, low cost equipment is more effective than physical activity counselling for improving physical function and maximal strength in community-dwelling older adults receiving home care.

Trial registration: ISRCTN1067873

Keywords: Elderly, Independent living, Strength training, Home-based exercise, Functional mobility, Elastic band

Background

Aging is associated with reduced muscle mass [1] and strength [1, 2] followed by a decline in physical function (e.g., ability to walk, rise from a chair, walk stairs) [2]. Furthermore, the ability to generate force rapidly decreases more than maximal strength in older adults [2, 3], and it has been argued that power and rate of force development (RFD) is more important for physical function and the ability to carry out activities of daily life [3, 4]. To promote healthy aging and the ability to live independently in aging populations, it is essential to identify effective strategies to counteract or delay these age-related changes.

Resistance training has proven to be safe and effective to counteract loss of muscle mass [5], strength [5, 6], and physical function in older adults [6, 7]. Resistance training is often performed at fitness centers using resistance training machines and free weights [4, 7]. However, approaches that can be easily incorporated into real-life settings have been called upon, as lack of availability, training experience, and affordability may limit older adults' access to traditional training facilities [8, 9]. One possibility is to provide resistance training programs using easily available, low-cost equipment such as elastic bands, body weight, and other equipment (e.g., ankle weights, water canes) [10, 11]. Such equipment facilitates incorporation of resistance training in real-life settings. However, studies using such training programs show inconclusive results with respect to improvements in maximal strength [12–19] and body composition in older adults [14, 17, 20, 21], as well as their transferability to physical function [12, 13, 15, 16, 18–23]. Furthermore, few studies have investigated the effect of resistance training programs using easily available, low cost equipment on the ability to generate force rapidly and the results have been inconsistent [15, 16].

Most studies have examined healthy, community-dwelling older adults below the age of 80 years or those living in an institution [7, 10–12, 14, 17, 18, 20–22]. The oldest old (> 80 years) still living at home while receiving home care services remains understudied [15, 23], Effective interventions for this population could provide a golden window of opportunity to promote independent living by improving physical function and muscle strength. With an increasing older population, easily available, low-cost training programs might reduce the need for home care services. Thus, this cluster randomized trial examined the effectiveness of an 8 months resistance training program using easily available, low cost equipment, compared to a control group receiving physical activity counselling, on physical function, muscle strength, and body composition in community-dwelling older adults receiving home care. We hypothesized that greater improvements in physical function and muscle strength would be demonstrated in the resistance training group than the control group.

Methods

Trial design

The Independent Self-Reliant Active Elderly (ISRAE) study is an open label, two-armed, parallel group cluster randomized controlled trial (RCT), conducted in three municipalities (Sogndal, Leikanger and Luster) in Western Norway, from August 2016 to August 2018. A cluster RCT was chosen to avoid contamination and to increase adherence. Participants were divided into 12 clusters (range 5–16 participants) where participants living in the same geographical area belonged to the same cluster. The clusters were allocated (3:2 ratio) to the resistance training group (RTG) or the control group (CG) receiving physical activity counselling. The intervention lasted for 8 months and participants were followed for 1 year after the end of the intervention. Here, we report the intervention effects at the participant level on physical function tests, maximal strength, RFD, and body composition four and 8 months after study inclusion.

The Regional Committee for Medical and Health Research Ethics and the Norwegian Centre for Research Data approved the study (2016/51 and 49,361/s/AGH, respectively), and it was conducted in accordance with the Declaration of Helsinki. Due to changes in design, the study was registered retrospectively (ISRCTN registry:1067873) and is reported according to the Consort statement extension to cluster RCTs [24]. Oral and written information about the study was given to all participants and written informed consent was signed before randomization.

Participants

Participants were recruited through the health care services in the three municipalities. Older adults above 70 years, living at home, and receiving home care due to functional and/or medical disabilities were eligible for inclusion. Participants were excluded if they had serious cognitive impairment (e.g. Alzheimer's disease, dementia), physical diagnoses/conditions that could affect testing or training, and/or disapproval from a medical doctor due to contraindications for training. During inclusion, an amendment was made to the inclusion criteria; seven individuals otherwise meeting the eligibility criteria, but were below 70 years (median 67 (range 63–69) years) were included in the study to increase the sample size.

Intervention

RTG was offered a resistance training program twice per week for 8 months, from end of September 2016 to the end of May 2017. The intervention was targeted at the participant level. Each session lasted for 30–45 min and was supervised by trained exercise instructors. Training was performed in groups at the local health care centers using easily available, low cost equipment such as elastic bands (ROPES a/s, Aasgardstrand, Norway), body weight, and water canes. The included exercises aimed to strengthen the muscle groups most important for daily living activities (Table 1). To ensure progression, number of series and repetitions were manipulated, and new exercises were introduced (Table 1). Furthermore, the exercise instructors tailored the intensity to the individual by using chairs, adding water canes, and/or changing the thickness and tension (level of pre-stretch) of the elastic band. After the baseline testing, a 5 week introductory phase was conducted, focusing on proper execution of the exercises without going to fatigue. After this, volume and intensity were increased progressively and participants were encouraged to perform each exercise to fatigue – i.e. they were unable to complete more repetitions with proper technique. Participants were encouraged to train with high intentional velocity during the concentric phase (to increase RFD) and with slower controlled velocity in the eccentric phase (to increase the hypertrophic stimulus).. Additionally, participants were encouraged to continue their normal daily activity. Attendance to the resistance training was registered and defined as percentage of sessions met of sessions offered.

Participants allocated to CG received counselling on the national recommendations for physical activity and a physical education booklet from the Ministry of Health and Care Services. A researcher or research assistant contacted participants every 6th week by phone or a visit, reminding them about the national recommendations for physical activity and motivating them to stay active.

Outcomes

Testing was conducted at the health care centers by assessors who were not blinded to allocation.. All outcomes were measured at the participant level.

Physical function

Five tests in random order were used to assess physical function. All tests were performed two or three times. Verbal encouragement was given. Time was measured using a stopwatch. Participants could use crutches, walker, and/or armrests of the chair and stairs if necessary. Use of assistive devices was registered at baseline, four, and 8 months to ensure similar test conditions throughout. If the registration of assistive devices was incomplete, the measurement was registered as missing.

Chair rise The test measures the time needed to complete five sit-to-stand cycles [15]. A straight back chair with armrests was used and participants were told

Table 1 Progression of the resistance training program

Phase	Length (Weeks)	Number of exercises	Description of exercises	Series	Repetitions performed
1	5	5	Rowing, chest press, squats, biceps curl, knee extension	2	10-12[b]
2	10	5	Same as phase 1	3	10–12
3	10	6	Same as phase 1 + shoulder press	3	8–10
4	10	7	Same as phase 3 + up-and-go[a]	4	8–10

[a] Rising from a chair, walking 3 m and turning around a cone, walking back and sitting down
[b] Introductory phase, repetitions not performed until fatigue

to rise to a fully extended position and sit back down five times. The best trial was used for analysis. Coefficient of variation (CV) ranged from 10 to 14%.

8 ft-up-and-go The test measures the time needed to rise from a chair, walk 2.4 m, turn, walk back to the chair, and sit down [25]. A straight backrest chair with armrests was used. The best trial was used for analysis. CV ranged from 8 to 12%.

Gait speed Preferred and maximal gait speed (m/s) was assessed over 20 m [15]. For preferred speed, participants were instructed to walk in a comfortable pace, while for the maximal speed they were instructed to walk as fast as possible without running. Participants started approximately one meter before and slowed down one meter after the 20 m course. The mean of the trials was used for preferred gait speed while the best trial was used for maximal gait speed. CV ranged from 5 to 8%,

Stair climb The test measures the time needed to walk up a flight of stairs. As testing was conducted at the different health care centers, the same staircase was not used for all participants. However, each participant walked the same staircase at all three test times. The number of steps ranged from 16 to 24, with a vertical climb of 2.7 to 4.0 m. Participants were instructed to ascend the staircase in the same way as they normally would. The best trial was used for analyses. One cluster (CG $n = 15$) did not have access to stairs at their health center and was not included in analyses. CV ranged from 6 to 8%.

Maximal strength and rate of force development

Muscle strength was measured during maximal voluntary isometric contraction (MVC) of the knee extensors. Participants were seated in a custom-made flexi-bench (Pivot 430 Flexi-bench, Sportsmaster, Norway) and a non-elastic band (ROPES a/s, Aasgardstrand, Norway) attached to a force cell (Ergotest A/S, Porsgrunn, Norway) was used to measure force development. The knee angle was 90-degrees and the band was placed around the preferred ankle [15]. Two to three trials were performed separated by a 1-min resting period and the best trial was used for analysis. Participants were instructed to contract as “fast and forcefully as possible” for at least 5 s and verbal encouragement was given. Maximal strength (MVC) was defined as the highest mean force output over a 3-s window. RFD was calculated over a 200-millisecond window at the steepest vertical force generation [15]. CV for maximal strength and RFD was 8–9 and 28%, respectively.

Grip strength

Grip strength (CV = 5–6%) was measured using a handheld dynamometer (Baseline® Hydraulic Hand Dynamometer, Elmsford, NY, USA). The participants were instructed to squeeze as hard as they could for three to 5 s using the preferred arm. Verbal encouragement was given. The best of three trials was used for analyses.

Body composition

Height was measured without shoes using a stadiometer. Body composition (body mass index (BMI), percentage body fat, and fat free mass) was measured barefooted and in light clothes with bioelectrical impedance analysis using a Tanita weight (Tanita MC 780MA S, Illinois, USA). Participants with a pacemaker did not perform the bioelectrical impedance analysis.

Randomization and blinding

Randomization was done at cluster level in a 3:2 ratio and carried out in Excel by the project leader using the following procedure: (i) each cluster was given a number [1–16] and large clusters (> 10 participants) were weighted with two numbers. (ii) A random numbers table was used to allocate clusters to RTG based on the assigned numbers (iii). The procedure was stopped when RTG consisted of 60% of the participants (i.e. seven clusters). (iv) The remaining five clusters (40% of participants) were allocated to CG.

For practical reasons none of the researchers or research assistants were blinded. Further, due to the nature of the intervention it was not possible to blind participants or exercise instructors.

Statistical analysis

Analyses were performed according to the intention to treat principle. The between-group effects were analyzed using multilevel linear mixed models. The baseline level was obtained by merging the two groups [26] and we included the interaction between group and time (baseline, four, and 8 months;2 groups × 3 times). Cluster and participant-id were entered as random effects, accounting for cluster randomization and dependency of repeated measures. Visual inspection of the residuals of outcomes was used to assess normality. Non-normal outcomes were transformed using the natural logarithmic scale. These outcomes were back transformed using the formula exp.$(\mu + \frac{\sigma^2}{2})$ to obtain the arithmetic mean estimates. The estimates from the analyses were used to predict outcomes for the two groups at the different time points.

A per-protocol analysis including participants with ≥60% attendance to exercise sessions was conducted. In addition, sensitivity analyses were performed. First, an analysis was conducted including participants who met the original inclusion criteria for age (i.e. ≥ 70 years). Second, for the physical function outcomes, we performed an analysis with adjustment for the baseline value of the outcome without using combined baseline. Lastly, we adjusted stair climb for i) vertical climb and ii) number of steps.

For normally distributed variables, descriptive data is presented as mean and standard deviation (SD) and results are presented as mean and 95% confidence interval (95% CI). For non-normal variables, descriptive data is presented as median and 25–75 percentile (Interquartile range, IQR) unless stated otherwise. The estimated mean difference between two groups represents the ratio of the geometric mean for RTG to the geometric mean for CG [27] and are presented as ratios and 95% CI. Intra-cluster correlation coefficients (ICC) were calculated for all outcomes as between cluster variation divided by total variation [28]. Cohen's d effect sizes and 95% CIs were calculated for between-group changes from baseline to four and 8 months. An effect size of 0.2, 0.5, and 0.8 was considered small, medium, and large, respectively [29]. A p-value of < 0.05 was considered statistically significant. All analyses were performed in STATA 15 (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC).

Results

We invited 123 older adults fitting the inclusion criteria to participate in the study, 104 met for baseline testing and were divided into 12 clusters eligible for randomization. Six participants were included after randomization and assigned to a cluster based on their geographical residency. Three participants using wheelchairs could not perform testing and were excluded. Number of participants and clusters analyzed was 76–106 and 11–12, respectively. The flow of participants through the study is illustrated in Fig. 1. There were no adverse events reported in any of the groups.

Participant characteristics

Baseline characteristics of the groups are presented in Table 2. The median age was 86 (80–90) years and the majority were women (60%). Most of the participants used assistive walking devices (60%). The mean attendance to training sessions was 51%. The dropout rate was 44% (RTG $n = 31$; CG $n = 16$) and those dropping out were somewhat older (median age 88 (83–91) years), with similar representation of males and females (55% females).

Physical function

Figure 2 show changes in physical function from baseline to four and 8 months. After 4 months, RTG improved in stair climb (18%, $p = 0.03$) and maximal gait speed (8%, $p = 0.01$) compared to CG (Table 3, Fig. 2). No other statistically significant between-group differences were found after 4 months. After 8 months, RTG improved in all physical function tests (9–24%, p = 0.01–0.03) compared to CG (Table 3, Fig. 2). Supplementary Table S1 shows between-group effect sizes.

Maximal strength and rate of force development

There were no statistically significant between-group differences after 4 months (Table 3). After 8 months, RTG improved in leg- (18%, $p = 0.03$) and relative leg (16%, $p = 0.01$) MVC strength compared to CG (Table 3). No statistically significant between-group differences were found after 8 months for leg RFD and grip strength. Supplementary Table S1 shows between-group effect sizes.

Body composition

No statistically significant between-group differences were found after four or 8 months for body composition (Table 3). Supplementary Table S1 shows between-group effect sizes.

Per protocol- and sensitivity analyses

Following the per-protocol analysis, the between-group difference in 8 ft-up-and-go after 8 months was slightly smaller and no longer statistically significant (10%, $p = 0.06$). The per-protocol analyses did not change the other findings (Supplementary Table S2). After removing participants under 70 years, the between-group difference was slightly smaller and no longer statistically significant for stair climb (17%, $p = 0.06$) after 4 months, and maximal gait speed (7%, $p = 0.11$) and leg MVC (13%, $p = 0.05$) after 8 months (Supplementary Table S3). No other changes were demonstrated following the sensitivity analyses (Supplementary Table S4-S5).

Discussion

Among community-dwelling older adults receiving home care, resistance training using easily available, low cost equipment improved physical function (chair-rise, 8 ft-up-and-go, stair climb, preferred- and maximal gait speed) and maximal leg strength after 8 months compared to physical activity counselling. Smaller and fewer between-group differences were observed at 4 months. We found no between-group differences for explosive leg strength, grip strength, or body composition.

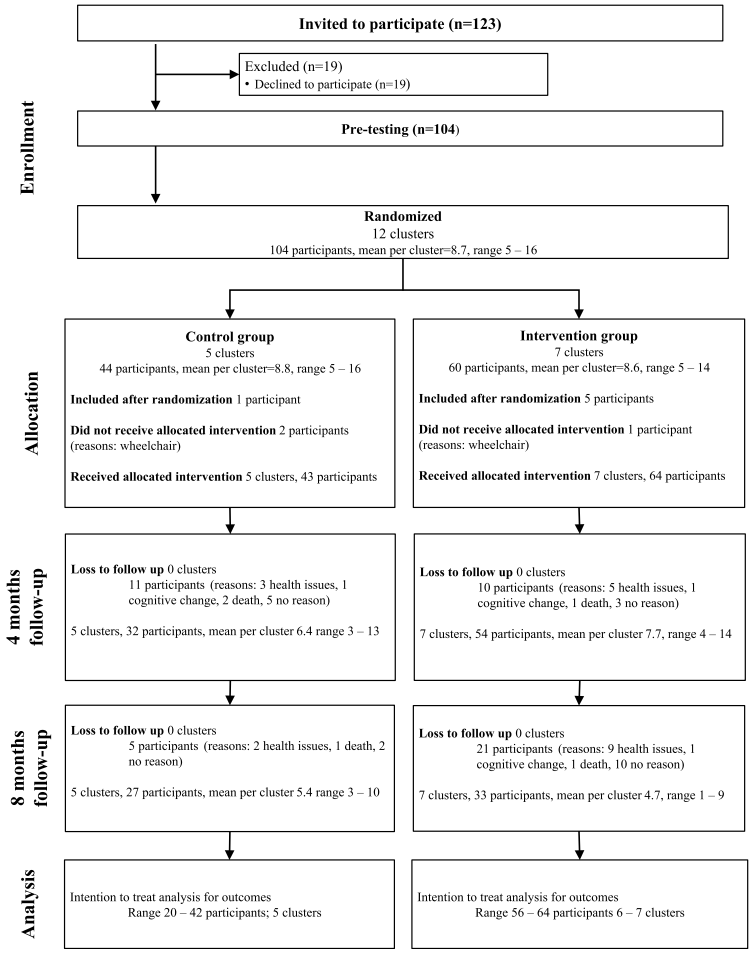

Fig. 1 Flow of participants through the study

Our findings are in line with a systematic review and a meta-analysis reporting small to moderate improvements in physical function and muscle strength in older adults following comparable resistance training programs [10, 11]. In a previous study on institutionalized older adults (mean age 83 years), no effects were found for maximal leg strength, however, the number of chair stand repetitions increased in the resistance training group compared to a control group after 6 months of training [13]. Another study including older adults in their 80s and 90s receiving home care found no effects on physical function nor maximal strength after 10 weeks of resistance training using elastic bands, body weight, and water canes [15]. This finding is supported by a study using a comparable sample [23]. The lack of effect on RFD and body composition we observed is consistent with other studies using comparable resistance training programs in older adults (e.g., elastic bands, body weight) [14, 15]. However, some studies including older adults in their 60s and 70s have reported reduced body fat and improved muscle mass [20, 21].

The lack of consistent findings could be explained by several study-differences, such as differences in protocols and outcomes for physical function and muscle strength, training volume and duration, and

Table 2 Baseline characteristics of participants

Characteristics	RTG (*n* = 64)	CG (*n* = 43)	ICC
Age (years) median (IQR)	86.5 (80–90)	86.0 (80–90)	
Sex			
Female n (%)	42 (66)	22 (51)	
Use of walking aids n (%)*	33 (52)	31 (72)	
Height (cm) mean (SD)	160 (9)	164 (9)	
Body mass (kg) median (IQR)	66.5 (55.5–79.5)[a]	70.4 (62.4–80.2)[b]	
Body Mass Index (kg/m^2) median (IQR)	25.1 (23.6–28.1)[a]	27.0 (23.7–30.3)[b]	0.00
Fat mass (%) median (IQR)	29.5 (24.4–37.4)[c]	30.4 (23.4–38.2)[d]	0.05
Fat free mass (kg) median (IQR)	42.9 (37.5–55.3)[e]	51.3 (43.2–61.2)[f]	0.02
Chair rise (s) median (IQR)	16.0 (12.7–20.7)[a]	19.3 (16.9–24.3)[g]	0.01
8 ft. up and go (s) median (IQR)	11.9 (8.5–18.6)[h]	16.0 (10.7–19.7)[i]	0.07
Stair walk (s) median (IQR)	18.8 (12.7–29.3)[j]	23.1 (19.0–33.6)[k]	0.00
Preferred gait speed (m/s) mean (SD)	0.78 (0.28)[a]	0.66 (0.18)[l]	0.07
Maximal gait speed (m/s) mean (SD)	1.1 (0.43)[a]	0.9 (0.28)[l]	0.06
Leg MVC (N) mean (SD)	185 (82)[a]	175 (67)[g]	0.00
Leg MVC relative (N/kg) mean (SD)	2.8 (1.0)[h]	2.3 (0.8)[m]	0.00
Leg RFD (N/s) mean (SD)	406 (323)[a]	447 (279)[g]	0.10
Grip strength (kg) mean (SD)	25.4 (8.1)	28.0 (7.8)[g]	0.00

RTG Resistance training group, *CG* Control group, *ICC* Intra cluster correlation, *MVC* Maximal voluntary isometric contraction, *RFD* Rate of force development, *IQR* Interquartile range 25- to 75 percentile, *SD* Standard deviation, *N* Newton
*Includes walker or crutches. One participant in CG with missing data
[a]*n* = 63 [b]*n* = 40 [c]*n* = 59 [d]*n* = 36 [e]*n* = 58 [f]*n* = 31 [g]*n* = 42 [h]*n* = 62 [i]*n* = 41 [j]*n* = 55 [k]*n* = 20 [l]*n* = 41 [m]*n* = 39

populations that are not entirely comparable (e.g., different health statuses). These issues are discussed more specifically below.

Our participants had little or no previous experience with resistance training. The design of the training program was in line with recommendations for resistance training programs for older adults [30]. However, the training volume (2 × 30-45 min/week) and attendance to training sessions (51%) might have been too low to produce enough long-term training stimuli, especially for muscle growth [31]. Low volume and intensity, especially the first 5 weeks, could further explain the fewer and smaller effects seen after four compared to 8 months of training. The larger effects seen after 8 months could indicate that training duration is of importance for this group of older adults (> 80 years). Furthermore, elastic bands provide light resistance that increases at the end of the range of motion [32] and greater force is generated during the last half of the concentric phase, when the velocity is lower. Thus, characteristics of the elastic bands may limit the ability to effectively load the muscles in the concentric phase with high velocity. The lack of training effect for RFD could also be explained by large within subject variation in RFD. Training specificity could also explain our findings, as several of the included exercises (e.g., the squat, knee-extension, and up-and-go) are highly transferrable to the physical function- and strength tests. Lastly, CG was more disabled (worse performance on physical function tests and more use of walking aids) and more overweight compared to RTG at baseline. This could hamper the ability to find between-group differences due to regression towards the mean [33]. Furthermore, the higher fat free mass in CG at baseline could explain the lack of training effect on muscle growth.

An effective resistance training program could reduce the need for home care, thereby promoting independent living. This resistance training program used easily available, low-cost equipment, making it feasible and possible to implement in real-life settings of older adults (e.g., health care centre or at home). Importantly, the decreased performance seen in CG from baseline to 8 months, but not in RTG, could indicate that reductions in physical function and muscle strength can be counteracted in the oldest old (> 80 years). However, after training, RTG still demonstrated a preferred gait speed below what has been recommended to represent good health and physical function in older adults (≥1.0 m/s) [34]. Furthermore, RTG did not reach normative age-thresholds (80–90 years) for 8 ft-up-and-go (5.2–9.6 s) [25]. Thus, whether the improvements

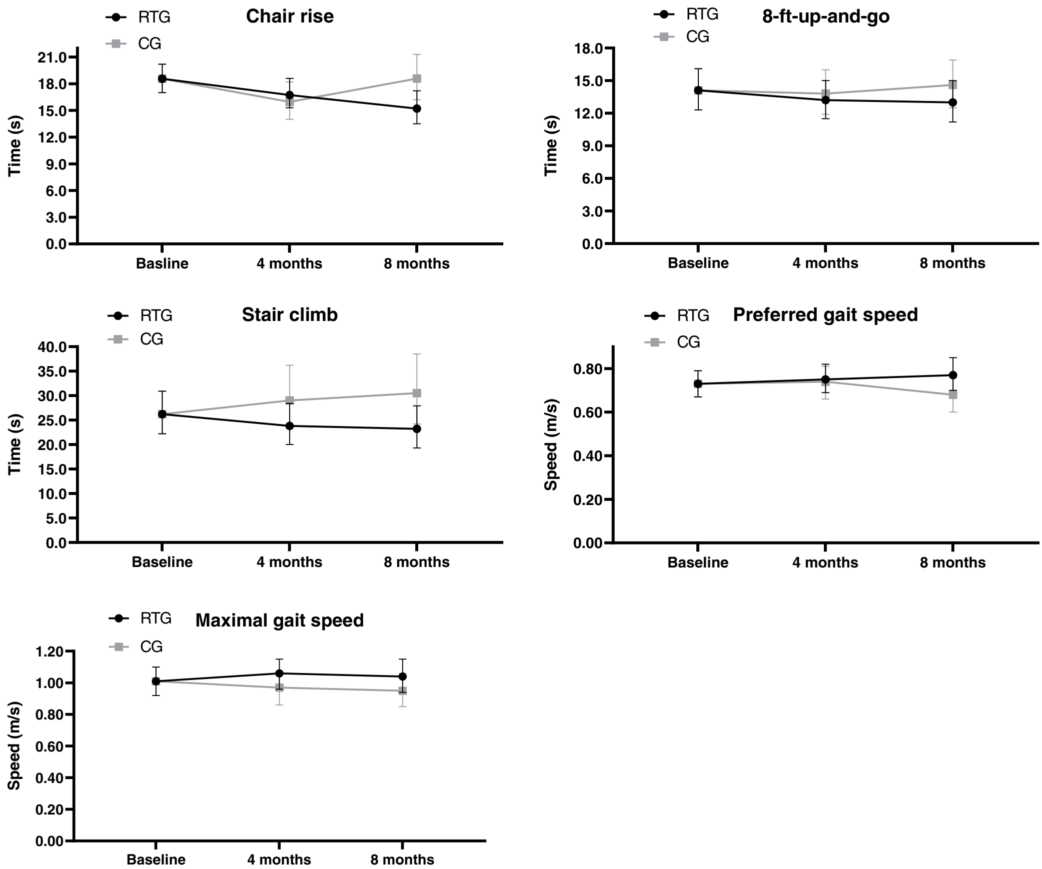

Fig. 2 Changes in physical function from baseline through four and eight months. Values are estimated means and 95% confidence intervals

demonstrated are transferrable to improving independence are unknown. We therefore speculate that action should be made before older adults are at the threshold for institutionalization. Whether greater benefits are achievable in a comparable sample by increasing volume and intensity should be investigated. Furthermore, we experienced a large dropout (44%) and low attendance, which was not surprising given the age and health status of the participants, as shown by others [35, 36]. Future studies should include strategies aimed at maximizing compliance, such as strengthening older adults' self-efficacy and motivation [36]. Future research should also evaluate the effect of earlier implementation, as well as the cost-effectiveness of implementing long-term resistance training in older adults' real-life settings.

The main strength of the study is its ecological validity with the long-term resistance training program utilizing easily availed, low cost equipment that could be incorporated into older adults' real-life settings. Additionally, the inclusion of participants receiving home care, possibly representing a window of opportunity for delaying institutionalization strengthens our study. Some limitations need to be addressed. First, the participants varied in age, physical function, and use of assistive walking devices, thus, the generalizability of the findings are unknown. Second, six participants were included after randomization, possibly biasing group allocation. Third, nutritional intake, quality of nutrition, and hydration was not standardized before testing, reducing the sensitivity to detect subtle changes in body

Table 3 Physical function, strength and body composition from baseline to four and eight months

Outcome	Analyzed		Baseline Mean (95% CI)	4 months		Between-group difference		8 months		Between-group difference	
	RTG n	CG n		RTG Mean (95% CI)	CG Mean (95% CI)	Mean (95% CI)	*p*	RTG Mean (95% CI)	CG Mean (95% CI)	Mean (95% CI)	*p*
Chair rise (s)[a]	63	42	18.6 (17.0–20.2)	16.7 (15.1–18.6)	16.0 (14.0–18.2)	1.05 (0.91–1.20)	0.500	15.2 (13.5–17.2)	18.6 (16.2–21.3)	0.81 (0.70–0.96)	0.010
8 ft-up-and-go (s)[a]	63	41	14.1 (12.3–16.1)	13.2 (11.5–15.0)	13.8 (11.9–16.0)	0.96 (0.87–1.05)	0.350	13.0 (11.2–15.0)	14.6 (12.5–16.9)	0.89 (0.80–0.99)	0.030
Stair climb (s)[a]	56	20	26.2 (22.2–30.9)	23.8 (20.0–28.4)	29.0 (23.3–36.2)	0.82 (0.69–0.98)	0.030	23.2 (19.3–27.9)	30.5 (24.2–38.5)	0.76 (0.62–0.93)	0.007
Preferred gait speed (m/s)[a]	63	41	0.73 (0.67–0.79)	0.75 (0.69–0.82)	0.74 (0.66–0.81)	0.01 (−0.04–0.07)	0.600	0.77 (0.70–0.85)	0.68 (0.60–0.76)	0.09 (0.03–0.16)	0.006
Maximal gait speed (m/s)[a]	63	41	1.01 (0.92–1.10)	1.06 (0.96–1.15)	0.97 (0.86–1.07)	0.09 (0.02–0.16)	0.010	1.04 (0.94–1.15)	0.95 (0.85–1.06)	0.09 (0.00–0.17)	0.030
Grip strength (kg)	64	42	26.4 (24.7–28.0)	26.5 (24.6–28.4)	24.9 (22.7–27.0)	1.2 (−0.5–3.7)	0.134	22.7 (20.5–24.9)	23.3 (21.0–25.5)	−0.6 (−3.0–1.9)	0.639
Leg MVC (N)	64	42	181 (166–195)	195 (179–212)	179 (160–198)	16 (−2–34)	0.074	201 (182–219)	175 (155–194)	26 (6–46)	0.010
Leg MVC relative (N/kg)	63	42	2.6 (2.4–2.8)	2.8 (2.6–3.0)	2.6 (2.3–2.8)	0.2 (−0.02–0.5)	0.073	2.9 (2.7–3.1)	2.5 (2.3–2.8)	0.4 (0.1–0.7)	0.005
Leg RFD (N/s)	64	42	431 (365–497)	436 (356–517)	337 (241–434)	99 (−8–205)	0.069	384 (292–476)	383 (282–483)	1 (− 118–120)	0.982
BMI (kg/m^2)[a]	63	43	26.4 (25.4–27.5)	26.6 (25.5–27.7)	26.5 (25.4–27.7)	1.00 (0.98–1.02)	0.890	26.3 (25.2–27.4)	26.5 (25.3–27.6)	0.99 (0.97–1.02)	0.600
Fat mass (%)[a]	59	37	28.9 (26.6–31.4)	28.9 (26.4–31.7)	27.8 (25.0–30.9)	1.04 (0.95–1.14)	0.380	28.2 (25.5–31.2)	29.7 (26.7–33.0)	0.95 (0.86–1.05)	0.310
Fat free mass (kg)[a]	59	35	47.2 (44.6–49.9)	47.5 (44.9–50.3)	47.1 (44.4–49.9)	1.01 (0.99–1.03)	0.390	46.8 (44.2–49.6)	47.1 (44.4–49.9)	0.99 (0.97–1.02)	0.670

Estimated means and 95% confidence intervals (95% CI) using linear mixed models (unadjusted model). [a] Between-group differences for transformed variables are presented as ratio of the geometric mean for RTG to the geometric mean for CG with corresponding 95% CI
RTG Resistance training group, *CG* Control group, *MVC* Maximal voluntary contraction, *RFD* Rate of force development, *N* Newton

composition. Fourth, dropout was high, but we used multilevel mixed models, which have the strength of handling missing data without imputation [26]. However, these models rely on the assumption of "missing at random" and we can not disregard the possibility of bias due to loss to follow up. Fifth, the sample is small for a cluster RCT and future studies with higher statistical power should be carried out. Lastly, some caution should be made when interpreting our findings due to multiple testing and lack of blinding.

Conclusion

In community-dwelling older adults receiving home care, resistance training improved all measures of physical function and maximal leg strength after 8 months compared to physical activity counselling. No effects were found for RFD, grip strength, or body composition. These findings suggest that resistance training programs utilizing easily available, low cost equipment could be beneficial to implement in real-life settings of community-dwelling older adults.

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s11556-020-00243-9.

Additional file 1:. Between-group Cohens' d effect sizes and 95% confidence intervals. This additional file is a one page table (.docx) showing the Cohens' d effect sizes for between-group differences for all outcomes.

Additional file 2:. Per protocol analysis including participants with ≥60% attendance to training sessions. Values are estimated means and 95% confidence intervals (95% CI), unless stated otherwise. This additional file is a table (.docx) showing results from the per protocol analysis (participants with ≥60% attendance to training) for all outcomes.

Additional file 3:. Sensitivity analysis including only participants over the age of 70 years. Values are estimated means and 95% confidence intervals (95% CI), unless stated otherwise. This additional file is a table (.docx) showing results from the sensitivity analysis including only the participants ≥70 years, as first intended by the inclusion criteria.

Additional file 4:. Sensitivity analysis of physical function outcomes without combined baseline, but adjusted for baseline differences of the outcome. Values are estimated means and 95% confidence intervals (95% CI), unless stated otherwise. This additional file is a table (.docx) showing results from the sensitivity analysis without using combined baseline, but adjusting for the baseline differences of the outcome. This sensitivity analysis was performed only for outcomes of physical function.

Additional file 5:. Sensitivity analysis of stair climb, adjusted for vertical climb and number of steps. Values are estimated means and 95% confidence intervals (95% CI), unless stated otherwise. This additional file is a table (.docx) showing results from the sensitivity analysis of stair climb, where we adjusted for vertical climb in one model and number of steps in another model.

Abbreviations

RT: The resistance training group; CG: The control group; MVC: Maximal voluntary isometric contraction; RFD: Rate of force development; N: Newton; N/kg: Newton per kilogram; m/s: Meters per second; SD: Standard deviation; IQR: Interquartile range; ICC: Intra-cluster correlation coefficient; CI: Confidence interval; CV: Coefficient of variation

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Authors' contributions

HBB was in charge of the main writing of the manuscript and data analyzes. AHS, VA, MF, KTC and TR all contributed in planning the study, while AHS and VA were in charge of running the study and collecting data. AHS, VA, MF, TR, KTC and LA reviewed the manuscript and gave appreciated input on revisions. LA contributed in planning of the statistical analysis. All authors read and approved the final manuscript.

Authors' information

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Availability of data and materials

The dataset used and analyzed during the current study is available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

The study involved human participants and all procedures were performed in accordance with the ethical standards of The Regional Committee for Medical and Health Research Ethics (2016/51) and the Norwegian Centre for Research Data (49,361/s/AGH), and with the Declaration of Helsinki. Informed consent was obtained from all participants in the study.

Consent for publication

Not applicable.

Competing interests

The authors report that they have no competing interests.

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Paper III

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Article

Physical Activity Level Following Resistance Training in Community-Dwelling Older Adults Receiving Home Care: Results from a Cluster-Randomized Controlled Trial

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Abstract: Older adults' physical activity (PA) is low. We examined whether eight months of resistance training increased PA level in community-dwelling older adults receiving home care. A two-armed cluster-randomized trial using parallel groups was conducted. The included participants were >70 years and received home care. The resistance training group performed resistance training using body weight, elastic bands, and water canes twice per week for eight months. The control group was informed about the national PA guidelines and received motivational talks. The ActiGraph GT3X+ accelerometer was used to estimate PA. Outcomes included total PA (counts per minute), sedentary behavior (min/day), light PA (min/day), moderate-to-vigorous PA (min/day), and steps (mean/day). Between-group differences were analyzed using multilevel linear mixed models. Twelve clusters were randomized to either resistance training (7 clusters, 60 participants) or the control group (5 clusters, 44 participants). A total of 101 participants (median age 86.0 (interquartile range 80–90) years) had valid accelerometer data and were included in the analysis. There were no statistically significant between-group differences for any of the PA outcomes after four or eight months. This study offers no evidence of increased PA level following resistance training in older adults with home care.

Keywords: strength training; elderly; independent living; exercise; physical behavior

1. Introduction

Physical Activity (PA) is important for successful ageing [1], reducing the risk of several non-communicable diseases [2,3] and all-cause mortality [4]. In Norway, only three out of ten community-dwelling older adults above 65 years achieved the recommended 150 min/week of moderate-to-vigorous-PA (MVPA) [5], decreasing to 5.6% in individuals above 80 years [6]. Low PA levels are related to reduced physical function and independence [3,7]; thus, maintaining and/or increasing PA levels into old age is important.

With increasing age, muscle strength, physical function (e.g., ability to rise from a chair and walking), and PA levels gradually decline [3]. Many older adults experience this as a vicious cycle; poor muscle strength is related to impaired physical function [3,8] and low PA levels [9], and impaired physical function is related to low PA [7,10]. For example, there is an association between muscle strength and walking speed [8], and walking is found to contribute greatly to older adults' daily PA [11,12]. While the benefits of resistance training on muscle strength and physical function in older adults are well established [3,13], the impact on PA levels is unclear [14–18]. Studies reporting no change in PA levels following resistance training [14,16–18] have failed to improve muscle strength and/or physical function. In contrast, in one study including institutionalized older adults where both leg strength and physical function improved, PA levels were found to increase [15]. Whether resistance training programs that improve muscle strength and physical function lead to a concurrent increase in PA levels should be more thoroughly investigated. Furthermore, time spent in sedentary behavior (SB) and light PA (LPA) have received much attention over the last decade due to their association with physical health and well-being in older adults [19,20]. Despite this, we are only aware of one study that has investigated whether engaging in resistance training is effective for reducing time spent in SB and increasing LPA, and the intervention was for a short duration (10 weeks) and the sample small [16].

The World Health Organization emphasizes the need for tailored resistance training programs that can be performed in older adults' key-settings, such as at home or in care centers [21]. Resistance training programs utilizing low-cost equipment (e.g., body weight, elastic bands) hold great potential, even for the oldest old (>80 years) [16,18]. These programs might overcome older adults' barriers, such as affordability and lack of availability [22], as training can be performed everywhere. Moreover, they facilitate the inclusion of functional movements and exercises that replicate older adults' daily activity patterns. Therefore, such resistance training programs, which aim to strengthen weakened muscles and improve physical function, could potentially increase PA, making movement easier.

We recently demonstrated that eight months of resistance training improved leg muscle strength and physical function in community-dwelling older adults receiving home care [23]. If the PA level increases as a natural consequence of improved leg strength and physical function, i.e., by making movement easier, resistance training can offer a wider range of benefits than previously established. The present study reports secondary outcomes on whether PA levels increased in older adults performing resistance training as compared to a control group receiving PA counselling. It was hypothesized that PA levels would increase more in the resistance training group compared to the control group.

2. Materials and Methods

2.1. Trial Design

The present paper used data from the Independent Self-Reliant Active Elderly (ISRAE) study, a two-armed, open-label, parallel group cluster-randomized controlled trial (RCT) performed in three Norwegian municipalities (Sogndal, Luster, and Leikanger) from August 2016 to June 2019. The intervention was for a period of eight months, and compared a resistance training group (RTG) to a control group (CG) receiving PA counselling. After the end of the intervention, we followed the participants for two years. The primary outcome of ISRAE is the ability to live independently and be self-reliant at home at the end of the two-year follow-up. We have previously reported the intervention effect on the secondary outcomes physical function and muscle strength [23]; thus, the method sections will partly overlap. This paper reports the effect of the intervention on PA levels four and eight months after study inclusion (secondary outcomes).

The study was evaluated by the Regional Committee for Medical and Health Research Ethics South East and the Norwegian Centre for Research Data (Bergen, Norway) (2016/51 and 49361/s/AGH, respectively) and was conducted in accordance with the Declaration of Helsinki and Norwegian laws and regulations. The study was registered in the ISRCTN registry (1067873, retrospectively registered). The results are presented according to the CONSORT statement extension to cluster-randomized trials [24]. Participants received written and oral information about the trial before signing a written informed consent form.

2.2. Participants

Participants were identified through the health care services in the three municipalities. Inclusion criteria were (i) age > 70 years, (ii) community-dwelling, and (iii) receiving home care due to medical and/or functional disabilities. Exclusion criteria were serious cognitive impairments (e.g., dementia, Alzheimer's disease), diagnoses/conditions affecting testing or training, or contraindications for training from a medical doctor. In addition, we included seven participants below 70 years (median age 67 (range 63–69) years), who otherwise met the inclusion and exclusion criteria. This was to increase the sample size, and a revision was made to the initial eligibility criteria.

2.3. Intevention

The RTG performed two exercise sessions a week during the eight months intervention, which lasted from the end of September 2006 to the end of May 2017. Details about the resistance training program have been published previously [23]. Briefly, training sessions were supervised by trained exercise instructors and lasted for 30–45 min. The resistance training program utilized elastic bands (ROPES a/s, Aasgardstrand, Norway), body weight, and water canes, which are considered low-cost and easily available equipment. Exercises included rowing, squats, chest press, knee extension, biceps curl, shoulder press, and up-and-go (i.e., participant standing up from a chair, walking 3 m and turning around a cone, walking back and sitting back down). The first five weeks after baseline testing served as an introductory phase focusing on correct execution of the exercises at a submaximal intensity. Thereafter, we increased the volume and intensity progressively according to recommendations [25], and exercises were to be performed to fatigue (i.e., unable to perform additional repetitions with the correct technique). The intensity was individually tailored with chairs and water canes and by changing the elastic bands' tension and thickness. The concentric phase was performed with high intentional velocity, while the eccentric phase was performed with slow, controlled intensity. Furthermore, the participants were urged to maintain their normal, habitual activity levels. Attendance was defined as the percentage of sessions met out of the total number of sessions.

Participants in CG received PA counselling in accordance with the national guidelines [26] and also received an educational brochure from the Ministry of Health and Care Services. Furthermore, every sixth week, they were visited or contacted by one of the researchers or research assistants. These conversations served to remind participants about the national PA guidelines and to motivate them to stay active.

2.4. Physical Activity Outcomes

The ActiGraph GT3X+ triaxial accelerometer (ActiGraph, LLC, Pensacola, FL, USA) was used to assess PA level, at participant level and at baseline after four and eight months. Participants were asked to wear the accelerometer in a belt over the right hip for at least 14 consecutive days and only to remove it when in contact with water or while sleeping. The accelerometer was initialized, and data were downloaded using ActiLife v.6.11 (ActiGraph, LLC, Pensacola, FL, USA). The sampling rate was 30 Hz, and data were analyzed in 10 s epochs. Vector Magnitude (VM) was used for analyses, and the ActiGraph low frequency extension (LFE) filter was applied. The LFE filter sets a lower frequency threshold for detecting accelerations, capturing slower movements often seen in older adults [27]. Non-wear time was defined as at least 90 consecutive min of zero counts, allowing for a 2 min interval of non-zero counts if accompanied by 30 min of consecutive zero up- or downstream [28]. The first day of wearing the accelerometer was excluded due to the risk of reactivity [29]. Files with at least 10 h of data for at least 4 days were considered valid [30]. Data between midnight and 6:00 a.m. were excluded.

Outcomes were total PA (TPA, counts per minute (cpm)), SB (min/day), LPA (min/day), MVPA (min/day), and steps (steps/day). The intensity thresholds were 0–199 cpm for SB [31], 200–1923 cpm for LPA [31,32], and $\geq$1924 cpm for MVPA [32] as suggested for older adults using VM. The number of steps was registered using the embedded pedometer function in GT3X+.

2.5. Randomization and Blinding

Participants were randomly allocated based on their geographical residency, i.e., participants living nearby belonged to the same cluster. Cluster randomization was chosen as it minimizes the risk of contamination and increases adherence. Twelve clusters (5–16 participants) were identified and allocated to RTG or CG. Clusters were randomized using a ratio of 3:2. The project leader conducted the randomization using the following procedure: (i) a number (1–16) was assigned to each cluster and clusters with ≥10 participants were weighted with two numbers; (ii) 60% of the participants (i.e., seven clusters) were allocated to RTG using a random numbers table; and (iii) the remaining participants (i.e., five clusters) were allocated to CG.

Due to practical concerns, we did not blind the researchers or research assistants. Furthermore, the nature of the intervention made it impossible to blind the participants and exercise instructors.

2.6. Statistical Analysis

The intention-to-treat principle was used to analyze the outcomes. Between-group effects were evaluated using multilevel linear mixed models. The baseline level of the outcome was generated by combining the baseline levels of the two groups [33]. Participant-id and cluster were entered as random effects, taking the dependency of repeated measures and cluster randomization into account. We included an interaction for group and time (baseline, four, and eight months). Normality was evaluated by visually inspecting the residuals of the outcomes. The outcomes for the groups at baseline after four and eight months were predicted using the estimates from the analyses.

Per-protocol analyses, including participants in RTG with more than 60% attendance, were performed. In addition, we performed some sensitivity analyses. First, we excluded participants under the age of 70 years, based on the initial eligibility criteria. Second, the combined baseline was removed, and we adjusted for the baseline value of the outcome (adjusted model 1). Lastly, as the main analyses were not adjusted for covariates, we conducted sensitivity analyses adjusting for accelerometer wear time, age, and BMI (adjusted model 2) to assess the robustness of our results.

Descriptive data are presented as mean and standard deviation (SD) or median and 25–75 percentiles (interquartile range, IQR). Results from the analyses are presented as estimated means and at 95% confidence intervals (CI). We calculated the intra-cluster correlation coefficients (ICC) as the between-cluster variation divided by total variation [34]. Statistical significance was set to a p-value of <0.05. STATA 15 (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, TX, USA: StataCorp LLC) was used for analyses.

3. Results

In total, 123 older adults meeting the inclusion criteria were invited to the study. Of those, 104 met for baseline testing and were split into 12 clusters. Furthermore, we included six participants after randomization. These participants were allocated to the correct cluster based on their geographical residency. Three participants in wheelchairs who could not carry out testing were excluded from analyses. Figure 1 illustrates the flow of participants throughout the study. We did not experience any adverse events.

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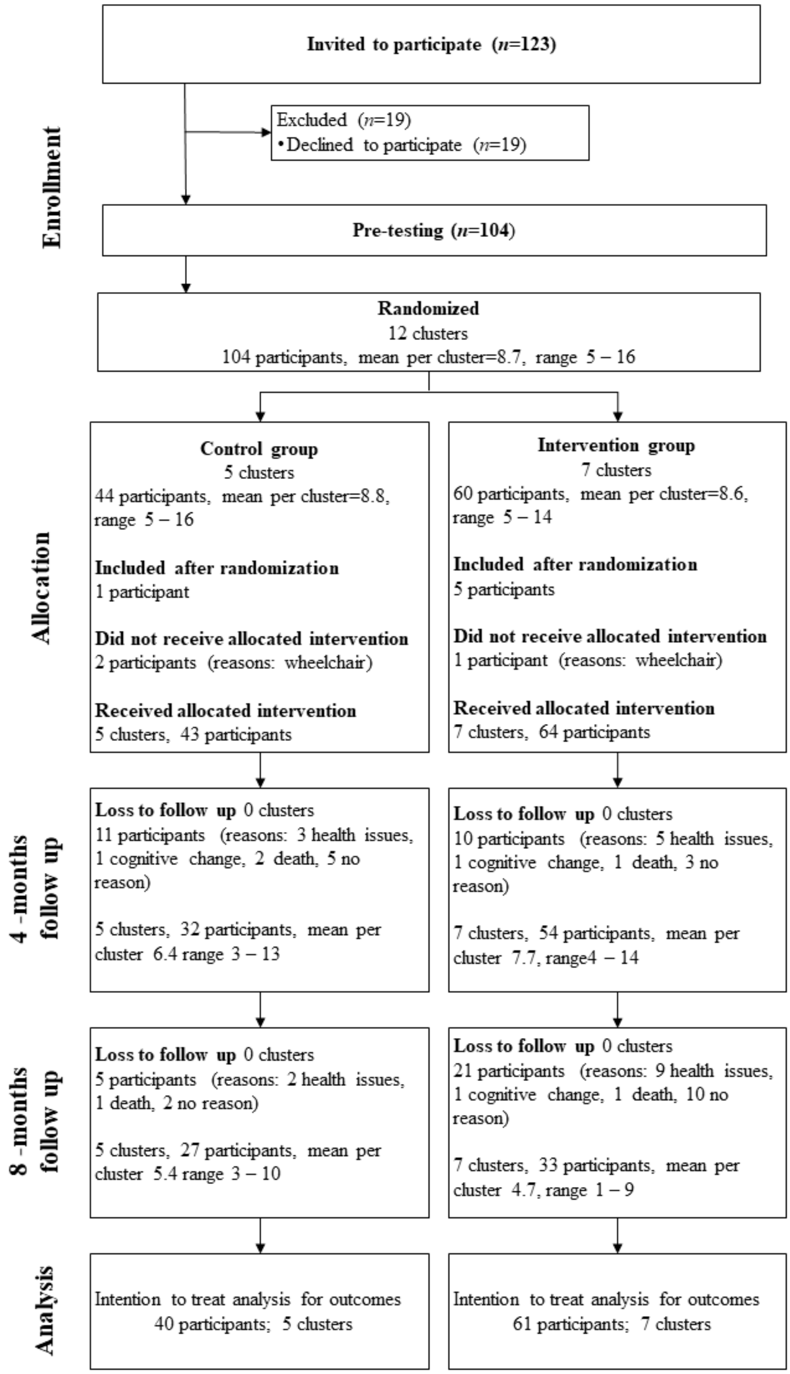

Figure 1. CONSORT (Consolidated Standards of Reporting Trails) flow chart of participant recruitment.

3.1. Participant Characteristics

3.1. Participant Characteristics

Table 1 presents baseline characteristics. The median age was 86 (IQR 80–90) years, and 60% were women. Assistive walking devices were used by 60%. Average attendance to resistance training was 51%, and 44% dropped out (RTG n = 31, CG n = 16). Six participants had no valid data at any measurement point and were not included in analyses. Participants without valid data were older (median 90 (IQR 87–90) years), and a higher number (67%) were male compared to those included in the analyses (median age 86 (IQR 80–90) years and 39% male). This left 101 participants divided into 12 clusters to be included in the analyses.

Table 1. Baseline characteristics of the participants.

Characteristics	RTG (n = 64)	CG (n = 43)	ICC
Age (years), median (IQR)	87 (80–90)	86 (80–90)	
Women, n (%)	42 (66)	22 (51)	
Use of walking devices, n (%) *	33 (52)	31 (72)	
Height (cm), mean (SD)	160 (9)	164 (9)	
Weight (kg), median (IQR)	66.5 (55.5–79.5) [a]	70.4 (62.4–80.2) [b]	
Body Mass Index (kg/m^2), median (IQR)	25.1 (23.6–28.1) [a]	27.0 (23.7–30.3) [b]	
Wear time (min/day), mean (SD) [§]	805 (77) [c]	817 (70) [d]	
Number of valid days, median (IQR) [§]	13 (12–14) [c]	13 (11–14) [d]	
TPA (cpm), mean (SD)	278 (165) [c]	224 (138) [d]	0.16
SB (min/day), mean (SD)	600 (100) [c]	643 (85) [c]	0.10
LPA (min/day), mean (SD)	170 (73) [c]	145 (64) [c]	0.10
MVPA (min/day), mean (SD)	35 (35) [c]	29 (30) [d]	0.16
Steps (steps/day), mean (SD)	6623 (3258) [c]	5223 (2623) [d]	0.18

RTG, resistance training group; CG, control group; ICC, intra cluster correlation; IQR, interquartile range; SD, standard deviation; TPA, total physical activity; cpm, counts per minute; SB, sedentary behavior; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity. * Includes walker or crutches, one participant in CG with missing data. [§] Minutes of wear and valid days of accelerometer wear. [a] n = 63 [b] n = 40 [c] n = 60 [d] n = 39.

At baseline, mean accelerometer wear time was 809 (SD 74) min/day, and the median number of valid days was 13 (IQR 11–14) (Table 1).

3.2. Physical Activity Level

There were no significant between-group differences for any of the PA outcomes from baseline to four and eight months (p = 0.371–0.880) (Figure 2A–E). Estimated mean TPA at baseline was 261 cpm (95% CI 217–306). Mean difference between RTG and CG was 5 cpm (95% CI−28–37) after four months and 20 cpm (95% CI−16–37) after eight months (Figure 2A). Estimated mean SB at baseline was 616 min/day (95% CI 593–639), and the mean difference between groups was 8 min/day (95% CI−38–22) after four months and 9 min/day (95% CI−42–23) after eight months, with CG spending slightly more time in SB compared to RTG (Figure 2B). For LPA, the estimated mean at baseline was 161 min/day (95% CI 144–178), and the mean difference between groups was −1 min/day (95% CI−21–18) in favor of CG after four months, and 8 min/day (95% CI−13–29) in favor of RTG after eight months (Figure 2C). For MVPA, the estimated mean at baseline was 34 min/day (95% CI 24–43), and the mean difference between groups was 1 min/day (95% CI−5–7) and 3 min/day (95% CI−3–10) after four and eight months, respectively (Figure 2D). The estimated mean steps per day were 6105 (95% CI 5247–6964). After four and eight months, the mean difference between the groups was−250 steps/day (95% CI−987–485) at four months and−90 steps/day (95% CI−896–716) at eight months, both in favor of CG (Figure 2E).

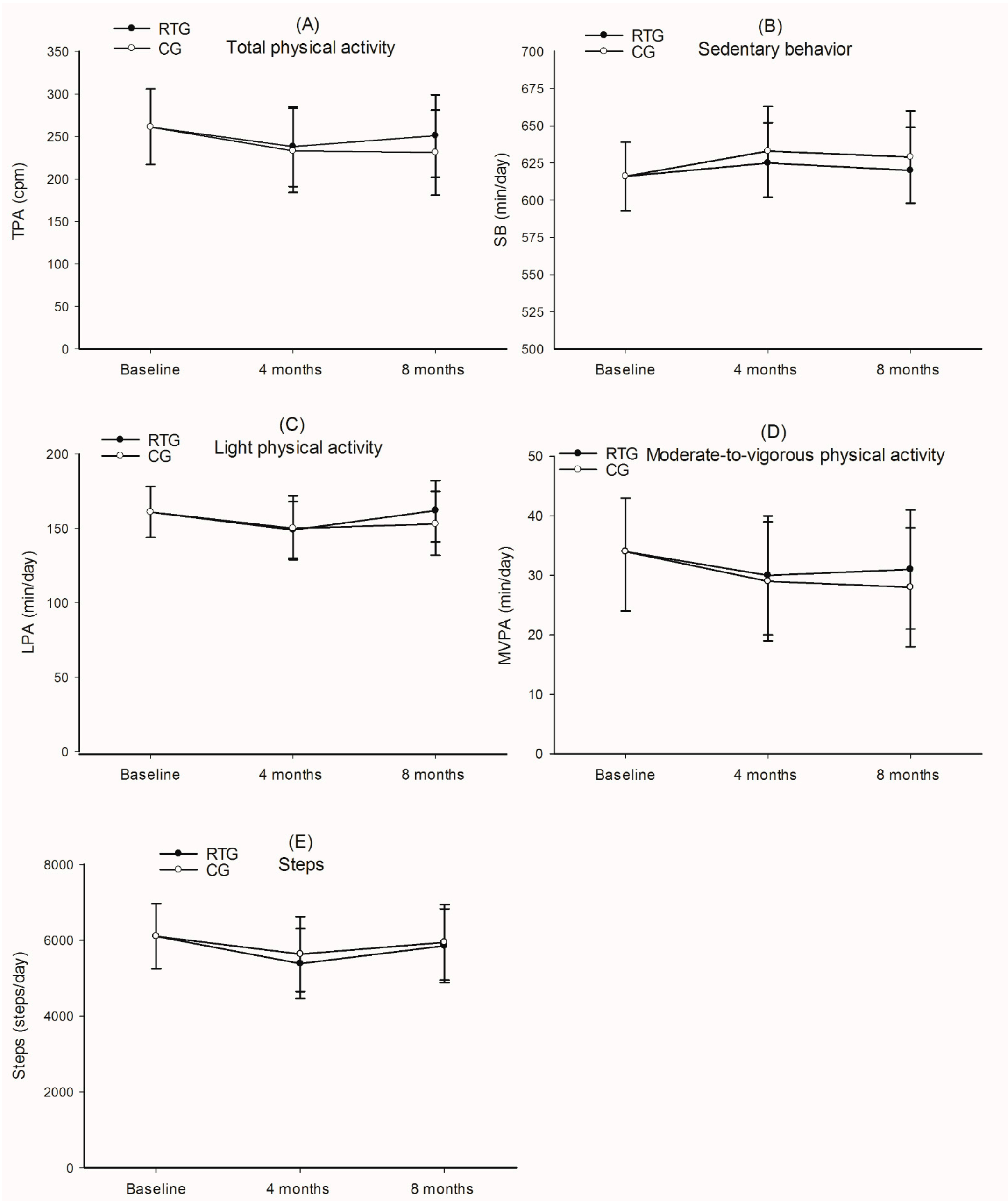

Figure 2. Changes in physical activity from baseline to four and eight months. Values are estimated means and 95% confidence intervals. RTG, resistance training group; CG, control group; Total PA, total physical activity; cpm, counts per minute; SB, sedentary behavior; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity. (**A**) total physical activity (TPA, cpm); (**B**) Sedentary behavior (SB, min/day); (**C**) Light physical activity (LPA, min/day); (**D**) Moderate-to-vigorous physical activity (MVPA, min/day); (**E**) Steps (steps/day).

3.3. Per Protocol Analyses

3.3. Per Protocol Analyses

There were no changes in the conclusions following the per-protocol analyses including participants in RTG with more than 60% attendance (Supplementary Table S1). Similarly, no changes in the conclusions were found following the other sensitivity analyses (Supplementary Tables S2–S4).

4. Discussion

There were no differences in TPA, SB, LPA, MVPA, or steps between participants in RTG receiving resistance training and participants in CG receiving PA counselling after four or eight months.

Our findings support a meta-analysis reporting that exercise interventions alone are not enough to stimulate older adults to increase their PA levels [35]. In a previous RCT, Oesen and co-workers [18] showed that elastic band resistance training had no effect on the number of steps taken by older adults living in a retirement facility (>80 years). Likewise, in a previous study from our lab [16], no change in PA levels was found in older adults receiving home care (>80 years) following 10 weeks of resistance training. However, these studies did not report improved leg strength [16,18] or physical function [16], which we expect is necessary to increase PA levels. In contrast, Fiatarone and colleagues [15] reported an effect of resistance training on PA levels, as well as leg strength and physical function, when compared to various leisure activities in institutionalized older adults (mean age 87.1 years). In the same study, leg strength and physical function improved. The contrasting findings may relate to differences in study design, training protocol (e.g., volume, frequency, equipment), populations included (e.g., different age and health status), and assessment of PA.

Over the last decade, the importance of SB and LPA for older adults' health has been highlighted. Higher LPA and less time spent in SB are associated with several important health outcomes [19,20] and better physical function [10] in older adults. Consequently, the World Health Organization 2020 guidelines on PA and SB recommend both decreasing SB and increasing PA [36]. We found no effect of the resistance training program on SB or LPA. To our knowledge, only one previous study has included SB and LPA, and this study reported similar results [16].

Several factors could explain why we could not confirm our hypothesis. Although we designed the resistance training program according to recommendations [25], the attendance at the exercise sessions was low, with a mean of one session per week (51% attendance). Studies show that training programs of higher volume and frequency are more effective for older adults [37,38], which could explain our findings. Fiatarone and co-workers [15] reported large strength gains (26–216%) in institutionalized older adults, and our 16–18% increase in strength [23] might not have been sufficient to increase PA. Another possible explanation is that the resistance training program was not specific enough and that including strength exercises with a functional movement pattern do not necessarily transfer into increased PA. Although our aim was to investigate whether resistance training alone could be effective in increasing PA, combining resistance training with specific elements targeting PA, such as walking [39], balance training, and/or behavioral strategies (e.g., goal setting and education) [40,41] could be more effective. For example, walking interventions have been successful in increasing steps and muscle strength in older adults with osteoarthritis [39] and behavioral strategies [40] have been proposed as essential for changing PA). Furthermore, it has been suggested that older adults may reduce their spontaneous PA during the day to save energy for an upcoming training session or substitute spontaneous PA with inactivity due to muscle soreness and fatigue [42]. Lastly, participants' characteristics (e.g., old age, home care, use of walking aids) could explain the lack of training effect considering that increasing PA level is less likely in those who are physically limited compared to healthy older adults [40].

Although using accelerometers to estimate PA are recommended, the lack of consensus on analytical approaches limits the comparability between studies [43]. Estimated MVPA was higher in our sample compared to previous estimates for older adults [5,6,44]. We used age-relative intensity thresholds instead of absolute thresholds to estimate MVPA. Relative thresholds are found to estimate more time in MVPA [45,46] and increase step count [46], which could explain our high PA levels. Furthermore, we estimated PA over 14 days, while the previously mentioned study reporting resistance training to be quite effective used 72 h [15]. Whether 72 h is adequate to capture an actual change in behavior, and not a spontaneous change, can be questioned [47].

Most of the PA estimates were at their lowest after four months. This was not surprising as the four months assessment was conducted in January and February, and the Norwegian winter is cold and snowy. Thus, this is most likely explained by seasonal variation in weather conditions [48].

The 14 days of objective PA measurement and age-appropriate intensity thresholds strengthens this study. Furthermore, we included estimates of SB and LPA, and showing the entire intensity spectrum of PA strengthens our study. Notwithstanding, some limitations should be acknowledged. First, dropout was high (44%), but this was not surprising due to the participants' health and high age. We used multilevel mixed models which handles missing data by using all available data [33]. However, this relies on the assumption of missing at random and bias might be present as a result of the loss to follow up. We cannot rule out that some of the participants that dropped out without reason withdrew for reasons related to the training. Second, we included six participants after randomization, which could bias group allocation. Third, we did not estimate energy expenditure, making it impossible to conclude whether RTG used less of their maximal capacity during exercising and daily life activities (improved their stamina) after the intervention. Lastly, the sample size is small for a cluster RCT, and the study was not blinded. Thus, due to study limitations, these findings should be interpreted with some caution.

5. Conclusions

In conclusion, eight months of resistance training compared to PA counselling did not change TPA, SB, LPA, MVPA, or steps per day in community-dwelling older adults receiving home care. This study indicates that a resistance training program, utilizing low-cost, easily available equipment does not alone increase PA levels in this group of older adults as compared to receiving PA counselling. We recommend that future studies combine resistance training with walking, balance training, and/or behavioral strategies to affect muscle strength, physical function, and PA level in older adults. Furthermore, future studies should continue to investigate the entire intensity spectrum, from SB to MVPA, in older adults.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/ijerph18136682/s1, Supplementary Table S1—Per-protocol analysis of participants with ≥60% attendance to training. Supplementary Table S2—Sensitivity analysis including participants above 70 years. Supplementary Table S3—Sensitivity analysis with adjustment for baseline value of the outcome and without combined baseline. Supplementary Table S4—Sensitivity analysis with adjustment for body mass index, age, and accelerometer wear time.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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