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Effects of a recreational team handball-based exercise program on cardiometabolic and musculoskeletal health profile and physical fitness in inactive postmenopausal women

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Resumo

A menopausa é definida como a cessação permanente da menstruação e caracterizada por diversas alterações hormonais, nomeadamente a diminuição dos níveis de estrogénio que está associada a diversas condições adversas na saúde. Os desportos de equipa, e particularmente o andebol de recreação, têm mostrado efeitos benéficos na saúde de diferentes populações e surgem como uma abordagem adequada para ir de encontro ao interesse das mulheres em pós-menopausa e para mantê-las motivadas e comprometidas com o exercício a longo prazo. No entanto, estudos nesta população são escassos. Para colmatar esta lacuna na literatura, foram realizados quatro estudos com o objetivo de descrever as exigências fisiológicas e físicas da prática de andebol de recreação (estudo I), os seus efeitos a curto (estudos II e III) e a longo prazo na saúde e aptidão física de mulheres em pós-menopausa, bem como descrever a adesão a longo prazo a este modelo de exercício (estudo IV). O andebol de recreação é uma modalidade intermitente com momentos de alta intensidade e ações específicas de elevada exigência, capaz de induzir adaptações positivas na saúde cardiometabólica e óssea e na aptidão física a curto prazo (16 semanas), que se mantiveram ou apresentaram melhorias adicionais a longo prazo (36 semanas). Dado que a menopausa está associada a efeitos deletérios na saúde a diferentes níveis, o conjunto de efeitos positivos da prática de andebol de recreação na saúde desta população é da maior importância. As participantes relataram elevado divertimento na prática, o que pode ter contribuído para o seu envolvimento na intervenção (76% completam as 36 semanas do programa). Não foram registadas lesões graves e a incidência de lesões foi de 0.8 lesões por cada 1000 horas de exposição, o que atesta a segurança do programa. Em suma, o andebol de recreação demonstrou ser um modelo de exercício eficaz, viável e seguro para melhorar a saúde geral e a aptidão física das mulheres em pós-menopausa e para as manter fisicamente ativas a longo prazo.

PALAVRAS-CHAVE: MENOPAUSA; DESPORTOS DE EQUIPA; EXERCÍCIO INTERMITENTE DE ALTA INTENSIDADE; CONSUMO MÁXIMO DE OXIGÉNIO; METABOLISMO ÓSSEO.

Abstract

Menopause is defined as the cessation of menses and is characterized by several hormonal changes, namely a decrease in estrogen levels which is associated to several adverse health-related conditions. Team sports, and particularly recreational team handball (RTH), have shown evidence of their beneficial effects in the health of different populations, and emerge as a suitable exercise approach to meet postmenopausal women's interest and to keep them motivated and engaged in exercise at long-term. However, studies with this population are scarce. To address this gap in the literature, four original studies were conducted aiming to describe the physiological and physical demands of RTH practice (original study I), its effects at short- (original study II and III) and long-term on health and physical fitness of postmenopausal women, as well as to describe the long-term adherence to this exercise mode (original study IV). RTH is a high-intensity intermittent exercise mode, with high-demanding actions, able to induce positive adaptations in cardiometabolic and bone health and in physical fitness at short-term (16 weeks), which were maintained or enhanced at long-term (36 weeks). Since the menopause is associated with deleterious health effects at different levels (e.g., cardiovascular diseases, metabolic syndrome, osteoporosis), the broad-spectrum positive health effects of RTH practice in this population are of the most importance. Participants reported high fun, which could have contributed to engaging in the exercise intervention (76% completed the 36-week program). Moreover, no severe injuries were recorded, and the injury incidence was 0.8 injuries per 1000 h of exposure, emphasizing the safety of the program. Taking together, RTH was shown to be an effective, feasible and safe exercise mode to improve general health profile and physical fitness in postmenopausal women and to keep them physically active at the long-term.

KEYWORDS: MENOPAUSE; TEAM SPORTS; HIGH-INTENSITY INTERMITTENT EXERCISE; MAXIMAL OXYGEN UPTAKE; BONE METABOLISM.

List of abbreviations

ALM	Appendicular lean mass
BMC	Bone mineral content
BMD	Bone mineral density
CTX	Carboxy-terminal type-1 collagen crosslinks
CVD	Cardiovascular disease
FSH	Follicle-stimulating hormone
GLUT4	Glucose transporter 4
GnRH	Gonadotropin-releasing hormone
HbA1c	Glycated hemoglobin
HDL	High-density lipoprotein cholesterol
HR	Heart rate
HR_{max}	Maximal heart rate
HT	Hormonal therapy
LDL	Low-density lipoprotein cholesterol
LH	Luteinizing hormone
NO	Nitric oxide
P1NP	Procollagen type-1 amino-terminal propeptide
PA	Physical activity
RTH	Recreational team handball
STRAW	Stages of Reproductive Aging Workshop
TRG	Triglycerides
VO_{2max}	Maximal oxygen uptake
VO_{2peak}	Peak oxygen uptake
YYIE1	Yo-Yo intermittent endurance level 1 test
YYIE2	Yo-Yo intermittent endurance level 2 test

CHAPTER I

General Introduction

General Introduction

Menopause is defined as the cessation of menses and marks the end of the reproductive status (Bruce & Rymer, 2009; Nelson, 2008). It is a permanent condition that occurs around the age of 51 years and accompanies women in more than one third of their lives (Bruce & Rymer, 2009; Nelson, 2008). Menopause is associated to several hormonal changes, mainly the markedly decrease in estrogen levels (Baber, Panay, & Fenton, 2016). Estrogen levels are high during the reproductive phase and start presenting some variation later in this stage, then decreasing during menopause transition to postmenopause phase (Harlow et al., 2012). Estrogen is mainly secreted by follicles and its main action is to inhibit the secretion of gonadotropin-releasing hormone (GnRH), which in turn secrets hormones responsible for follicles ovulation (Hall, 2015). The strict control over these mechanisms allows the normal reproductive cycle. However, due to ovarian aging and to the dysregulation in central nervous system, more follicles are recruited or lost across the lifespan (Broekmans, Soules, & Fauser, 2009; Diamanti-Kandarakis et al., 2017; Hall, 2015). Thus, the acceleration of recruitment along with the diminished number of follicles lead to the cessation of the menstrual cycle (Hall, 2015). A significant depletion of estrogen occurs after the final menstrual period (Harlow et al., 2012). Besides its well-known role in the reproductive function, estrogen also exerts its effects on different target tissues, such as blood vessels, skeletal muscle and bones. Therefore, it is crucial at different levels, namely in vascular and musculoskeletal function, in musculoskeletal development, in body mass and energy homeostasis and in glucose and lipid metabolism (Brown, 2008; Faulds, Zhao, Dahlman-Wright, & Gustafsson, 2012; Lizcano & Guzmán, 2014; Mauvais-Jarvis, Clegg, & Hevener, 2013; Novella, Dantas, Segarra, Medina, & Hermenegildo, 2012). In this regard, several health adverse effects, apart from the reproductive ones, are expected in menopausal transition and in postmenopausal status due to the lack of estrogen action in different tissues.

From the menopausal transition until several years during postmenopausal stage, women experience various symptoms, generally divided

in vasomotor, urogenital and psychological symptoms, and are mainly affected by hot flushes and vaginal dryness (Bruce & Rymer, 2009). Due to the condition and associated consequences of the menopausal symptoms, there is an inevitably impact on women's social life, well-being, ability to work, sexual health and, consequently, quality of life (Bruce & Rymer, 2009; Nappi & Palacios, 2014; Nelson, 2008). Other health-related conditions, even though non-exclusive to postmenopausal women, are exacerbated at this stage. The risk of developing cardiovascular diseases (CVDs) increases after menopause (Novella et al., 2012), being the principal cause of mortality and morbidity in postmenopausal women (Baber et al., 2016). Moreover, CVDs risk factors, namely obesity, diabetes, dyslipidemia and hypertension, are prevalent in postmenopause (Tandon, Mahajan, Sharma, & Sharma, 2010). Changes in body composition are also observed across menopause. A decrease of around 10% in bone mineral density (BMD) is shown during menopause transition (Greendale et al., 2012). Similarly, a decrease in muscle mass and in muscle strength is observed in this period (Greendale et al., 2019; Maltais, Desroches, & Dionne, 2009). Sarcopenia (which is characterized by low muscle mass and strength) and osteoporosis (which is characterized by low bone mass) are two key-factors related to increased risk of falls and fractures that lead to physical disability, and ultimately, mortality in postmenopausal women (Cruz-Jentoft et al., 2019; Guadalupe-Grau, Fuentes, Guerra, & Calbet, 2009; The North American Menopause Society, 2021). Therefore, strategies that mitigate symptoms and health-related conditions that affect this population are essential.

Hormonal therapy (HT) has been widely applied to treat menopause-related symptoms, having also important beneficial effects in the associated negative health-related conditions above mentioned (Baber et al., 2016). In fact, HT has shown to be effective in decreasing fasting glucose, glycated hemoglobin (HbA1c), total cholesterol and low-density lipoprotein cholesterol (LDL) and in increasing high-density lipoprotein cholesterol (HDL), and also in preventing bone loss (Bagger et al., 2004; Slopien et al., 2018; Xu, Lin, Wang, Xiong, & Zhu, 2014). Taken together, HT is usually considered a reliable and effective approach to mitigate postmenopausal women's deleterious health-conditions.

Nonetheless, it must be used with caution, particularly in over 60-year-old women or women at postmenopause stage for more than 10 years, since estrogen replacement therapy in later stages of menopause increases the risk of coronary events (Baber et al., 2016; Hodis & Mack, 2014). Therefore, alternative approaches to treat menopause-related symptoms and health conditions must be considered.

Exercise has been shown as a potential therapy to several diseases (B. K. Pedersen & Saltin, 2015), namely those that affect postmenopausal women, even though it is still unclear the effectiveness of exercise in mitigating menopausal symptoms (Daley, Stokes-Lampard, Thomas, & MacArthur, 2014; Stojanovska, Apostolopoulos, Polman, & Borkoles, 2014). Exercise-based programs have been recommended to improve menopausal women's health (Grindler & Santoro, 2015), showing benefits on body composition, cardiovascular and bone health, and physical fitness (Asikainen, Kukkonen-Harjula, & Miilunpalo, 2004). The results of different exercise programs based on aerobic, resistance, balance and combined exercise showed a decrease in body and fat mass, a decrease in blood pressure and blood lipids, an increase in BMD and bone mineral content (BMC) and an increase in strength, endurance, cardiorespiratory fitness, flexibility, balance, and coordination (Angın, Erden, & Can, 2015; Asikainen et al., 2004; Carcelén-Fraile et al., 2021; García-Garro et al., 2020; Lee, Kim, & Kim, 2012; Liu et al., 2022; C. Sun et al., 2022).

Notwithstanding this knowledge, the physical activity (PA) levels in the general population, including women at postmenopausal age (i.e., over 55 years) are alarmingly low (European Comission, 2017, 2022). Thus, the Global Action Plan on PA 2018-2030 targets to reduce the global prevalence of physical inactivity in 15% by 2030 (World Health Organization, 2018). Lack of motivation is one of the main barriers to exercise (European Comission, 2022), suggesting that the offered exercise options are not sufficiently appealing to most of the general population. In fact, the World Health Organization has made a call for innovative approaches to increase PA that are attractive and affordable (World Health Organization, 2016). In this context, sport and active recreation were

pointed out as suitable strategies to increase the levels of PA (World Health Organization, 2018).

Recreational team sports are an alternative exercise modality that offers a social and enjoyable environment, fostering engagement and motivation to regularly exercise (Andersen, Ottesen, & Thing, 2019; Castagna, de Sousa, Krustrup, & Kirkendall, 2018; Castagna, Krustrup, & Póvoas, 2020a), thus, potentially counteracting the main barrier to exercise (European Comission, 2022). Among the different recreational team sports, football has been widely studied, showing positive results in cardiovascular, metabolic and bone health, as well as in physical fitness and body composition (Bangsbo, Hansen, Dvorak, & Krustrup, 2015; Krustrup et al., 2010; Krustrup & Krustrup, 2018; Milanović, Čović, Helge, Krustrup, & Mohr, 2022; Milanović, Pantelić, Čović, Sporiš, & Krustrup, 2015; Milanović et al., 2019; Sarmento et al., 2020). The effects of recreational football practice on health of different populations have already been reported, namely for 18-65-year-old women (Krustrup et al., 2018), 48-68-year-old men and women, in this last case, all in postmenopausal status (de Sousa et al., 2014) and over 55-year-old men and women (Skoradal, Helge, et al., 2018; Skoradal, Weihe, et al., 2018). However, studies focusing solely on postmenopausal women are missing. Additionally, studies that analyze the effect of other recreational team sports practice on postmenopausal women's health are also scarce. To the best of our knowledge, only the effect of floorball was analyzed in this population, revealing positive results on cardiovascular and bone health, body composition and aerobic performance (Nyberg et al., 2014; Seidelin et al., 2017). These results encouraged the researchers to test the potential benefits of other team sports, in order to widen the evidence on the effectiveness of these exercise modality options, and to ascertain if they could also meet the populations' interests.

Among the possibilities, recreational team handball (RTH) emerged as a promising beneficial health-related strategy. It is a high-intensity and intermittent exercise, with high aerobic and anaerobic demands, characterized by high heart rate (HR), distance covered ranging from 3-6 km, with high-intensity movements (namely fast running and sprinting) and high-demanding actions (such as stops,

jumps and changes of direction, among others), and thus able to positively elicit the cardiovascular and musculoskeletal systems (Hornstrup et al., 2019; Hornstrup et al., 2020; Hornstrup et al., 2018; Póvoas et al., 2017; Stojiljković et al., 2020). Accordingly, previous studies reported increases in muscle mass, BMD, BMC, bone turnover markers, maximal oxygen uptake (VO_{2max}), HDL, aerobic performance and balance, and decreases in fat mass, resting HR and fasting glucose, after short-term interventions with young men and women (20-30-year-old) (Hornstrup et al., 2019; Hornstrup et al., 2018), adult/middle-aged men (33-55-year-old) (Póvoas et al., 2018) and overweight premenopausal women (35-50-year-old) (Hornstrup et al., 2020). The current knowledge allows to foresee the potential effect of RTH practice in improving a diversity of factors and conditions that affect postmenopausal women's health. Nonetheless, data regarding the long-term effects of RTH practice are still lacking. Similarly, apart from football, there is also a lack of studies addressing the long-term health effects of other recreational team sports. Even though, one study showed that an additionally period of 40 weeks of floorball practice was able to preserve the health and physical fitness enhancements achieved after 12-weeks, in postmenopausal women, despite of a 50% dropout (Seidelin et al., 2017). The health effects of RTH practice in postmenopausal women at short- and also at long-term are of interest, namely because postmenopausal status remains across lifespan. Moreover, the adherence to this kind of exercise must be assessed.

CHAPTER II

Aims

Aims

Based on the current knowledge provided by the literature on the effects of exercise on postmenopausal women's health and the gap regarding the effects of recreational team sports practice, in particular of RTH, in this population, as well as its effects at the long-term, the main aims of this thesis were to describe the physiological and physical demands of RTH practice as well as its effects (at short- and long-term) on health and physical fitness in postmenopausal women.

Thus, experimental studies were developed with the following specific aims:

Original Study I

To analyze the physiological and physical demands of RTH and the intensity variability of the training sessions in postmenopausal women without previous experience with the sport.

Original Study II

To analyze the short-term effects of a RTH-based exercise program on aerobic performance, cardiorespiratory fitness and metabolic health markers in inactive postmenopausal women without previous experience with the sport.

Original Study III

To analyze the short-term effects of a RTH-based exercise program on bone health, postural balance and body composition in inactive postmenopausal women without previous experience with the sport.

Original Study IV

To determine the long-term (36 weeks) adherence and the health and physical fitness effects of a RTH-based exercise program in postmenopausal women without previous experience with the sport, and to compare them with the alterations shown after the first 16 weeks (short-term).

CHAPTER III

Theoretical Background

Theoretical Background

Menopause

Menopause is a condition in women's life characterized by the permanent cessation of menses (Nelson, 2008). It is retrospectively diagnosed after 12 months of amenorrhea not associated to a pathological cause, or can be induced by surgery, chemotherapy or radiation (Nelson, 2008). It occurs around the age of 51 years with ethnic and regional variations (Baber et al., 2016). Thus, women could spend more than one third of their lives in this condition. Additionally, premature menopause could occur if installed before 40 years of age, regardless of being natural or not (Baber et al., 2016). From a physiological point of view, menopause is, particularly, associated to several hormonal changes.

Hormonal changes during menopause

The cessation of menses results from the depletion of ovarian follicles and reduced secretion of estrogen and progesterone and marks the end of the reproductive period of women's life (Bruce & Rymer, 2009; Nelson, 2008). The Stages of Reproductive Aging Workshop (STRAW) is the gold standard classification to characterize reproductive aging changes, dividing women's life in three phases: reproductive, menopause transition and postmenopause (Harlow et al., 2012). During the largest part of the reproductive phase, menstrual cycles are regular and follicle-stimulating hormone (FSH) concentration is low in contrast with the high level of estrogen. Then, in the later reproductive stage, fecundity begins to decline, menstrual cycles suffer slighter changes in flow and length, while FSH and estrogen levels also show some variation. Menopause transition is the period before the final menstrual period and it is characterized by a variability in menstrual cycle length and frequency, with periods of amenorrhea of 60 or more days, an elevation in FSH levels and a decrease in estrogen concentration. The final menstrual period marks the start of the postmenopausal stage that will remain across the lifespan. During early postmenopause, FSH

continues to increase, whereas estrogen decreases, until stabilizes ~2 years later in late postmenopause period (Harlow et al., 2012).

A regular menstrual cycle results from a close connection between the hypothalamus, the pituitary gland and the ovaries (Broekmans et al., 2009; Hall, 2007, 2015). The pulsatile secretion of GnRH from the hypothalamus stimulates the secretion of FSH and luteinizing hormone (LH) in the anterior pituitary gland (Bruce & Rymer, 2009; Hall, 2007). FSH stimulates the follicles growth and LH stimulates ovulation and corpus luteum formation (Hall, 2007). Developed follicles, in their turn, secrete estrogen, progesterone, inhibin B and inhibin A (Hall, 2015). Estrogen decreases the quantity of GnRH secreted and progesterone decreases the frequency of GnRH pulses, while inhibin B and A contribute with negative feedback over the FSH secretion in the pituitary gland (Hall, 2007, 2015). Moreover, estrogen also decreases the response of pituitary at GnRH effect (Hall, 2015). The negative feedback over the FSH release is crucial to ensure that a single dominant follicle is selected, whilst the cessation of negative feedback from estrogen and progesterone over the hypothalamus is also important to increase FSH levels and initiate the next follicular recruitment (Broekmans et al., 2009; Hall, 2015), which underlines the importance of the strict control over these mechanisms.

The decrease in quantity and quality of oocytes over women's lifespan is pointed out as an indicator of reproductive aging (Broekmans et al., 2009). In fact, at birth, women possess a maximum and limited number of follicles (~1-2 million), that suffer a steady decline until puberty (~300,000-400,000) (Broekmans et al., 2009). During the reproductive years, some follicles reach maturity and others are lost by apoptosis, getting a critical value of ~1000 close to menopausal transition (Broekmans et al., 2009; Hall, 2015). A reduced pool of resting follicles between 100 and 1000 leads to the cessation of menstrual cycles (Hall, 2015). Moreover, with age, hypothalamus loses the sensitivity to negative feedback of estrogen, and thus, the GnRH release increases (Diamanti-Kandarakis et al., 2017). In this regard, FHS levels increase, leading to an acceleration of follicular recruitment and exacerbating the follicle loss (Hall, 2015). Concomitantly, less inhibin B is secreted due to the decreased number of oocytes and the ovarian

negative feedback on FSH also decreases, even though without compromising the estrogen levels (Hall, 2007), that only have a significant depletion in later stages of menopause transition and reach its lower concentration after the final menstrual period (Broekmans et al., 2009; Harlow et al., 2012).

Estrogen action and effects

Estrogen exerts diverse effects on its target tissues, through estrogen's receptors located on specifics cells (Tostes, Nigro, Fortes, & Carvalho, 2003). Estrogen's receptors in vascular smooth muscle and endothelium underline an estrogen effect in vascular function (Novella et al., 2012; Tostes et al., 2003). As example, vasodilation is mediated by nitric oxide (NO), whose bioavailability is affected by estrogen, both in the increase of NO levels and in the decrease of molecules involved in NO inhibition (Novella et al., 2012). Also, estrogen exerts an inhibitory effect in the production of vasoconstrictor agents like endothelin-1 and angiotensin II (Tostes et al., 2003). Taking the last one as example, angiotensin II has a crucial action in renin-angiotensin system, which contributes to the regulation of blood pressure, being an additional effect of estrogen in the renin-angiotensin system the inhibition of angiotensin-converting enzyme and angiotensin-1 receptor expression (Novella et al., 2012).

Estrogen positively contributes to body mass and energy homeostasis through the maintenance of food intake and energy expenditure. Estrogen acts in neural activity and high concentrations of this hormone inhibit energy intake and stimulate energy expenditure (Mauvais-Jarvis et al., 2013). An example of its action is the increase of sensitivity to cholecystokinin and leptin, both hormones involved in satiety signaling (Faulds et al., 2012; Mauvais-Jarvis et al., 2013). Estrogen is also known to control glucose and lipid metabolism. Estrogen expression decreases fatty acids, triglycerides (TRG) synthesis and lipogenesis and increases fat oxidation, providing the use of lipids as energy source (Faulds et al., 2012; Lizcano & Guzmán, 2014; Mauvais-Jarvis et al., 2013). Thus, estrogen inhibits adipose tissue deposition and regulates fat distribution (Mauvais-Jarvis et al., 2013). With regard to glucose metabolism, estrogen plays

a role in maintaining insulin action and sensitivity and glucose tolerance, namely by its direct and indirect control in glucose metabolism enzymes (Lizcano & Guzmán, 2014; Mauvais-Jarvis et al., 2013). Other example is that estrogen is suggested to induce glucose transporter 4 (GLUT4) expression, and thus, to stimulate glucose uptake (Mauvais-Jarvis et al., 2013). Nonetheless, a strict control over the estrogen concentration is crucial, since excessive levels, in contrast, lead to insulin resistance and decrease in GLUT4 expression (Mauvais-Jarvis et al., 2013).

Estrogen acts over skeletal muscle through estrogen's receptors located in the cell membrane, cytoplasm and nuclear membrane (Brown, 2008). There are inconsistent results regarding the anabolic effect of estrogen in muscle mass, however, the effect of this hormone in muscle metabolism (in line with the previous mentioned), in strength/contractile function and its role in the protection against injuries and in recovery are assumed (Brown, 2008; Collins, Laakkonen, & Lowe, 2019; Lowe, Baltgalvis, & Greising, 2010). The possible mechanisms by which estrogen acts on the skeletal muscle are the following: acts as an antioxidant and membrane stabilizer and mitigates the inflammatory response mediating the infiltration of neutrophils and macrophages into the muscle after exercise-induced muscle damage; enhances activation and proliferation of satellite cells responsible for muscle repair; modulates myosin binding, therefore impacting muscle strength; enhances the expression of heat shock proteins, which are implicated in protein folding, maintenance of protein structure and anti-apoptotic signaling (Collins et al., 2019; Enns & Tiidus, 2010; Ikeda, Horie-Inoue, & Inoue, 2019; Lowe et al., 2010).

Bone remodeling results from osteoclastic and osteoblastic activity with both osteoclasts and osteoblasts responding to estrogen effect, namely by suppressing the breakdown of bone and increasing bone formation, respectively (Brown, 2008). These are some mechanisms by which estrogen influences bone metabolism: induces transcription of Fas ligand, which induces osteoclast apoptosis; increases transcription of osteoprotegerin, which inhibits nuclear factor κB ligand (a cytokine important in osteoclast activation and differentiation); represses pro-osteoclastic cytokines (e.g., interleukin-1, interleukin -6 and TNF-

α); regulates anti-apoptotic proteins in osteoblasts; induces alkaline phosphatase transcription, which increases osteoblasts differentiation (Khalid & Krum, 2016). Thus, at menopause, when estrogen deficiency is clear, there is an increase of osteoclastic activity, and consequently, bone resorption without an equivalent increase in bone formation, which leads to bone loss (Tella & Gallagher, 2014).

Due to the action of estrogen in the physiological system, it is expectable that the decreased secretion of this hormone culminates in adverse effects in women's health during menopause transition and, afterwards, in the postmenopause stage.

Menopause symptoms and health-related effects

Menopausal symptoms include vasomotor, urogenital, and psychological symptoms, as well as other physical symptoms, such as muscle, bone and joint pain, fatigue, asthenia, and breast tenderness (Bruce & Rymer, 2009; Diamanti-Kandarakis et al., 2017). Hot flushes and vaginal dryness are the most significant symptoms that affect women in this phase (Bruce & Rymer, 2009).

Vasomotor symptoms are described as a spontaneous sensation of warmth and include hot flushes (sensation of heat), hot flashes (sweating) and night sweating (hot flashes at night), usually associated to palpitations and headaches (Nelson, 2008). Hot flushes affect more that 75% of menopausal women and occur mainly in the first postmenopausal year (Bruce & Rymer, 2009). Hot flushes can occur at any time of the day and night, and be accompanied by night sweating, which interferes with normal sleep pattern and quality, leading to insomnia and irritability, that are psychological symptoms also typical in menopausal women (Bruce & Rymer, 2009). Vasomotor symptoms negatively impact women's social life, psychologic health, well-being, ability to work, and thus quality of life (Bruce & Rymer, 2009).

With estrogen's receptors located in the vaginal walls and urogenital tract, the physiological responses to low concentration of estrogen induce reduced vaginal blood flow and secretions, changes in tissues and in vaginal fluid pH, reduction in elasticity and distensibility of the vaginal walls, as well as diminished

quality of paraurethral connective tissue (Bruce & Rymer, 2009; Nappi & Palacios, 2014; Nelson, 2008). These changes result in vaginal and urethral atrophy leading to several urogenital symptoms that can affect at least 50% of women, namely dryness, itching, irritation, dyspareunia, dysuria, frequency, nocturia, urgency and incontinence (Bruce & Rymer, 2009; Nappi & Palacios, 2014; Nelson, 2008). In contrast to vasomotor symptoms described above, urogenital symptoms can persist for years during postmenopause, affecting sexual health and quality of life (Nappi & Palacios, 2014).

In addition, anxiety, depression, mood changes, sleep disturbance and cognitive changes are some psychological symptoms, common in menopause transition, that could be associated to vasomotor and urogenital symptoms among other causes (Nelson, 2008). Nonetheless, it is still not clear if psychological symptoms are associated to the decrease of estrogen levels (Bruce & Rymer, 2009). Sleep disorders are likely to be the most reported psychological symptom, with 40-60% of women reporting sleep disorders during menopause and at postmenopause (Nelson, 2008), namely trouble falling asleep, disturbed sleep and frequent awakenings (Gracia & Freeman, 2018). There is a strong correlation between hot flushes and poor sleep, and many hot flushes events concur with periods of wake, entailing that sleep disturbance is mainly attributed to vasomotor symptoms (Baker, de Zambotti, Colrain, & Bei, 2018). Indeed, other menopause-related conditions, such as poor health, chronic illness or pain, anxiety, depression, and medications can also contribute to sleep disorders (Gracia & Freeman, 2018). Sleep disorders also impact physical health, productivity and quality of life (Baker et al., 2018).

Besides experiencing menopause-related symptoms, women after menopause are also at increased risk of developing some pathological conditions, such as type-2 diabetes, osteoporosis and CVDs (Stojanovska et al., 2014). Indeed, premenopausal women benefit from the protective role of estrogen, which explains, at least in part, why they have lower cardiovascular risk compared to men of the same age and postmenopausal women (Novella et al., 2012). However, after menopause this risk increases, being similar between sexes at older ages (Novella et al., 2012). In fact, CVDs are the principal cause

of morbidity and mortality in postmenopausal women (Baber et al., 2016) and obesity, diabetes, dyslipidemia, and hypertension are the main CVDs risk factors for this population (Tandon et al., 2010). Indeed, menopause is related with increased body mass and abdominal obesity, reduced glucose tolerance, abnormal plasma lipids and increased blood pressure (Keller et al., 2010; Marchi et al., 2017; Rosano, Vitale, Marazzi, & Volterrani, 2007).

Women are usually predisposed to obesity (Keller et al., 2010) increasing its prevalence across the lifespan (Hales, Carroll, Fryar, & Ogden, 2020). As an example, in the United States, women aged 20-39 years have an obesity prevalence of 39.7%, which increases to 43.3% between 40-59 years (includes the menopause transition stage) and remains high at older ages (≥60 years) (Hales et al., 2020). The increase in body mass gain seems not be linear to age increase, but instead to increase particularly during menopausal transition (Keller et al., 2010). Accordingly, body mass is higher in postmenopausal than in premenopausal women (Ambikairajah, Walsh, Tabatabaei-Jafari, & Cherbuin, 2019). Nevertheless, women's body mass gain has been associated to age and environmental factors, more than menopause *per se* (Ambikairajah et al., 2019; Baber et al., 2016). In fact, as the onset of menopause overlaps the period when several deleterious health-effects related to aging are more pronounced, it becomes demanding to differentiate the aging from the hormonal effects (Novella et al., 2012). Conversely, changes in body composition are explained both by increasing age and ovarian aging, namely the increase in fat mass and waist circumference and the decrease in skeletal muscle mass (Sowers et al., 2007).

Fat mass increases prior to menopause transition, being the increase accelerated and accompanied by the decrease of lean mass two years before the final menstrual period (Greendale et al., 2019). Consequently, body fat percentage, visceral fat, and waist circumference are higher in postmenopausal than in premenopausal women (Ambikairajah et al., 2019). Fat mass, and particularly its distribution, is of most importance, as it is reported that women with normal body mass, but central obesity (waist circumference >88 cm) are at higher risk of all-cause mortality than those with normal body mass and no central obesity, and at similar risk than those with obesity (body mass index ≥30) and

central obesity (Y. Sun et al., 2019). Alongside with the last menstrual period, a redistribution of fat occurs in the abdomen (from a gynoid to an android pattern) (Rosano et al., 2007) and, consequently, postmenopausal women show higher abdominal subcutaneous and intra-abdominal fat than premenopausal women (Toth, Tchernof, Sites, & Poehlman, 2000).

Abdominal obesity (waist circumference ≥88 cm) is one of the factors that contributes to increased metabolic syndrome risk in women, together with dyslipidemia (TRG ≥150 mg/dL and HDL <50 mg/dL), elevated blood pressure (systolic blood pressure ≥130 mmHg and/or diastolic blood pressure ≥85 mmHg) and elevated fasting glucose (≥100 mg/dL) (Grundy et al., 2005). Note that the metabolic syndrome factors merge with CVDs risk factors. Indeed, the presence of metabolic syndrome (i.e., combination of at least 3 out of the 5 factors) indicates increased risk of atherosclerotic CVD (Grundy et al., 2005). In a sample of 500 postmenopausal women, 60% showed abdominal obesity, 39% dyslipidemia (21% with low HDL and 31% with high TRG), 56% hypertension and 21% diabetes. Additionally, 78% were overweight, 30% had high total cholesterol and 27% high LDL concentrations. Globally, 13% of the women in the sample were diagnosed with metabolic syndrome (Tandon et al., 2010). Menopause status was pointed out as a possible predictor of metabolic syndrome (Eshtiaghi, Esteghamati, & Nakhjavani, 2010). In a sample of 940 women (20-76-year-old), metabolic syndrome prevalence was 26%, with a prevalence of 54% in postmenopausal women (n=215) and 18% in premenopausal women (n=725) (Eshtiaghi et al., 2010). Another study that analyzed the prevalence of metabolic syndrome in pre (n=277) and postmenopausal women (n=681) reported 22.2% in postmenopausal, but only 9.4% in premenopausal women and 18.5% in the total sample (Marchi et al., 2017). Regarding metabolic syndrome factors, postmenopausal women showed lower HDL levels, higher blood pressure and higher fasting glucose levels than premenopausal women (Marchi et al., 2017). Blood pressure and glucose levels are of particular interest, since the combination of hypertension and diabetes doubles the risk of CVDs for women compared with men (Rosano et al., 2007).

Osteoporosis is related, at least in part, to estrogen deficiency (Ji & Yu, 2015). Accordingly, estrogen deficiency and early menopause are risks factors for osteoporosis in women (Tella & Gallagher, 2014). Bone mass increases until adulthood and peak bone mass is achieved at 30-40 years of age, after which starts to decline (Tella & Gallagher, 2014). Small changes are observed in BMD in pre- and early perimenopause, while in the late perimenopause and during the first postmenopausal years a decrease in bone mass is evident (Finkelstein et al., 2008), with the average loss in BMD being about 10% during menopausal transition (Greendale et al., 2012). Due to the ethnic-specific bone loss pattern (even though mainly related to body mass) (Finkelstein et al., 2008), representative samples must be considered in epidemiological studies. Taking United States as example, the prevalence of osteoporosis is 13.1% in 50-64-year-old women and 27.1% in women over 65 years, and the prevalence of osteopenia is >50% (Sarafrazi, Wambogo, & Shepherd, 2021). The prevalence of osteoporosis and osteopenia is higher in women than in men, regardless the age range (Sarafrazi et al., 2021). The prevalence of osteoporosis rises with age, and it is estimated that more than 50% of people over 80 years of age have osteoporosis, which contrasts with only ~30% in 50-60-year-old people (Ji & Yu, 2015).

Osteoporotic fractures are the major health risk of osteoporosis, with their incidence being high after 50 years of age (Ji & Yu, 2015). In fact, the International Osteoporosis Foundation reports that 1 in 3 women over 50 years of age will experience osteoporosis fractures (International Osteoporosis Foundation). Thus, besides postmenopausal women having higher incidence of osteoporosis than men, they also have higher incidence of fractures (Chen, Fu, Lin, & Fan, 2018). The location of osteoporotic-related fractures seems to have a temporal sequence, being more prevalent at the lower end of the radius (50 years), followed by vertebral fractures (60-75 years) and hip fractures at later ages (>75 years) (Tella & Gallagher, 2014), with hip, spine and wrist being the most susceptible areas to fractures in this specific population (Chen et al., 2018). The occurrence of an osteoporotic fracture increases the risk of a subsequent fracture

and several deleterious potential consequences, such as disability, financial issues and, ultimately, mortality are usually associated (Cauley, 2013).

Besides low BMD or other clinical risk factors, low lean mass has revealed to be an independent contributor of body composition to fractures risk among older adults (Hars & Trombetti, 2017). The decline in lean mass is affected by menopausal hormonal changes and continues after the final menstrual period, thus both muscle mass and BMD values are lower in postmenopausal when compared to premenopausal women (Sipilä et al., 2020). Low muscle quantity and quality are indicators of sarcopenia, which is associated with increased susceptibility to falls, fractures, physical disability, several other diseases, and ultimately, to mortality (Cruz-Jentoft et al., 2019). Sarcopenia is a multifactorial pathophysiological condition that can occur in any stage of life, being more common in older adults (Cruz-Jentoft et al., 2019). However, hormonal changes during menopausal transition are an important “accelerator” of its development (Buckinx & Aubertin-Leheudre, 2022).

Due to the association of hormonal changes with menopausal symptoms and health menopausal-related effects, it is not surprising that HT appears as a potential therapeutic strategy to mitigate the symptoms and deleterious health conditions in postmenopausal women.

Hormonal therapy in menopause

Hormonal therapy, including treatment with estrogen, progestogen or combined therapies, has been extensively studied in women with menopause-related symptoms and remains the most effective way to treat vasomotor and urogenital symptoms in this population, and also improve other menopause symptoms-related complains (Baber et al., 2016). Estrogen replacement decreases fasting plasma glucose and HbA1c, thus improving glucose homeostasis and decreasing the risk of diabetes development (Slopien et al., 2018; Xu et al., 2014). Moreover, estrogen replacement therapy decreases total cholesterol and LDL and increases HDL (Xu et al., 2014). Taking together, due to the contribution of diabetes and dyslipidaemia to CVDs and knowing the

positive effects of estrogen in vascular function, HT can be pointed out as a cardioprotective strategy (Baber et al., 2016). Furthermore, HT offers benefits for the prevention of postmenopausal bone loss, decreasing the risk of osteoporotic fractures (Bagger et al., 2004). Indeed, HT is referred as the most appropriated therapy for fracture prevention in early menopause (Baber et al., 2016). Thus, HT seems to be a very inclusive treatment to menopausal-health related conditions.

Nevertheless, HT does not have the same benefits in all stages of menopause and can even entail some risks (Baber et al., 2016; Diamanti-Kandarakis et al., 2017). For women over 60 years or in postmenopausal stage for more than 10 years, HT is not appropriated and, in some cases, should not be considered (Hodis & Mack, 2014). In fact, some clinical trials have reported that HT using estrogen replacement not only fails to induce cardiovascular benefits for women in later stages of menopause, but also further increases the risk for coronary events (Baber et al., 2016; Novella et al., 2012). A possible explanation is that after the detrimental effects of aging are established, the benefits of estrogen can no longer succeed (Novella et al., 2012).

Therefore, alternative treatments for menopausal symptoms and deleterious health conditions are warranted. Additionally, to maintain menopausal women's health, it is recommended to adopt a group of strategies that include, besides HT, a healthy lifestyle behaviour focused on proper diet regimens, exercise programs, while avoiding smoking and alcohol consumption (Baber et al., 2016).

Exercise and menopause

Exercise has been considered as a potential therapy against 26 different chronic pathological conditions, namely psychiatric, neurological, metabolic, cardiovascular, and pulmonary diseases, as well as musculoskeletal disorders and cancer (B. K. Pedersen & Saltin, 2015). These include some of the diseases and conditions that affect postmenopausal women, namely depression, anxiety, CVDs, type 2 diabetes, obesity, metabolic syndrome, hyperlipidemia, and osteoporosis, and emphasizes the importance of exercise during the pre and

postmenopausal periods. Moreover, it highlights the potential of exercise as an alternative to HT for the improvement of postmenopausal women's health or on the other side, as a complementary therapy in order to provide an additional effect.

Nevertheless, there is still inconsistent evidence regarding the relevance of exercise as an effective strategy for mitigating menopausal symptoms (Daley et al., 2014; Stojanovska et al., 2014), even though it has been demonstrated to reduce its severity (Stojanovska et al., 2014). In fact, active women with high PA levels have less severe menopausal symptoms compared to those with low PA levels (Skrzypulec, Dabrowska, & Drosdzol, 2010). Moreover, an inverse association between PA levels and body mass, waist circumference, fat percentage, fasting glucose, total cholesterol, TRG and LDL was reported in postmenopausal women (Harraqui et al., 2023). Accordingly, the frequency of overweight and obesity, abdominal obesity, high fat mass percentage, hypertension, pre-diabetes and diabetes was higher in women with low (<600 MET-min/week) PA level than in those with moderate (≥600 MET-min/week) and intense (≥3000 MET-min/week) PA level (Harraqui et al., 2023). Physical active women present enhanced metabolic profile, balance, muscle strength, cognition and quality of life, and lesser extent of cardiovascular events, fractures and some cancers (Baber et al., 2016). Also, physical performance (step length, walking speed, balance and strength) was related to BMD in postmenopausal women (Lindsey, Brownbill, Bohannon, & Ilich, 2005), with increased cardiorespiratory fitness level being positively associated with a reduced risk for low BMD, osteopenia, and osteoporosis (DeFina et al., 2016). Furthermore, a higher appendicular lean mass (ALM) and ALM index was observed in menopausal women with higher PA levels than less active counterparts (Sipilä et al., 2020).

Considering the referred above, exercise-based interventions have been recommended to improve postmenopausal women's health, namely aerobic, resistance, balance and stretching exercises (Grindler & Santoro, 2015). In fact, evidence suggests that aerobic exercise (walking, cycling, swimming, aerobic dancing, stair walking), resistance exercise (with sandbags, weight machines, wrist weight, ankle weight, elastic bands or calisthenic exercise) and combined

exercise (aerobic, resistance and flexibility) induces health-related benefits, namely in body composition (decreased body mass and body fat), bone health (increased BMD and BMC), muscle strength and endurance, cardiorespiratory fitness, flexibility, postural balance, and coordination (Asikainen et al., 2004). Moreover, improvements in lipid profile were also found, however, in exercise-based studies aiming at dyslipidemic or at overweight women (Asikainen et al., 2004). Balance training is usually included in exercise programs that combine aerobic and resistance training (multicomponent training) (Bull et al., 2020). The improvement of postural balance is of the most importance to prevent the risk of falls, which ultimately could lead to bone fractures. Yoga, Tai Chi/Qigong and Pilates are part of a group of unconventional exercise modalities that are able to fit in the multiple exercise categories (Hoke et al., 2020). These exercise modalities have shown promising results in postmenopausal women's health. Yoga has shown to induce improvements in body and fat mass, as well as in all the variables that contribute to metabolic syndrome (waist circumference, dyslipidemia, blood pressure, fasting glucose and insulin) (Lee et al., 2012). Tai Chi/Qigong and Pilates have shown to positively impact BMD and physical performance (aerobic capacity, flexibility, strength and balance) (Angın et al., 2015; Carcelén-Fraile et al., 2021; García-Garro et al., 2020; Liu et al., 2022; C. Sun et al., 2022).

Team sports for health

Although the variety of exercise options and the positive health effects shown in different populations, particularly in postmenopausal women, are clear and consensual, the levels of PA are still alarmingly low (European Comission, 2022). In fact, data from the 2022 Eurobarometer on Sport and PA showed that 45% of the Europeans report never to exercise or play sport. One of the main barriers to exercise is the lack of motivation (European Comission, 2022), which suggests that the offered PA options are not sufficiently appealing to most of the general population. In this context, the World Health Organization has made a call for innovative approaches to increase PA that are attractive and affordable

(World Health Organization, 2016). Ultimately, the target of the Global Action Plan on PA 2018-2030 is to reduce the global prevalence of physical inactivity in 15% by 2030, with sport and active recreation being pointed out as suitable strategies to increase the PA levels (World Health Organization, 2018). Moreover, the inclusion in the guidelines of playful team activities, such as ball games, that increase motivation through social contact and enjoyment, has also been put in perspective (M. T. Pedersen et al., 2017).

Recreational team sports, such as football, team handball, basketball and touch rugby have emerged as alternative exercise modalities that, due to their social nature and enjoyable feature, are likely able to keep people engaged and motivated in regular exercise (Andersen et al., 2019; Castagna et al., 2018; Castagna et al., 2020a). Also, a variety of social and psychological outcomes are associated with team sport participation, such as emotional support, sense of belonging and social network and interaction (Andersen et al., 2019). Indeed, motivational problems were also pointed out as an important reason for individual exercise practitioners giving up from the activities, while football participants kept involved in the exercise programs (Krustrup & Bangsbo, 2015). Besides the social interaction that characterizes recreational team sports, the low perceived exertion reported by football participants when compared to other activities, is also reported as a possible explanation to participants' adherence to the exercise programs beside the intervention period (Bangsbo et al., 2015; Krustrup & Bangsbo, 2015).

Recreational football has been widely studied. When compared to individual exercise activities, recreational football was shown to be as effective as jogging and interval running in increasing VO_{2max}, as effective as jogging in decreasing fat mass, and as effective as strength training in increasing lean and bone mass in young and middle-aged men (Krustrup et al., 2010). Moreover, it is interesting to note that although aerobic exercise improves particularly cardiorespiratory fitness and fat mass, and strength training improves particularly lean and bone mass, the combination of both is needed when the target is a set of factors. In this regard, recreational football practice by itself improves cardiorespiratory fitness and fat, lean and bone mass, which highlights the broad-

spectrum health benefits of this exercise modality when compared to other activities alone. Indeed, there is evidence on the effects of recreational football in improving the health of different populations, with and without diseases, in relation to cardiovascular, metabolic and musculoskeletal health, physical fitness and body composition (Bangsbo et al., 2015; Milanović et al., 2022; Milanović et al., 2015; Milanović et al., 2019; Sarmento et al., 2020). The results derive from short-, medium- and long-term interventions, involving mainly 2-3 sessions per week of 40-60 min of football practice, and were proposed to be related to the nature of the activity (Bangsbo et al., 2015; Milanović et al., 2022; Milanović et al., 2015; Milanović et al., 2019; Mohr et al., 2023; Sarmento et al., 2020). In fact, recreational football practice combines strength, endurance and aerobic high-intensity interval training, that altogether positively stimulate cardiovascular, musculoskeletal and metabolic adaptations that, ultimately, can improve global health (Krustrup et al., 2010; Krustrup & Krustrup, 2018; Randers et al., 2010). These recreational football-based programs are in line with PA guidelines for adults and older adults targeting, at least, 150 to 300 minutes of moderate-intensity aerobic PA or 75 to 150 minutes of vigorous-intensity aerobic PA or a combination of both. Muscle-strengthening activities at moderate or greater intensity involving all major muscle groups on at least 2 days a week are recommended for additional health benefits. For older adults is also recommended at least 3 days of functional balance and strength training at moderate or greater intensity as part as their weekly PA (Bull et al., 2020).

The effect of recreational football practice in 18-65-year-old women's health profile has been described in detail (see review Krustrup et al., 2018), and individual research projects have also studied 48-68-year-old type 2 diabetic men and women in postmenopausal status (de Sousa et al., 2014) and also in over 55-year-old men and women (Skoradal, Helge, et al., 2018; Skoradal, Weihe, et al., 2018). However, studies that analyze the effect of recreational team sports practice specifically on postmenopausal women's health are scarce. To the best of our knowledge, only the effect of floorball practice was analyzed in postmenopausal women, with positive results being shown on cardiovascular health (VO_{2max}, diastolic blood pressure and biomarkers of vascular function),

body composition (fat mass and lean mass), bone health [BMD and procollagen type-1 amino-terminal propeptide (P1NP)] and aerobic performance after 12 weeks of practice (Nyberg et al., 2014; Seidelin et al., 2017). Moreover, the continuing of the exercise practice for more 40 weeks allowed to preserve most of the benefits achieved at 12 weeks and conduced to an improvement in glucose regulation (namely by decreasing HbA1c and increasing in GLUT4 expression) (Seidelin et al., 2017). Thus, other recreational team sports that can meet the populations' interests and that simultaneously can be effective as health-enhancing activities should be studied.

Team handball is a sport that attracts millions worldwide (International Handball Federation, 2022). Moreover, it's easy to play as the main ability required is a basic motor gesture of catching and throwing a ball. Its recreational version shows similar physiological and physical characteristics to those reported for recreational football, as it is a high-intensity and intermittent exercise with high aerobic and anaerobic solicitations and high-demanding actions (Póvoas et al., 2017). Mean and peak HRs range from 82-85% and 93-95% of maximal HR (HR_{max}), respectively, with 63-82% of the match time being spent >80% $HR_{max.}$ Mean blood lactate values range from 3.6-4.4 mmol/l and mean covered distance ranges from ~3-6 km, with 5-6% of the total match time being spent with high-intensity movements (fast running and sprinting). A variety of high-demanding specific game actions are performed, namely stops, changes of direction, one-on-one situations, turns, shots, and mainly jumps, catches and throws (Hornstrup et al., 2019; Hornstrup et al., 2020; Hornstrup et al., 2018; Póvoas et al., 2017; Stojiljković et al., 2020). This encouraged the development of randomized controlled trials to analyze the effects of this exercise modality on health of different populations (Hornstrup et al., 2019; Hornstrup et al., 2020; Hornstrup et al., 2018). Indeed, sort-term (12-16 weeks) team handball-based exercise programs have shown to positively improve young men and women's health (20-30-year-old) (Hornstrup et al., 2019; Hornstrup et al., 2018), as well as adult/middle-aged men (33-55-year-old) (Póvoas et al., 2018) and premenopausal women's health (35-50-year-old) (Hornstrup et al., 2020). The results showed favorable changes in the following parameters: muscle mass

(+2%), fat mass (-1 to -7%), BMD (femur: +1 to 2%; whole-body: +2%), BMC (whole-body: +53 g), osteogenic function [osteocalcin: +45 to 56%; P1NP: +65%; carboxy-terminal type-1 collagen crosslinks (CTX): +25%], VO_{2max} (+7 to 14%), time in an incremental treadmill test (+12 to 16%), aerobic performance [Yo-Yo intermittent endurance level 1 test (YYIE1) performance: +26 to 35%; Yo-Yo intermittent endurance level 2 test (YYIE2): +80%], balance (-6 falls), resting HR (-10 bpm), HDL (+11%) and fasting glucose (-7%) (Hornstrup et al., 2019; Hornstrup et al., 2020; Hornstrup et al., 2018; Póvoas et al., 2018).

The effect of this sport on the health of other populations was put in perspective for future studies. Due to the results reported in the literature, there is evidence of the potential effect of RTH practice in improving postmenopausal women's health, namely cardiorespiratory fitness, body mass, fat and lean mass, blood glucose and lipids, and ultimately, physical fitness, e.g., aerobic performance, muscular strength and postural balance.

CHAPTER IV

Original Studies

Original Study I

Pereira, R., Krustrup, P., Castagna, C., Resende, C., Carneiro, I., Magalhães, J., & Póvoas, S. (2024). Exercise intensity and reliability during recreational team handball training for 50–77-year-old unexperienced women. *Biology of Sport, 41*(4). https://doi.org/10.5114/biolsport.2024.132995.

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Exercise intensity and reliability during recreational team handball training for 50–77-year-old unexperienced women

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ABSTRACT: This study analyzed the physiological and physical demands of recreational team handball (RTH) and the training sessions' (matches) intensity variability in 50–77-year-old postmenopausal women (n = 20) without prior experience with the sport. Heart rate (HR), blood lactate, rating of perceived exertion (RPE), distance covered, time spent in different locomotor categories, accelerations, decelerations, Player Load (PL), game actions and fun levels were evaluated in 245 matches, played indoor (n = 130) or outdoor (n = 115), as small-sided games (3 × 15-min periods). Mean and peak HRs were 79 and 88% of maximal HR (%HR_{max}), showing reliable values across the training sessions, with time spent in the HR zones showing excellent relative reliability, though poor absolute reliability. Time spent > 80 and > 90%HR_{max} was 48% and 14% of total match time, respectively. Mean and peak blood lactate values were 2.6 ± 0.8 and 2.9 ± 0.9 mmol·l^{-1}, respectively. RPE was 5.5 ± 1.5, showing good relative though poor absolute reliability, and fun levels were 8.4 ± 1.1 (0–10 scale). Total distance covered was 1878 ± 333 m and the participants spent 54%, 3% and < 1% of total match time walking, fast running and sprinting, respectively. Total PL was 224 ± 41 (AU), with 67% of total match time being spent in low-intensity zones. Participants performed a total of 38 specific high-demanding actions per match, mainly throws (10.6 ± 5.8) and stops (11.0 ± 3.6). RTH training, played as small-sided games, is a high-intensity exercise training mode with high aerobic and anaerobic demands, low RPE and high fun levels for 50–77-year-old women without prior experience with the sport. Average cardiovascular demands were consistent across the training sessions.

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INTRODUCTION

Although the unequivocal positive health effects of physical activity (PA) and exercise, physical inactivity levels in Europe are high, particularly in over 55-year-old men and women [1]. Lack of motivation and interest is one of the main barriers to exercise or play sport, while enjoyment and fun have been reported as motives for being physically active [1, 2]. Thus, the World Health Organization (WHO) has made a call for innovative, health-enhancing exercise options, highlighting the role of sport in counteracting physical inactivity, and improving health by setting promotion of sport for all as a central policy recommendation in the WHO Global Action Plan on PA 2018–2030 [3]. In fact, team sports seem to meet the population's interests, based on the estimated high number of participants [4]. Football, team handball (TH), floorball, basketball, touch rugby and futsal have been adapted to its recreational versions (i.e., involving lower number of players, smaller areas, limited body contact, simpler rules) to be used in exercise interventions aiming at health

enhancements [4]. Team sports are an example of multicomponent exercise modalities, casuistically and intermittently combining low to high-intensity locomotion activities and high-demanding specific actions (e.g., jumps, accelerations, decelerations, changes of direction and stops) [4]. Therefore, the physical demands of team sports are aligned with the PA guidelines for adults and older adults that focus on moderate to vigorous-intensity aerobic PA, muscle-strengthening activities and balance training, to improve cardiorespiratory and muscular fitness, bone health, functional balance and preventing falls [5]. Exercise interventions using recreational team sports usually entail 2 weekly sessions of 40–60 min (i.e., 80–120 min/week), with mean heart rates (HRs) ranging from 71–85% of maximal HR (HR_{max}) [4]. Hence, team sports practice under these conditions (volume and intensity) meets part of the PA guidelines [5]. Moreover, ball games and team sports have been reported to be a motivating exercise mode [6], thus counteracting one of the main barriers to exercise [1, 2].

Recreational team handball (RTH) has shown to induce several health benefits, namely by improving cardiovascular, bone and metabolic health and physical fitness of different populations [7–12]. Particularly in postmenopausal women, RTH practice showed to improve peak oxygen uptake (VO_{2peak}), aerobic performance, bone mineral density (BMD) and content (BMC), bone turnover markers, postural balance, body mass, body fat, and total and low-density lipoprotein cholesterol [11, 12]. This is a population of interest considering the deleterious broad-spectrum impact of menopause on women's health [13], and that physical inactivity levels increase with age, and are higher in women than in men [1]. Nonetheless, even though the health benefits of RTH practice in this population have been described, its working demands have not been addressed in detail so far. Information on the external and internal load experienced during small-sided RTH games will result of great practical interest as it may explain the reasons underlying the observed health adaptations and allow for training prescription accuracy. Moreover, due to the casuistic nature of this exercise modality, it is of importance to know how the cardiovascular stress (HR) varies between training sessions that are based on RTH matches.

Therefore, the aim of this study is to examine the physiological (internal load) and physical demands (external load) induced by the most frequently used small-sided RTH games (i.e., 4 v 4 to 6 v 6) in postmenopausal women without prior experience with the sport and to analyze the intensity (HR) variability between training sessions (matches). Based on the results of previous studies [14, 15], we hypothesized that small-sided RTH games are a vigorous exercise activity, comprising high-intensity specific actions able to improve the cardiovascular and musculoskeletal systems of postmenopausal women. We also hypothesized that there is variability in the intensity (HR) among training sessions, although the cardiovascular stress is high on average, providing stimulus in the range to induce positive cardiovascular health adaptations.

MATERIALS AND METHODS

Participants

Recruitment started one month before the beginning of the trial. Twenty 50–77-year-old postmenopausal women (mean age 64 ± 7 years, stature 158 ± 7 cm, body mass 65.5 ± 10.9 kg, fat mass 36.0 ± 6.4%, VO_{2peak} 25.7 ± 3.4 mL · min · kg^{-1}) volunteered to participate in this study. Inclusion criteria were: women with menopause for at least 3 years and inactive (i.e., not complying with the PA guidelines for the last 6 months). Exclusion criteria were: participants that presented any contraindication to perform moderate-to-vigorous PA or incapacity to run or grip a ball.

All participants were informed verbally and in written about the purpose, potential risks, and benefits of the study and that they could withdraw at any time without penalty and signed a written informed consent. The study was carried out in accordance with the Declaration of Helsinki and ethical approval was provided by the local Ethics Committee (CEFADE 20 2019).

Experimental design

Internal and external load markers and fun levels evaluations were performed at the beginning of a RTH-based exercise intervention. Detailed description of the study is provided elsewhere [11, 12]. The participants randomly performed RTH matches (played as 4 v 4, 5 v 5 and 6 v 6), preceded by a standardized warm-up, in indoor (n = 130) and outdoor conditions (n = 115), organized in 3 × 15-min periods interspersed by 2-min breaks, and with at least 48 h of rest between matches. The matches were carried out on a regular TH court (40 × 20 m) adjusted in length and width to result in 34–36 m^2/player. The participants were hydrated at the beginning of the session and were allowed to drink water *ad libitum* to ensure the maintenance of proper hydration.

The participants rotated positions every 3 min in a random order, including the goalkeeper, and no exclusions or substitutions were applied. Dribbling was not allowed, and the ball was immediately put back in play by the goalkeeper after a goal. To avoid injuries, no hard tackles and physical contact were permitted, and the balls were made of soft material and lighter than the official ones.

The physiological and physical demands were analyzed considering internal [HR, blood lactate (BL), rating of perceived exertion (RPE)] and external [distance covered and time spent in different locomotor categories, accelerations, decelerations, Player Load (PL), and specific game actions] load variables and fun levels were also determined. In indoor conditions, only HR, RPE and fun levels were assessed, while in outdoor conditions all the study variables were evaluated. No differences were observed between indoor and outdoor conditions in mean and peak HR, time spent in the HR zones, RPE and fun levels (data not shown) and therefore, the data from the matches performed in these two conditions were analyzed together.

Experimental procedures

The participants were familiarized with all the procedures before the data collection. HR was evaluated using HR monitors (Firstbeat Technologies Ltd., version 4.7.2.1., Jyväskylä, Finland). Mean and peak HR are expressed as absolute ($b \cdot min^{-1}$) and relative values (%HR_{max}) and individual HR_{max} was determined according to a multiple testing approach [16]. HR zones were ≤ 60, 61–70, 71–80, 81–90 and 91–100% of individual HR_{max}. Capillary blood samples (~30 μL) were collected from the right earlobe at rest (baseline) and randomly in each match period, using a portable electroenzymatic lactate device analyzer (Lactate Pro 2 LT-1730, Arkray, Amsterdam, The Netherlands) to access BL concentrations ($mmol \cdot l^{-1}$). RPE (0–10, AU, Borg scale) [17] and fun levels (0–10, AU, visual analogic scale) [18] were evaluated at the end of the training sessions.

Distance covered (m) and time spent (s) in different locomotor categories (standing, walking, jogging, fast running and sprinting), accelerations and decelerations, and PL were measured using global positioning system (GPS) units (Catapult MinimaxX S4; Catapult Sports, Canberra, Australia), following standardized procedures. Catapult Sprint software (Catapult Innovations, Canberra, Australia, version 5.1.1) was used to export the data. The validity and reliability of the accelerometers have been described elsewhere [19]. In this study, individual speed thresholds were considered to normalize external load variables. For every participant, the mean velocity of each locomotor category over a set distance (20 m) was determined using telemetric photoelectric cells (Brower Timing System, IRD-T175, UT, USA). The mean velocity of the participants in each category was 6, 8, 12 and 13 $km \cdot h^{-1}$ for walking, jogging, fast running and sprinting, respectively. The resulting scores were used to set individual thresholds for the considered arbitrary speed categories. PL (estimated by triaxial accelerometry, measured at a 100 Hz sampling rate) was presented as total PL (AU) and percentage of time spent in PL zones (< 0.1, 0.1–0.3, 0.3–0.6, 0.6–1.0, 1.0–1.5, 1.5–2.0, > 2.0). The number of accelerations and decelerations was determined and categorized as low (1.50–2.14 $m \cdot s^{-1}$), medium (2.14–2.78 $m \cdot s^{-1}$) and high-intensity (> 2.78 $m \cdot s^{-1}$), according to manufacture settings (Catapult Sprint Version 5.1.1 software manual, Catapult Innovations, Canberra, Australia). Individual workload ($Kg \cdot m$) was calculated multiplying the total distance covered by the body mass. Qualitative analyses were performed using video recordings (SONY-DCR-SX65E, digital video camera recorder, UK) to account for game actions, namely jumps, throws, stops, changes of direction, and one-on-one situations. The external load data [i.e., total distance covered (ICC 0.59; 0.30–0.80), total PL (ICC 0.69; 0.44–0.86), time spent in fast running (ICC 0.84; 0.67–0.93) and jogging (ICC 0.75; 0.53–0.89)] demonstrated good to excellent relative reliability. The matches were held under neutral temperature (17–22°C) and humidity (50–70%) conditions.

Statistics

Data are presented as mean ± standard deviations (SD). Differences in internal and external load variables between the three periods were assessed by one-way repeated measures analysis of variance (ANOVA) with Bonferroni post hoc test. Differences in HR variables, RPE and fun in indoor and outdoor conditions were assessed by Student's paired *t*-test. Practical significance was assessed by calculating Cohen *d* and interpreted as trivial (< 0.2), small (0.2–0.5), medium (0.5–0.8) and large (> 0.8) [20]. Mean and peak HR and HR zones' absolute reliability was assessed using the typical error of measurement (TEM) and expressed as raw and as percentage of the coefficient of variation (%CV) in 3 randomly selected matches. Random errors were interpreted as good, moderate and modest to poor, if %CV and

TABLE 1. Heart rate and time spent in selected heart rate zones during each match period and total match duration of recreational team handball matches (mean ± SD)

Variables	1st period	2nd period	3rd period	Total match
Mean heart rate ($b \cdot min^{-1}$)	134 ± 15	137 ± 15*	136 ± 15	136 ± 15
Mean heart rate (%HR_{max})	77.8 ± 5.4	79.6 ± 5.5*	79.0 ± 5.8	78.8 ± 5.4
Peak heart rate ($b \cdot min^{-1}$)	151 ± 14	153 ± 15*	151 ± 15#	152 ± 14
Peak heart rate (%HR_{max})	87.5 ± 4.2	88.7 ± 4.7*	87.4 ± 5.0#	87.9 ± 4.5
Time ≤ 60%HR_{max} (%)	5.6 ± 6.3	2.8 ± 4.7*	2.9 ± 4.5*	3.8 ± 5.0
Time 61–70%HR_{max} (%)	18.7 ± 15.1	15.8 ± 12.6	17.1 ± 15.7	17.1 ± 13.5
Time 71–80%HR_{max} (%)	30.0 ± 13.1	32.2 ± 13.7	32.4 ± 13.9	31.5 ± 12.6
Time 81–90%HR_{max} (%)	33.0 ± 17.3	34.0 ± 16.6	34.0 ± 18.0	33.7 ± 16.2
Time 91–100%HR_{max} (%)	13.1 ± 16.7	15.8 ± 18.5	14.2 ± 16.5	14.4 ± 16.9
Time > 80%HR_{max} (%)	46.1 ± 26.6	49.8 ± 25.3	48.2 ± 28.7	48.1 ± 25.7

*Significantly different from the first period. #Significantly different from the second period.

TEM as %CV were ≤ 10%, > 10-20% and >20%, respectively [21]. The intraclass correlation coefficient ($ICC_{3,1}$) was used to calculate relative reliability [22, 23], with values 0.75–1.00 being considered as excellent, 0.41–0.74 as good, and 0.00–0.40 as poor [24]. Statistical Package for the Social Sciences (SPSS Inc., version 25) was used for data analysis. Statistical significance was set at $p \leq 0.05$.

RESULTS

Internal load variables and fun levels

Mean and peak HR and time spent in the HR zones during the RTH matches held in indoor and outdoor conditions are presented in Table 1. Mean HR increased from the first to the second period ($p = 0.002$; $d = 0.916$). Peak HR in the second period was higher than in the first ($p = 0.025$; $d = 0.662$) and third periods ($p = 0.005$; $d = 0.799$). Time spent ≤ 60%HR_{max} decreased from the first to the second ($p = 0.002$; $d = 1.062$) and third periods ($p = 0.034$; $d = 0.682$). No differences were found between the match periods in time spent in any other HR zones.

Baseline values and mean and peak BL values for the total match time during the RTH matches performed outdoors were 2.2 ± 0.7, 2.6 ± 0.8 and 2.9 ± 0.9 mmol·l^{-1}, respectively, with peak values being higher compared to baseline ($p = 0.047$; $d = 0.844$) and mean values ($p = 0.001$; $d = 1.717$). Mean BL was 2.6 ± 0.9, 2.4 ± 0.8 and 2.4 ± 0.6 mmol·l^{-1} for the first, second and third periods, respectively, with no differences between them and with baseline (Figure 1). Fun levels were reported as 8.4 ± 1.1 and RPE was 5.5 ± 1.5 (0–10, AU), during the RTH matches held in indoor and outdoor conditions.

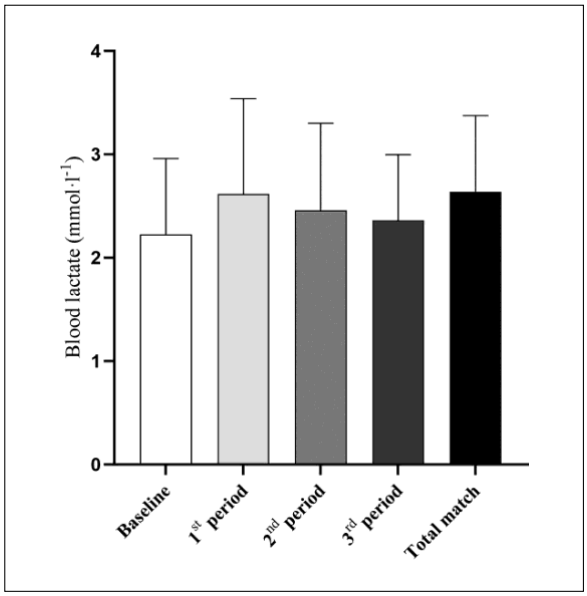


FIG. 1. Mean blood lactate at baseline and during the first, second and third periods and total match duration during recreational team handball matches.

External load variables

Distance covered, accelerations and decelerations, PL and game actions data were evaluated in outdoor matches.

Time spent and distance covered in each locomotor category, total distance covered, and individual workload are presented in Table 2. There were no differences between the match periods regarding these variables.

The number of low, medium, high and total accelerations and decelerations is presented in Table 3. Total decelerations increased from the first to the second period ($p = 0.039$; $d = 0.643$).

Time spent in PL zones and total PL are present in Table 4. No differences were found in total PL between the match periods. Time spent in PL zone 0.1–0.3 ($p = 0.015$; $d = 0.729$) increased from the first to the third period, while time spend between 0.3–0.6 ($p = 0.036$; $d = 0.630$) and 1.0–1.5 ($p = 0.010$; $d = 0.879$) decreased from the first to the third period (Table 4). Time spent between 0.6–1.0 decreased over time (from the first to the second period: -1%; $p = 0.036$; $d = 0.629$; from the first to the third period: -2%; $p < 0.001$; $d = 1.197$).

The frequency of different game actions is described in Table 5. One-on-one situations decreased from first to the third period ($p = 0.050$; $d = 0.714$). No differences were found between the match periods in any other game actions.

Internal load reliability

HR variables' absolute and relative reliability are presented in Table 6. Mean and peak HR presented good to moderate absolute reliability (TEM%CV ≤ 10%; CV% < 20%) and excellent relative reliability (ICC > 0.75). Time spent in the HR zones presented excellent relative reliability, except for time ≤ 60%HR_{max} and time 71–80%HR_{max}, which was poor and good, respectively, and poor absolute reliability. RPE showed good relative reliability and poor absolute reliability.

DISCUSSION

This is the first study analyzing the physiological and physical demands of small-sided RTH games, and the intensity variability of the training sessions (matches) in inactive 50–77-year-old women without prior experience with this sport. The main findings were that RTH is a high-intensity exercise modality, showing consistent results across the training sessions, with time spent in the HR zones presenting excellent relative reliability, though poor absolute reliability between the training sessions.

Mean HR values were > 77%HR_{max}, which corresponds to vigorous PA [25] and almost half of the match time was spent in this intensity category. Mean HR increased from the first to the second period with high values being held across the 3 × 15-min periods.

TABLE 2. Time spent and distance covered in different locomotor categories, total distance covered and individual workload during each match period and total match duration of recreational team handball matches (mean ± SD)

Variables	1st period	2nd period	3rd period	Total match
Standing				
Time (s)	348 ± 81	351 ± 79	379 ± 97	1078 ± 226
Time (%)	38 ± 9	38 ± 9	40 ± 10	38 ± 8
Walking				
Distance (m)	458 ± 79	464 ± 63	458 ± 77	1380 ± 197
Distance (%)	76 ± 9	76 ± 9	77 ± 9	76 ± 9
Time (s)	504 ± 74	509 ± 65	502 ± 79	1516 ± 196
Time (%)	55 ± 8	55 ± 7	53 ± 8	54 ± 7
Individual workload (Kg·m)	29468 ± 5511	29939 ± 5283	29663 ± 6570	89071 ± 16163
Jogging				
Distance (m)	93 ± 48	92 ± 53	89 ± 53	274 ± 148
Distance (%)	14 ± 7	14 ± 7	13 ± 7	14 ± 7
Time (s)	46 ± 24	46 ± 25	44 ± 26	135 ± 72
Time (%)	5 ± 3	5 ± 3	5 ± 3	5 ± 3
Individual workload (Kg·m)	5981 ± 3243	5931 ± 3501	5797 ± 3493	17709 ± 9900
Fast running				
Distance (m)	66 ± 65	67 ± 62	71 ± 63	205 ± 178
Distance (%)	9 ± 9	10 ± 9	9 ± 8	10 ± 8
Time (s)	26 ± 27	26 ± 26	27 ± 25	80 ± 74
Time (%)	3 ± 3	3 ± 3	3 ± 2	3 ± 3
Individual workload (Kg·m)	4329 ± 4306	4395 ± 4029	4715 ± 4368	13439 ± 12019
Sprinting				
Distance (m)	6 ± 12	7 ± 13	7 ± 15	19 ± 36
Distance (%)	1 ± 1	1 ± 1	1 ± 1	1 ± 1
Time (s)	2 ± 4	2 ± 4	2 ± 4	5 ± 10
Time (%)	0.1 ± 0.3	0.1 ± 0.4	0.2 ± 0.5	0.1 ± 0.3
Individual workload (Kg·m)	342 ± 714	429 ± 899	480 ± 1102	1252 ± 2425
Total distance covered (m)	622 ± 131	631 ± 111	626 ± 137	1878 ± 333
Total individual workload (Kg·m)	40119 ± 8940	40695 ± 8465	40656 ± 10673	121471 ± 25652

TABLE 3. Number of accelerations and decelerations during each match period and total match duration of recreational team handball matches (mean ± SD)

Variables	1st period	2nd period	3rd period	Total match
Low accelerations	6.1 ± 4.0	5.7 ± 3.5	5.8 ± 3.4	17.6 ± 10.4
Medium accelerations	3.8+ 2.2	3.8 ± 2.6	3.2 ± 2.1	10.8 ± 6.4
High accelerations	3.1+ 1.6	3.1 ± 2.2	3.1 ± 1.9	9.2 ± 5.1
Total accelerations	13.0 ± 6.9	12.6 ± 7.6	12.0 ± 6.7	37.6 ± 20.7
Low decelerations	3.5 ± 2.9	4.1 ± 2.9	3.7 ± 3.0	11.4 ± 8.5
Medium decelerations	1.4 ± 1.1	1.8 ± 1.1	1.5 ± 1.2	4.8 ± 3.1
High decelerations	0.9 ± 0.8	0.8 ± 0.6	0.7 ± 0.7	2.4 ± 1.7
Total decelerations	5.8 ± 4.4	6.7 ± 4.2*	6.0 ± 4.7	18.6 ± 13.0

*Significantly different from the first period.

TABLE 4. Time spent (%) in different Player Load zones and total Player Load during each match period and total match duration of recreational team handball matches (mean ± SD)

Variables	1st period	2nd period	3rd period	Total match
Player Load Zones				
Time <0.1 (%)	25.28 ± 6.92	25.98 ± 7.40	27.67 ± 8.25	26.31 ± 6.45
Time 0.1-0.3 (%)	39.75 ± 6.93	41.37 ± 6.69	41.84 ± 6.36*	41.01 ± 6.39
Time 0.3-0.6 (%)	17.65 ± 4.65	17.19 ± 4.45	16.29 ± 5.10*	16.92 ± 4.59
Time 0.6-1.0 (%)	10.25 ± 3.37	9.24 ± 3.16*	8.33 ± 3.29*	9.26 ± 3.18
Time 1.0-1.5 (%)	5.80 ± 3.30	5.26 ± 2.79	4.76 ± 2.54*	5.31 ± 2.78
Time 1.5-2.0 (%)	1.04 ± 1.57	0.94 ± 1.38	0.93 ± 1.41	0.98 ± 1.42
Time >2.0 (%)	0.03 ± 0.15	0.07 ± 0.21	0.06 ± 0.15	0.06 ± 0.18
Total Player Load (AU)	77 ± 16	73 ± 14	72 ± 15	224 ± 41

*Significantly different from the first period.

TABLE 5. Game actions during each match period and total match duration of the recreational team handball matches (mean ± SD)

Actions	1st period	2nd period	3rd period	Total match
Jumps	2.2 ± 2.2	1.9 ± 1.6	1.7 ± 1.3	5.9 ± 4.8
Throws	3.7 ± 2.7	3.5 ± 1.8	3.4 ± 1.9	10.6 ± 5.8
Stops	3.7 ± 1.3	3.7 ± 1.2	3.5 ± 1.6	11.0 ± 3.6
Changes of direction	2.5 ± 1.5	2.3 ± 1.2	2.1 ± 1.5	6.9 ± 3.9
One-on-one situations	1.4 ± 1.0	1.5 ± 1.4	0.9 ± 0.9*	3.8 ± 2.9

*Significantly different from the first period.

TABLE 6. Reliability of heart rate variables (mean, peak and time spent in selected heart rate zones) and rating of perceived exertion across the three analyzed training sessions

Variables	ICC	95%CI	TEM	95%CI	TEM%CV	95%CI	CV%
Mean heart rate ($b \cdot min^{-1}$)	0.93	0.84–0.98	4.82	3.71–7.00	3.6	2.8–5.3	12.25
Mean heart rate (%HR_{max})	0.82	0.60–0.94	0.45	0.35–0.66	3.6	2.8–5.3	7.74
Peak heart rate ($b \cdot min^{-1}$)	0.95	0.87–0.98	4.34	3.34–6.31	2.9	2.2–4.2	11.06
Peak heart rate (%HR_{max})	0.84	0.62–0.94	2.54	1.96–3.70	2.9	2.2–4.2	6.39
Time ≤ 60%HR_{max} (%)	0.37	-0.02–0.71	2.11	1.62–3.06	67.9	49.6–116.8	153.4
Time 61–70%HR_{max} (%)	0.78	0.52–0.92	8.74	6.73–12.70	132.6	92.7–253.6	76.70
Time 71–80%HR_{max} (%)	0.74	0.46–0.90	0.54	0.41–0.78	101.4	71.5–177.8	77.31
Time 81–90%HR_{max} (%)	0.78	0.61–0.90	0.50	0.42–0.64	70.4	54.1–111.0	56.47
Time 91–100%HR_{max} (%)	0.82	0.59–0.93	11.11	8.56–16.16	135.9	93.2–254.1	113.99
Time > 80%HR_{max} (%)	0.77	0.51–0.92	0.51	0.39–0.74	69.9	50.9-120.9	57.93
RPE (AU; 0–10)	0.72	0.48–0.87	1.02	0.82–1.39	23.7	18.6–33.7	38.66

CI - Confidence interval; CV - coefficient of variance; ICC – Intraclass Correlation Coefficient; RPE – Rating of perceived exertion; TEM – Typical Error of the Measure.

Additionally, time ≤ 60%HR_{max} (light-intensity) decreased after the first period. Thus, RTH is a vigorous-intensity exercise mode for postmenopausal women, able to be sustained over 45 min, and thereby can contribute for meeting the PA guidelines (volume and intensity). Nonetheless, the cardiovascular demands of RTH were lower for postmenopausal women than for younger populations [8–10, 14, 26], and were slightly higher than for 67-year-old men [15]. Moreover, there is consistency in mean and peak cardiovascular intensity across the training sessions, with high relative reliability, in spite of the absolute variability in the time spent in the HR zones. The collected data provide evidence for a satisfactory intra-individual consistency of the cardiovascular responses to RTH matches, despite the spontaneous nature of the considered exercise mode. However, it was evident that there is variability in the magnitude of the cardiovascular demands between training sessions, which suggests that if specific outcomes are targeted, such as a reaching a certain amount of time spent at a given cardiovascular intensity, a keen assessment and monitoring of the exercise intensity should be performed. Despite these findings, the resulting variability located the cardiorespiratory demands in the range considered helpful in producing sound health benefits in the participants [25], thus corroborating our hypothesis.

In this study, 14% of total match time was > 90%HR_{max}. Time > 90%HR_{max} has been largely correlated with changes in cardiorespiratory fitness [7]. Accordingly, increases of 14%, 11% and 7% in cardiorespiratory fitness were reported for middle-aged men [7], young men [8] and postmenopausal women [12], involved in RTH-based exercise interventions, spending 21%, 14% and 11% of total match time > 90%HR_{max}, respectively. Cardiorespiratory fitness is associated with reduced incidence of cardiovascular diseases and all-cause mortality [27], and consequently, any increase or even maintenance in $\dot{V}O_{2max}$ is relevant. Thus, exercise modalities such as RTH that have the potential to improve $\dot{V}O_{2max}$ are of the outmost importance. Nonetheless, even though postmenopausal women were shown to attain higher HRs and spend more time in higher intensity HR zones than older men, lower BL accumulation was found in comparison to their male counterparts (mean BL: 3.6–3.9 $mmol \cdot l^{-1}$; peak BL: 4.7–5.6 $mmol \cdot l^{-1}$) [15]. This is probably the result of a higher aerobic energy production and thus a lower anaerobic energy production of the considered female population during the RTH matches. However, comparison between BL concentrations across sexes should only be performed when normalizing for individual maximal values [28].

On the other side, this high-intensity physiological response contrasts with the amount of time spent in low-intensity locomotor categories. In fact, half of the total distance covered was performed walking and almost the total match time (92%) was spent standing or walking. Also in recreational football, high HRs were observed even when 70% of the match time was spent standing or walking, which suggests that other actions, besides the locomotor profile, could play a role in the match intensity [29]. Additionally, these findings highlight the relevance of HR or, in alternative, RPE being monitored in real time, to better assess and regulate exercise intensity. An increase was shown in decelerations from first to the second period and in time spent in low-intensity PL zone (0.1–0.3) from first to the third period, as well as a decrease in one-on-one situations. This decrement in external load demands was not in accordance with the high internal load demands during the matches, suggesting that external load variables pattern may not reflect changes in internal load, or vice versa, and highlights the importance of combining both measurements.

Despite all, a total of 38 accelerations (mainly low) and 19 decelerations were recorded. The number of accelerations, decelerations and total distance covered were correlated with changes in leg BMC of men with prostate cancer that participated in a recreational football exercise-based program for 12 weeks [30], being potential promoters of an osteogenic effect. Although, there are similarities between the physical demands of football and TH [31], the potential of these actions to induce skeletal muscle adaptations remains to be studied in TH. This would be of interest in future studies, as in fact, it has been previously showed that TH training results in positive bone adaptations [8, 10], namely in postmenopausal women [11]. Additionally, the frequency of different actions was also suggested as a contributor to the musculoskeletal adaptations shown in RTH players [14]. The number of actions performed by our participants was lower than that observed in other populations [8, 10, 15], which could be related, at least in part, to the inexperienced sport status of the population, and could have resulted in more ball losses and time-outs. Notwithstanding, RTH practice seems to offer a sufficient stimulus for postmenopausal women that increased lumbar spine BMD and BMC and femur BMC, and the expression of bone turnover markers after 16 weeks of practice [11].

The total distance covered by postmenopausal women was lower than that shown for younger populations playing RTH, namely young [26] and adult/middle-aged [14] men, that covered ~3 and ~6 km, respectively. However, the goalkeepers were not considered in the analysis of these studies, which can possibly explain the differences shown, as in our study the participants rotated positions, namely as outfield players and goalkeepers. Nonetheless, even when compared with 67-year-old men that covered ~5 km when playing RTH in 5v5 to 7v7 formats alternating between outfield and goalkeeper positions, postmenopausal women covered less than half the total distance [15]. The lower total distance covered per player in our study may have been the result of the lower area per player used in our study compared with the previous RTH mentioned studies (34–36 m^2 per player vs. 57, 57–80 and 66–100 m^2 per player [14],[15],[26]). In fact, an increase in the area per player resulted in an increase in the distance covered in recreational football players [32]. These particularities are of the most importance when the aim is to increase the external load imposed by exercise.

RPE was reported as 5.5 (hard; 0–10 AU), which is partly in accordance with other recreational team sport studies (range:

3.9–5.4) [26]. A higher RPE was expected, due to the vigorous intensity of the activity. Former TH players playing this sport recreational version reported a RPE of 7.6 (very hard) during RTH matches [14], which could reflect their ability to accurately evaluate the exercise intensity based on their training and competing experience. Nonetheless, a high level of fun (8.4, 0–10 AU) was reported by the participants. This finding is of the most importance, since lack of motivation is one of the main barriers to exercise, and thus RTH practice can potentially contribute for reducing the levels of physical inactivity shown in this population.

This study addresses the gap in the literature regarding the characterization of RTH in postmenopausal women without prior experience with the sport. It showed that exercise intensity is high and can be sustained during the total match duration (45 min), contributing to attain the PA guidelines. Moreover, due to its multicomponent nature, a feature recommended by PA guidelines, RTH-based programs can offer an alternative option to conventional exercise programs available for older populations. A strength of this study is the detailed characterization of the physical and physiological demands of RTH in this population, with the results supporting our study hypothesis, and also proving insights on the reasons that may explain the physical fitness, cardiovascular and musculoskeletal adaptations. Moreover, RTH showed to be a versatile exercise modality that can be played in different settings (indoor/outdoor), being thus adaptable to different contexts. Nonetheless, although there were no differences in internal load variables between indoor and outdoor conditions, it would be relevant to compare external load variables in these conditions, in order to better ascertain the physical characteristics of RTH practice in different settings. So, the lack of information about the external load demands in indoor conditions is a limitation of this study. Future studies should analyze the differences in the working demands of different game formats in this population, as well as for older populations with experience with the sport.

CONCLUSIONS

Recreational TH training, played as small-sided games, is a high-intensity exercise training mode, showing cardiovascular intensity consistency across training sessions with high aerobic and anaerobic demands, low RPE and high levels of fun for 50–77-year-old women without prior experience with the sport. These results are in line with previous studies using RTH with other populations and support the positive cardiorespiratory fitness, metabolic and musculoskeletal health effects of RTH practice shown in this population. Given the variability reported across matches, preliminary and or sustained activity demands control, i.e., HR monitoring and field testing, is suggested to optimize training responses.

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Conflict of interests

The authors declare that they have no competing interests.

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Original Study II

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Original Article

Effects of a 16-week recreational team handball intervention on aerobic performance and cardiometabolic fitness markers in postmenopausal women: A randomized controlled trial

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ABSTRACT

Background: Postmenopausal women have an elevated risk of developing cardiovascular diseases, which can be counteracted by conventional exercise regimes or recreational football. Less is known about the impact of exercise programmes based on other team sports. Thus, we examined the effects of recreational team handball on aerobic performance, cardiorespiratory fitness and cardiometabolic health in untrained postmenopausal women.
Methods: Sixty-seven participants (age 68 ± 6 years, stature 157 ± 6 cm, body mass 67 ± 10 kg, fat mass 37 ± 7%, VO_{2peak} 25.2 ± 3.6 mL/min/kg, Yo-Yo intermittent endurance level 1 test performance (YYIE1) 230 ± 103 m) with no previous experience of team handball were randomly allocated to either a team handball (THG, n = 41) or a control (CG, n = 26) group. THG performed 2–3 60-min training sessions per week for 16 weeks. YYIE1 performance and cardiometabolic markers were evaluated at baseline and post-intervention.
Results: Average attendance during recreational team handball training was 1.9 ± 0.4 sessions per week, with mean heart rates of 76 ± 6%HR_{max} and 18 ± 9 min (44 ± 20% of total time) played at HR > 80%HR_{max}. A between-group effect was observed for YYIE1 performance, with a more pronounced improvement in aerobic exercise performance in THG compared to CG (70 ± 62 vs 15 ± 44%; $p < 0.001$). Within-group improvements ($p < 0.05$) were observed for THG with regard to VO_{2peak} (7 ± 10%), incremental treadmill test time to exhaustion (TTE) (11 ± 14%), total cholesterol (−3 ± 9%) and low-density lipoprotein cholesterol (−2 ± 14%), with no significant changes in CG except an increase ($p < 0.05$) in TTE. Post-intervention values were higher for THG vs CG for YYIE1 performance (88%; 406 ± 216 vs 216 ± 75 m) and VO_{2peak} (10%; 27.5 ± 3.8 vs 24.9 ± 3.6 mL/min/kg).
Conclusions: Recreational team handball can be used to obtain moderate-to-vigorous aerobic intensities, and just 2 weekly 60-min team handball training sessions for 16 weeks can result in improvements in aerobic performance and in markers of cardiorespiratory fitness in postmenopausal women with no previous experience of the sport.

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Abbreviations: ANCOVA, analysis of covariance; ANOVA, analysis of variance; CG, control group; CI, confidence interval; CRF, cardiorespiratory fitness; CV, cardiovascular; CVD, cardiovascular disease; HDL, high-density lipoprotein cholesterol; HR, heart rate; HR_{max}, maximal heart rate; LDL, low-density lipoprotein cholesterol; OGTT, oral glucose tolerance test; PA, physical activity; RER, respiratory exchange ratio; RPE, rating of perceived exertion; SD, standard deviation; SPSS, Statistical Package for the Social Sciences; TC, total cholesterol; TGs, triglycerides; THG, team handball group; TTE, time to exhaustion; VO_{2max}, maximal oxygen uptake; VO_{2peak}, peak oxygen uptake; YYIE1, Yo-Yo intermittent endurance test level 1.

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Introduction

The population's average life expectancy is rising. Between 2000 and 2015, it increased worldwide by 5 years (from 66.5 to 71.4 years).[1,2] However, in the same period, healthy life expectancy (i.e. number of years lived in full health) decreased in a similar range (from 63.1 to 58.5 years), being 11.7% lower than life expectancy.[1,2] Cardiovascular (CV) diseases (CVD) are the major cause of health loss, with a reported 422 million cases, 206 million of which were in the female population.[3] Postmenopausal women are at increased risk of developing CVD,[4] which is the major cause of morbidity and mortality in this population,[5] experiencing adverse lipid profile, and elevated serum glucose and insulin.[6–8]

Conventional exercise programmes (aerobic, resistance and combined exercise) have been shown to be effective at counteracting these health risks by enhancing cardiorespiratory fitness (CRF) and metabolic fitness in postmenopausal women.[9] Nonetheless, 72% of women over 55 years report never or seldomly exercising or playing sport, with lack of motivation being one of the major underlying reasons.[10] Consequently, in order to overcome the high physical inactivity rates, the World Health Organization[11] has made a call for innovative exercise modes that can be effective at improving the health of populations while keeping the motivational level high, thus ensuring long-term adherence to exercise. Within team sports, recreational football has shown positive physiological health effects in CV, metabolic and musculoskeletal health, both in healthy and clinical groups.[12–15] Recently, results from descriptive and training studies have shown that recreational team handball is also an accessible, high-adherence and high-attendance exercise mode. Team handball is an Olympic team sport played between two teams of seven players (six outfield players and one goalkeeper). Players can only manipulate the ball with their hands, except for goalkeepers, who can use any part of their body to defend throws within their own goal area, which cannot be entered by outfield players. The sport offers an alternative to conventional exercise modes, imposing a high aerobic component [mean heart rates (HRs) ~80% of maximal HR (HR_{max})] associated with multiple actions performed at high intensity that stress the anaerobic metabolism and have a high impact on the musculoskeletal system.[16–20] In fact, in these studies, CV, metabolic, body composition and well-being improvements were observed in adults of both sexes, regardless of the participants' previous experience of the sport.[17–20] Nevertheless, only floorball, a team sport similar to field hockey played on an indoor court with plastic sticks, has been studied in postmenopausal women, showing positive effects on aerobic performance, CRF and lipid profile.[21,22] Hence, studies on the health and physical fitness effects of other team sports, such as team handball, are warranted in this population, especially taking into account its popularity with former practitioners and also fans who are attracted to this sport worldwide.[23]

The purpose of this study was therefore to analyse the effects of a recreational team handball-based exercise programme on aerobic performance and markers of CRF and metabolic fitness in untrained postmenopausal women with no previous experience of the sport. We expected improvements in the aerobic performance, CRF and metabolic health profile of the participants after the exercise intervention.

Methods

Participants and study design

Untrained postmenopausal women aged 49–79 years and in menopause for at least 3 years were invited to participate in this study. Eighty participants met the criteria to participate and did not present any contraindications for performing moderate-to-vigorous physical activity (PA) (Fig. 1). Three participants dropped out before the baseline evaluations for personal reasons. After the baseline evaluations, six participants dropped out, also for personal reasons. Thus, 71 participants with no previous experience of the sport were stratified by peak oxygen uptake (VO_{2peak}) and randomly allocated (3:2 ratio) to either a team handball group (THG, n = 42) or a control group (CG, n = 29). THG underwent a 16-week recreational team handball-based training intervention. CG participants were instructed to maintain their regular daily PA. During the intervention, two CG participants dropped out for personal reasons and one participant was excluded because she started a new exercise programme. For personal reasons, one participant in THG was unable to start the exercise programme at the set date and complete the 16 weeks, and was thus excluded from the analysis. Sixty-seven participants (age 68.3 ± 6.2 years, stature 156.9 ± 5.8 cm, body mass 66.6 ± 9.7 kg, fat mass 37.2 ± 6.7%, VO_{2peak} 25.2 ± 3.6 mL/min/kg, Yo-Yo intermittent endurance level 1 test performance (YYIE1) 230 ± 103 m) were re-evaluated after 16 weeks. No significant differences were observed between the groups at baseline in respect of the evaluated variables (Table 1), except for sedentary behaviour. Thus, sedentary behaviour was used as a covariate in the statistical analysis.

Before providing written informed consent, all participants were informed verbally and in writing about the purpose, potential risks and benefits of the study and made aware that they could withdraw at any time without penalty. The study was conducted in accordance with the Declaration of Helsinki, and ethical approval was provided by the Ethics Committee of the Faculty of Sport, University of Porto, Porto, Portugal.

Sample size estimation for the main outcome [maximal oxygen uptake (VO_{2max})] was calculated for a sample power of 95%, with an effect size of 0.25, at a significance level of 5%. The final number of participants represented a dropout rate of 20%.

Measures and test procedures

All participants were evaluated at baseline and after 16 weeks (post-intervention). Evaluations were performed on two separate days. On the first evaluation day, each participant performed the CV health evaluations. Resting HR measurements were followed by the incremental treadmill test to exhaustion for CRF assessment. On the second evaluation day, body mass, stature, body fat, metabolic markers and aerobic performance were evaluated. No exhausting physical activity was allowed in the two days before testing. Blood sampling was performed after an overnight fast (at least 8 h), while the participants were instructed to have a light meal before the other evaluations.

Body mass, stature and body fat were measured with the participants in light clothes and without shoes. The participants stayed still and quiet in an upright position, facing forwards, with their arms hanging freely.[24] Body mass (0.01 kg) and fat mass (%) were measured by a bioelectrical impedance scale (Tanita Inner Scan 532 BCE, Tokyo, Japan), and stature (0.1 cm) by a portable stadiometer (Seca 213, Hamburg, Germany).

Resting HR was measured in a quiet room at a constant temperature, with the participant in a supine position and after 15 min of rest.[25] CRF was assessed using a treadmill (H/PHCosmos, Quasar, Germany) according to a standardised incremental protocol.[26] Oxygen uptake and respiratory exchange ratio (RER) were determined by pulmonary gas exchange measurements (Oxycon Pro Metabolic Cart, Jaeger, careFusion, Germany). VO_{2peak} was considered as the highest 15-s mean value. During the test, the participants' HR was continuously monitored (Polar Wearlink, Kempele, Finland). Age-predicted HR_{max} was determined by the formula 208 – (age × 0.7).[27] The test finished at participants' voluntary exhaustion and the results were considered as VO_{2peak} if two of the following criteria were met: RER ≥ 1.1; HR_{max} ≥ 85% of age-predicted HR_{max}; failure of oxygen consumption to increase with increased exercise intensity.[28] Time to exhaustion (TTE) was recorded.

Fasting blood was drawn by a trained technician in a quiet room. An 8-mL blood sample was collected into serum separator tubes to measure total cholesterol (TC), high-density lipoprotein cholesterol (HDL),

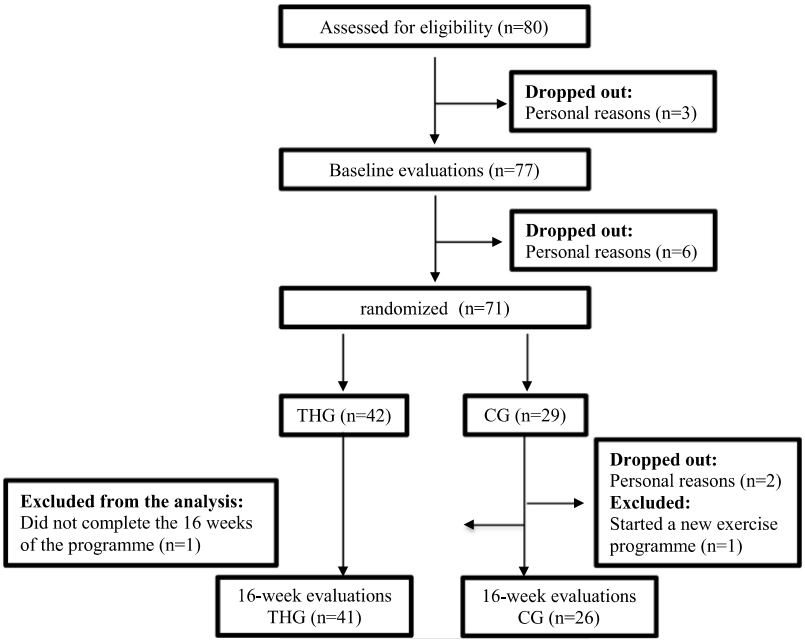


Fig. 1. Flow chart showing the number of participants enrolled, randomized and assessed.

low-density lipoprotein cholesterol (LDL), triglycerides (TGs), glucose and insulin. TC, HDL, LDL, TGs and glucose were analysed with an AU5400® (Beckman-Coulter, Hamburg, Germany). Insulin was determined using a Cobas® e411 automated analyser (Roche Diagnostics GmbH, Mannheim). After the fasting sample was drawn, an oral glucose tolerance test (OGTT) was performed. The participants were instructed to drink a glucose solution (0.2 L of solution containing 75 g of glucose) and after 2 h a new blood sample was collected in order to analyse glucose and insulin using the described standard methods.

After the second blood sample was drawn, participants had their regular breakfast, which they were instructed to bring in advance. Nearly 1 h later, the participants proceeded to an indoor court inside the evaluation facilities, where aerobic performance was assessed by the Yo-Yo intermittent endurance test level 1 (YYIE1).[29] Before the YYIE1 test, the participants were instructed to complete a standardised warm-up consisting of 10 min of running at different velocities including changes of direction.

The participants were familiarised with all testing procedures before the start of testing.

Exercise programme

THG underwent a 16-week recreational team handball-based exercise programme consisting of 2–3 60-min training sessions per week held at least 48 h apart. Each training session involved a standardised warm-up (comprising running, coordination, strength, flexibility and balance exercises) and three 15-min periods of recreational team handball played as small-sided games (mainly 5v5 and 6v6) and performed on an indoor court (40 × 20 m) adjusted to result in 34–36 m^2 per player. There was no permanent goalkeeper, and the participants rotated positions every 3 min in a random order, ensuring that participants spent a similar amount of time at the goal. No hard tackles were allowed, and the balls used during the training sessions were light and made of a soft material to avoid injuries. HR (Firstbeat Technologies Ltd., version 4.7.2.1, Jyväskylä, Finland) and rate of perceived exertion (RPE), 0–10 scale,[30] were monitored during all training sessions. RPE was assessed immediately after the training session.[31] A multiple testing approach was used for HR_{max} assessment, according to Póvoas et al.[29] Thus, individual HR_{max} was determined as the highest value reached during the VO_{2max} test, YYIE1 or training sessions.

Habitual PA, dietary intake and medication

The participants were instructed to maintain their usual PA besides that related to the intervention programme. Daily PA was measured using the International Physical Activity Questionnaire.[32] Regular medication was recorded.

Statistics

Results are presented as mean ± standard deviations (SD) and 95% confidence intervals (95% CI). Between-group and within-group changes at baseline and after 16 weeks regarding CV, aerobic performance and metabolic markers were analysed using a two-way analysis of covariance (ANCOVA) with Bonferroni post hoc procedures and sedentary behaviour at baseline as covariate. Between-group and within-group changes at baseline and after 16 weeks and intervention effects for habitual PA were analysed using a two-way repeated-measures analysis of variance (ANOVA) with Bonferroni post hoc procedures. Student's unpaired *t*-test was used to assess delta value differences between the groups. Practical significance was assessed by calculating Cohen *d* and interpreted as trivial (<0.2), small (0.2–0.5), medium (0.5–0.8) and large (>0.8).[33] Statistical Package for the Social Sciences (SPSS Inc., version 25) was used for data analysis. Statistical significance was set at $p \leq 0.05$.

Results

Training sessions

The participants attended an average of 1.9 ± 0.4 (0.9–2.9) training sessions per week. During the small-sided team handball games, mean

Table 1
Cardiovascular health, aerobic performance and metabolic health at baseline and after 16 weeks of small-sided recreational team handball training or a continuation of usual lifestyle.

	Team handball group (n = 41)				Control group (n = 26)				Two-way ANCOVA		
	Baseline	16 weeks	Δ (abs)	Δ (%)	Baseline	16 weeks	Δ (abs)	Δ (%)	Time *p*	Group *p*	Interaction *p*
Aerobic performance											
YYIE1 (m)	248 ± 111	406 ± 216[a]	159 ± 165	69.9 ± 62.2	205 ± 88	216 ± 75[b]	11 ± 67[b]	14.8 ± 43.7[b]	0.168	0.006	0.002
Cardiovascular fitness variables											
VO_{2peak} (mL/min/kg)	25.8 ± 3.3	27.5 ± 3.8[a]	1.7 ± 2.2	6.6 ± 9.1	24.5 ± 3.6	24.9 ± 3.6[b]	0.4 ± 2.3	2.2 ± 10.1	0.129	0.079	0.096
Time to exhaustion (s)	656 ± 114	724 ± 120[a]	68 ± 83	11.2 ± 13.8	616 ± 112	667 ± 103[a]	51 ± 94	10.2 ± 19.2	0.261	0.199	0.973
Resting heart rate (bpm)	68 ± 9	65 ± 9	-2 ± 9	−2.7 ± 13.1	64 ± 9	65 ± 8	1 ± 5	1.9 ± 7.2	0.496	0.393	0.087
Metabolic fitness variables											
Fasting glucose (mmol/L)	5.0 ± 0.9	4.9 ± 0.9	−0.1 ± 0.5	−2.2 ± 9.0	4.9 ± 0.9	4.8 ± 0.6	−0.0 ± 0.5	0.6 ± 8.9	0.393	0.786	0.438
2-h OGTT glucose (mmol/L)	6.0 ± 1.8	6.3 ± 2.2	0.3 ± 1.5	7.3 ± 23.9	5.1 ± 1.2	5.8 ± 1.2[a]	0.8 ± 1.0	17.6 ± 20.7	0.373	0.173	0.121
Fasting insulin (μmol/L)	54 ± 29	51 ± 34	−4 ± 18	−6.7 ± 31.0	49 ± 29	51 ± 26	2 ± 17	12.9 ± 36.6[b]	0.646	0.269	0.226
2-h OGTT insulin (μmol/L)	292 ± 115	302 ± 199	10 ± 144	4.4 ± 37.9	273 ± 226	313 ± 279	40 ± 162	28.9 ± 56.1	0.323	0.711	0.158
Total cholesterol (mmol/L)	5.6 ± 0.8	5.5 ± 0.8[a]	−0.2 ± 0.5	−2.6 ± 9.2	5.4 ± 1.0	5.2 ± 1.0	−0.2 ± 0.4	−2.8 ± 8.4	0.017	0.168	0.652
HDL cholesterol (mmol/L)	1.5 ± 0.4	1.5 ± 0.4	−0.0 ± 0.2	−0.9 ± 11.6	1.5 ± 0.4	1.5 ± 0.4	0.0 ± 0.2	2.0 ± 10.2	0.856	0.822	0.358
LDL cholesterol (mmol/L)	3.6 ± 0.9	3.4 ± 0.8[a]	−0.1 ± 0.4	−2.3 ± 13.7	3.4 ± 0.9	3.2 ± 0.8	−0.2 ± 0.3	−4.5 ± 10.4	0.005	0.186	0.870
Total/HDL cholesterol ratio	3.91 ± 1.33	3.81 ± 1.10	−0.19 ± 0.54	−0.8 ± 11.6	3.76 ± 0.85	3.57 ± 0.76	−0.18 ± 0.34	−4.2 ± 8.3	0.018	0.296	0.823
Total/LDL cholesterol ratio	1.63 ± 0.25	1.64 ± 0.23	−0.00 ± 0.13	0.5 ± 7.2	1.63 ± 0.20	1.67 ± 0.22	0.03 ± 0.09	2.2 ± 5.1	0.137	0.505	0.452
LDL/HDL cholesterol ratio	2.53 ± 1.18	2.43 ± 0.98	−0.09 ± 0.46	−0.3 ± 17.4	2.37 ± 0.76	2.20 ± 0.64[a]	−0.17 ± 0.28	−5.9 ± 11.2	0.007	0.227	0.888
Triglycerides (mmol/L)	1.2 ± 0.4	1.1 ± 0.4	−0.1 ± 0.4	1.6 ± 35.4	1.1 ± 0.5	1.0 ± 0.5	−0.1 ± 0.4	−5.4 ± 30.2	0.632	0.618	0.533

Data are presented as mean ± SD.
Abs, absolute; YYIE1, Yo-Yo intermittent endurance test level 1; VO_{2peak}, peak oxygen uptake; OGTT, oral glucose tolerance test; HDL, high-density lipoprotein cholesterol; LDL, low-density lipoprotein cholesterol.
[a] Significantly different from baseline ($p \leq 0.005$).
[b] Significantly different from the team handball group ($p \leq 0.005$).

HR was 128 ± 16 bpm, corresponding to 76 ± 6%HR_{max}, with peak values of 149 ± 17 bpm (88 ± 6%HR_{max}). HR achieved 80%–90% and >90% of HR_{max} for 34 ± 14% and 11 ± 9% of total match duration, respectively. Thus, for 44 ± 20% (18 ± 9 min) of total match time, the participants' HR was >80% HR_{max}. Average match RPE was 4.8 ± 1.9 (0.1–9.3).

Aerobic performance

A time x group interaction ($p = 0.002$) was observed for YYIE1, with THG showing a more pronounced improvement than CG after 16 weeks of 70 ± 62% (248 ± 111 to 406 ± 216 m; $p < 0.001$; 95% CI: 49.20–90.68; $d = 1.176$) vs 15 ± 44% (205 ± 88 to 216 ± 75 m; $p > 0.05$; 95% CI: −4.54–34.21; $d = 0.167$; Table 1). Post-intervention values were 88% higher in THG vs CG for YYIE1 performance (406 ± 216 vs 216 ± 75 m, $p = 0.002$; Table 1; Fig. 2).

CV fitness variables

A within-group improvement was seen in THG after 16 weeks for VO_{2peak} (6.6 ± 9.1%; 25.8 ± 3.3 to 27.5 ± 3.8 mL/min/kg; $p < 0.001$; 95% CI: 3.42–9.78; $d = 0.764$; Table 1; Fig. 2), whereas no significant changes were observed in CG (24.5 ± 3.6 vs 24.9 ± 3.6 mL/min/kg; $p = 0.372$; 95% CI: −2.50–6.98; $d = 0.181$). Post-intervention values were 10% higher in THG vs CG for VO_{2peak} (27.5 ± 3.8 vs 24.9 ± 3.6 mL/min/kg; $p = 0.037$).

Time to exhaustion (TTE) in the incremental treadmill test increased for THG by 11.2 ± 13.8% (656 ± 114 to 724 ± 120 s; $p < 0.001$; 95% CI: 6.43–16.05; $d = 0.824$; Table 1) as well as for CG (10.2 ± 19.2%; 616 ± 112 to 667 ± 103 s; $p = 0.002$; 95% CI: 1.23–19.18; $d = 0.546$), with no significant post-intervention differences between groups.

Metabolic fitness variables

A significant within-group time effect was observed in THG for TC and LDL, with a reduction of 2.6 ± 9.2% (5.6 to 5.5 mmol/L; $p = 0.014$; 95% CI: −5.46–0.32; $d = 0.362$; Table 1) and 2.3 ± 13.7% (3.6 to 3.4 mmol/L; $p = 0.024$; 95% CI: −6.68–2.00; $d = 0.294$), respectively. An 18% increase was observed in glucose after the 2-h OGTT for CG (from 5.1 ± 1.2 to 5.8 ± 1.2 mmol/L; $p = 0.004$; 95% CI: 8.38–26.72; $d = 0.757$), while no significant alterations were observed for THG (from 6.0 ± 1.8 to 6.3 ± 2.2 mmol/L; $p = 0.236$; 95% CI: −0.94;15.46; $d = 0.228$). No significant post-intervention differences were observed between THG and CG for any of the metabolic fitness variables.

Habitual PA

No significant differences ($p > 0.05$) were observed between groups with regard to habitual PA, vigorous PA, moderate PA and walking at baseline (THG: 3051 ± 2834 MET-min/week, 657 ± 1435 MET-min/week, 1085 ± 1395 MET-min/week and 1309 ± 1140 MET-min/week, respectively; CG: 2458 ± 2364 MET-min/week, 859 ± 1775 MET-min/week, 761 ± 1162 MET-min/week and 838 ± 786 MET-min/week, respectively) and after 16 weeks (THG: 3038 ± 1936 MET-min/week, 1194 ± 1127 MET-min/week, 827 ± 1039 MET-min/week and 1017 ± 886 MET-min/week, respectively; CG: 3002 ± 2685 MET-min/week, 947 ± 1554 MET-min/week, 1143 ± 1491 MET-min/week and 911 ± 747 MET-min/week, respectively). Furthermore, there were no within-group changes from 0 to 16 weeks in these categories.

Although THG decreased sedentary behaviour after 16 weeks (245 to 195 min/week; $p = 0.011$), CG reported lower levels of sedentary behaviour than THG at that time point (137 vs 195 min/week; $p = 0.041$) and also at baseline (142 vs 245 min/week; $p = 0.004$), with no significant changes within the groups between the two evaluations.

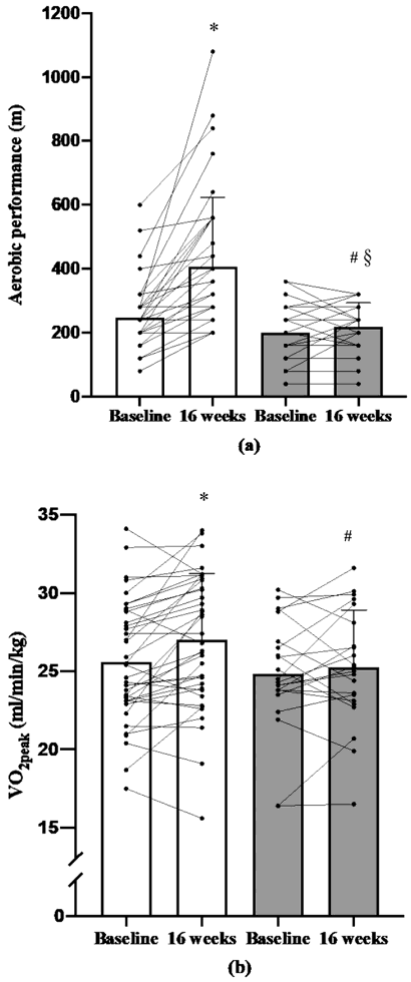


Fig. 2. Aerobic performance, as evaluated by the YYIE1 test (a), and VO_{2peak} (b) at baseline and after 16 weeks of small-sided recreational team handball training (THG, n = 41: white bars) or a continuation of usual lifestyle (CG, n = 26: grey bars). *Significantly different from baseline ($p \leq 0.005$); #significantly different from the team handball group ($p \leq 0.005$), §significant difference in change score (0 to 16 weeks) between groups.

Discussion

This is the first study to show that team handball can be used to elicit moderate-to-vigorous aerobic intensities in 49–79-year-old untrained women with no previous experience of the sport, and that a training programme comprising twice-weekly 60-min recreational team handball training sessions over 16 weeks can induce positive effects on aerobic performance and markers of CRF.

Aerobic performance

Aerobic performance, evaluated by YYIE1, has been shown to be largely associated with individual VO_{2max} in untrained individuals.[34] In this study, THG showed a marked 70% improvement in aerobic performance, measured by the YYIE1 test, which is in the same range as the improvements in YYIE1 performance observed in training studies with postmenopausal women playing floorball[22] and middle-aged and elderly participants playing football.[35,36] The reported magnitude of post-intervention changes mostly solidifies the evidence of the higher sensitivity of YYIE1 in tracking changes in endurance fitness compared to VO_{2max}.[34] It could be speculated that the resulting greater sensitivity of YYIE1 in tracking changes in endurance fitness in recreational team sports practitioners may be a reflection of the exercise mode commonalities. Indeed, recreational team handball, which involves accelerations, decelerations and changes of direction, may result in mainly peripheral neuromuscular adaptations, enabling greater economy during YYIE1 shuttle running. This may further promote interest in YYIE1 as a functional test in recreational team sports and warrant future studies addressing the effect of recreational team handball external load on changes in YYIE1 performance.

Additionally, increasing aerobic performance after a period of training will probably result in greater ability to train and to play at higher speed thresholds. In fact, more high-intensity running during the training sessions has been reported after a period of recreational football training for elderly men,[37] while in recreational team handball training, time spent at HR > 90%HR_{max} has been shown to be largely correlated with post-intervention changes in VO_{2max}.[17]

CV health-related variables

THG was successful in improving VO_{2peak} by 7%, and the 10% post-intervention difference in VO_{2peak} between THG and CG is likely to be a major contributor to the higher intermittent exercise capacity, as evaluated by YYIE1. Our findings are in line with other studies using floorball and football with postmenopausal women, which reported a VO_{2max} improvement of 4%–10% after 12 weeks of training (2×60 min/wk).[21,22,38] Somewhat higher (21%) improvements have been observed after 12–16 weeks of twice-weekly 60-min training regimes using recreational football for postmenopausal women, though the participants were younger than in the present study (57 ± 5 vs 68 ± 6 years).[39] Our results are also in accordance with those found for young adult men playing recreational team handball with no prior experience of the sport, which showed an 11% increase in VO_{2max},[19] while untrained adult former players showed the highest increase (14%).[17] These results indicate that VO_{2max} improvements resulting from recreational handball practice are more pronounced in men, which is the opposite of what has been found for recreational football, where similar VO_{2max} improvements were reported for participants of both sexes (13% for men and 15% for women) in a similar age range (men: 20–43 years; women: 19–47 years).[40,41] Also, in football a similar VO_{2max} improvement (15% vs 13%, respectively) was observed for both older (63–74 years)[42] and younger (20–43 years) men,[40] though the same was not observed for women.[41,43] The level of improvement (15%) observed in young women (19–47 years; mean age 36 years)[41] tends to decrease (5%) when the age range is widened (25–65 years; mean age 44 years).[43] A 10% VO_{2max} increase was observed after 12 weeks of recreational football training in type 2 diabetic adults of both sexes (n = 44), including 27 women in menopause.[38] HR during the training sessions (3×40 min weekly) was above 90% of HR_{max} for 20% of the total training time (8 min out of 40),[38] which is almost twice the amount of time for the THG participants in our study (11%; 4 min out of 45). Notwithstanding the possible impact of the inclusion of male participants in the sample, the higher intensity of the training sessions may have been the cause of greater VO_{2max} improvements. Indeed, in recreational team handball, post-intervention changes in VO_{2max} have been shown to be largely correlated with time spent at HR > 90%HR_{max} during the training sessions.[17]

Surprisingly, both groups increased TTE despite differences in training-induced changes in aerobic fitness and performance. It could be speculated that motivation in the CG may have played a role in these unexpected results. This was confirmed by the analysis of RER at exhaustion in TT, confirming the likelihood of a longer TTE sustained by the anaerobic metabolism. Interestingly, the CG showed a 2.2% non-significant improvement in VO_{2max} that, although within the range of biological changes for this variable, may partly support a

different approach to the retest. From the practical point of view, the changes in TTE were approximately of 60 s, corresponding to 1 stage of the considered TT.

The VO_{2max} improvement in postmenopausal women is of greatest importance, since CRF is associated with reduced CVD and all-cause mortality.[44] For each 1 MET (3.5 mL/min/kg of VO_{2max}) increase, the risk of all-cause mortality and coronary heart disease and CVD decreases 13% and 15%, respectively, and a maximal aerobic capacity of at least 6 MET is needed for a reduced risk of any adverse event in 50-year-old women.[45] In our study, 16 weeks of recreational team handball practice induced a 0.4 MET increase in VO_{2max}.

Metabolic fitness profile

THG decreased TC and LDL, but no recreational team handball training-induced effects were shown for the remaining metabolic markers. Nevertheless, significant differences ($p = 0.02$) were shown in delta values between the groups in fasting insulin, with THG showing a 7% decrease and CG a 13% increase. Only CG showed an increase (18%) in glucose after OGTT.

Our results are partly in line with 12-week intervention studies using recreational team handball as an exercise mode for young men and women,[18,19] which also were not able to show significant alterations in blood profile, such as HDL and TGs, while a decrease in TC and LDL was observed in adult men.[17] Reductions in TC, LDL, TGs and glucose were observed after a 12-week recreational football programme combined with a caloric restricted diet in type 2 diabetics.[38]

Dyslipidaemia, high glucose and insulin resistance are factors contributing to metabolic syndrome that seem to have a greater impact in postmenopausal women due to estrogen decrease after menopause[46] and could lead to atherosclerosis and CVD events.[47] Although it was not able to reverse all the negative menopause-related metabolic outcomes, short-term recreational team handball practice was effective at reversing TC and LDL, while CG showed an increase in glucose after the 2-h OGTT. Additionally, recreational team handball practice seemed to be effective at positively impacting this adverse blood profile, with practical small improvements in fasting glucose and insulin.

Injuries

There was no record of any severe injuries during the programme, which is in concordance with previous studies.[18,19] One finger subluxation was reported, though this did not prevent the participant from completing the intervention. The overall incidence was 0.8 injuries per 1000 h of exposure. The use of balls made of soft material and continuous instructions on how to hold, throw and catch the ball, combined with no hard tackles being allowed, may have been the reasons for these results. Although recreational team handball seems to be a safe exercise mode, more research on this topic, namely its long-term effects, is warranted.

Summary

To the best of our knowledge, this is the first study to analyse the training intensity of recreational team handball for postmenopausal women and the effects of a short-term training programme on markers of aerobic and metabolic fitness. The results clearly show that recreational team handball can be used to obtain moderate-to-vigorous aerobic intensities for women with no prior experience of the sport and that a short training period of recreational team handball can increase aerobic performance and the ability of players to train at a higher intensity. Thus, twice-weekly 60-min team handball training sessions for 16 weeks resulted in marked increases in aerobic exercise performance with a concomitant increase in CRF for postmenopausal women. A somewhat surprising lack of significant alterations was observed in some metabolic markers, which may be attributable to possible alterations in diet. In fact, although the participants were instructed to maintain their normal diet, a combined exercise programme and rigorous controlled diet could have been more effective for improving the participants' metabolic health, and thus should be considered in future studies. Generally, short-term recreational team handball played as small-sided games is a high-attendance, high-intensity and low-risk exercise mode capable of improving aerobic performance and CV health in postmenopausal women with no experience of the sport. Further studies are warranted to analyse the effects of recreational team handball on other health-related menopause conditions, such as bone health, and the effects of long-term interventions using this exercise mode.

Authors' contributions

All authors agreed with the authors' order of presentation, read and approved the final version of the manuscript. RP conducted the data curation, formal analysis, investigation and wrote the original draft. JM and CC contributed to the conceptualization, formal analysis and reviewed and edited the manuscript. SP, PK and JM performed the supervision. EC and RS contributed to formal analysis and reviewed and edited the manuscript. JTG and SM carried out the formal analysis of the metabolic markers and reviewed and edited the manuscript. SP and PK performed the conceptualization, funding acquisition, formal analysis and reviewed and edited the manuscript.

Declaration of Competing Interest

The authors have no conflicts of interest to declare.

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Original Study III

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Full Length Article

Effects of recreational team handball on bone health, postural balance and body composition in inactive postmenopausal women — A randomised controlled trial

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ABSTRACT

This study reports the effects of a recreational team handball exercise programme (randomised controlled trial, RCT) on bone health, postural balance and body composition in inactive postmenopausal women without previous experience of the sport. Sixty-seven postmenopausal women (68.3 ± 6.2 years, stature 156.9 ± 5.8 cm, body mass 65.6 ± 9.6 kg, body fat 40.9 ± 5.9%, VO_{2peak} 25.2 ± 3.6 mL·min^{-1}·kg^{-1}) were randomised into team handball (THG, n = 41) and control (CG, n = 26) groups. During the 16-week intervention period, THG performed two to three 60-min training sessions per week, while CG continued with their habitual physical activity. Bone mineral density (BMD) and content (BMC), biochemical bone formation (osteocalcin (OC), procollagen type-1 amino-terminal propeptide (P1NP)) and resorption (carboxy-terminal type-1 collagen crosslinks (CTX)) markers, postural balance, body fat and lean mass were evaluated at baseline and post intervention. A time x group interaction ($p \leq 0.02$) was shown for lumbar spine BMD (+1.5%) and BMC (+2.3%), P1NP (+37.6 ± 42.4%), OC (+41.9 ± 27.0%) and postural balance (−7 ± 37% falls), in favour of THG with no changes in CG. This RCT showed that short-term recreational team handball practice had an impact on bone turnover and was effective for improving bone health and postural balance in postmenopausal women without previous experience of the sport, hence potentially helping to reduce the risk of falls and fractures.

Abbreviations: ANCOVA, analysis of covariance; ANOVA, analysis of variance; BMC, bone mineral content; BMD, bone mineral density; CG, control group; CI, confidence interval; CTX, carboxy-terminal type-1 collagen crosslinks; DXA, dual-energy X-ray absorptiometry; EDTA, ethylenediaminetetraacetic acid; HR, heart rate; HR_{max}, maximal heart rate; iSYS, immunoassay system; OC, osteocalcin; PA, physical activity; P1NP, procollagen type-1 amino-terminal propeptide; RCT, randomised controlled trial; RER, respiratory exchange ratio; RPE, rating of perceived exertion; SD, standard deviation; SPSS, Statistical Package for the Social Sciences; THG, team handball group; VO_{2max}, maximal oxygen uptake; VO_{2peak}, peak oxygen uptake; YYIE1, Yo-Yo intermittent endurance test level 1.

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1. Introduction

Menopause is defined as the cessation of menses and occurs at a median age of 51 years [1], with women spending nearly one third of their lives in this irreversible condition. Both menopause and ageing involve hormonal changes, and menopause is characterised by a decrease in oestrogens levels [1,2] that negatively impacts body composition by increasing body fat [3] and decreasing lean and bone mass [2], and ultimately increasing the risk of musculoskeletal disorders, such as sarcopenia and osteoporosis. These disorders are known to be associated with cardiovascular disease [4,5], and to potentiate the risk of falls [6] and fractures [7], whereas higher lean mass [8] and lower body fat [9,10] are associated with a decreased risk of fractures in postmenopausal women. Given that falls and fractures are associated with an increased risk of morbidity and mortality [6,11], exercise programmes namely aerobic, resistance and flexibility training have been considered as effective strategies for counteracting these adverse health conditions and menopause-related morbidities [12]. However, despite the effectiveness of traditional exercise modes, other options, such as team sports, which combine aerobic and anaerobic training, seem to show a positive modulatory impact on various health-related parameters [13]. For instance, recreational football offers a multicomponent training approach that has the potential to act on a range of health and fitness aspects, being as effective for decreasing body fat and increasing lean and bone mass as aerobic and strength training separately [14]. Moreover, recreational team handball, which physical and physiological demands are similar to recreational football, has been shown to positively affect body composition and bone health in young men [15] and women [16] by increasing muscle mass, femur bone mineral density (BMD), whole-body bone mineral content (BMC) and bone formation markers, and decreasing body fat. It has also proven effective for improving physical fitness (e.g. balance) in adult/middle-aged men with previous experience of the sport [17]. In addition, it has recently been shown that recreational handball is effective for improving aerobic performance and cardiorespiratory fitness in postmenopausal women [18]. Nonetheless, the effects of recreational team handball on bone health and fall prevention in postmenopausal women have not yet been addressed. So, to the best of our knowledge, this is the first study to evaluate the effects of a recreational team handball-based exercise programme (randomised controlled trial, RCT) on bone health, postural balance and body composition in inactive postmenopausal women without previous experience of the sport.

2. Methods

2.1. Participants

Eighty inactive postmenopausal women aged 49–79 years with menopause for at least 3 years and without medical contraindications to perform moderate-to-vigorous physical activity (PA) were recruited into this study (Fig. 1). Nine participants dropped out for personal reasons, three before the baseline evaluations and six immediately afterwards. Seventy-one participants without previous experience of the sport were randomly allocated to team handball (THG) and control (CG) groups. After randomisation, two CG participants dropped out for personal reasons and one was excluded from the analysis because she had enrolled in another exercise programme. In THG, one participant was not able to start the exercise programme at the set date and complete the 16-week programme for personal reasons and was thus excluded from the analysis. The final sample therefore comprised sixty-seven participants (THG: $n = 41$, age 67.3 ± 6.5 years, stature 156.7 ± 6.2 cm, body mass 66.9 ± 9.7 kg, body fat 41.3 ± 5.3%, VO_{2peak} 25.8 ± 3.3 $mL \cdot min^{-1} \cdot kg^{-1}$; CG: $n = 26$, age 69.9 ± 5.4 years, stature 157.1 ± 5.1 cm, body mass 63.5 ± 9.3 kg, body fat 40.3 ± 6.8%, VO_{2peak} 24.5 ± 3.6 $mL \cdot min^{-1} \cdot kg^{-1}$) who performed baseline and post-intervention evaluations at 16 weeks.

Sample size estimation for the main outcome (maximal oxygen uptake (VO_{2max})) of this RCT was performed for a sample power of 95% with an effect size of 0.25 at a significance level of 5% and for a dropout rate of 20% [18]. The results presented here therefore represent an

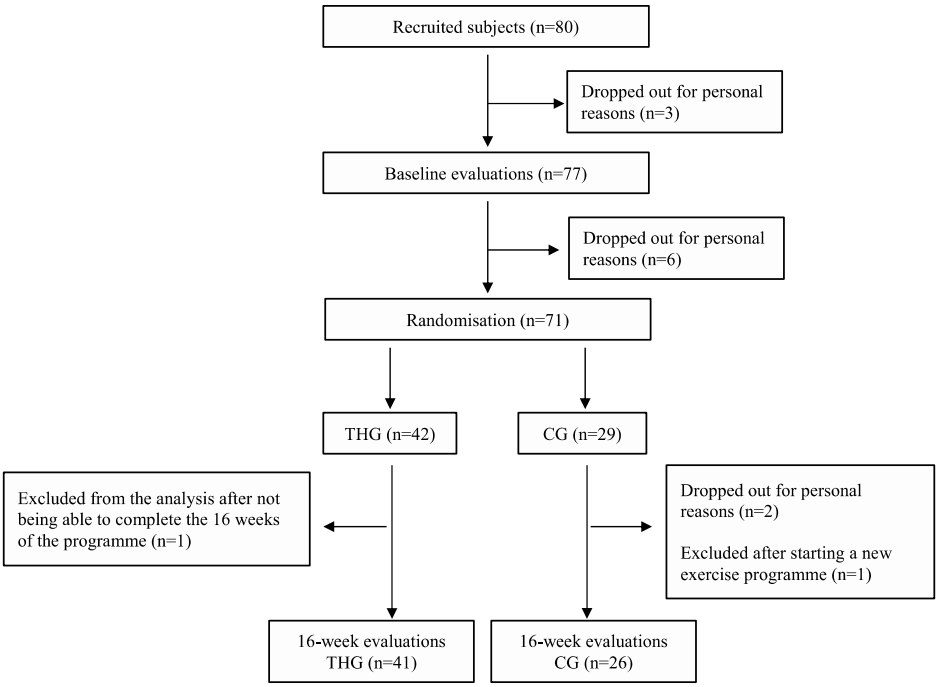


Fig. 1. Flow chart showing the number of participants enrolled, randomised and evaluated.

analysis of the secondary outcomes (BMD, BMC, biochemical bone markers, postural balance and body mass, body fat and lean mass) of this RCT. All participants signed a written informed consent providing information about the purpose of the study and its potential risks and benefits, and stating that they could withdraw at any time without penalty. The present study followed the Declaration of Helsinki, and the local Institutional Review Board provided ethical approval.

2.2. Study design

This was a randomised controlled trial. The participants were evaluated at baseline and post intervention (16 weeks) for body mass, body fat, lean mass, BMD, BMC, biochemical bone turnover markers and postural balance. After the baseline evaluations, the participants were stratified by peak oxygen uptake (VO_{2peak}) and randomly allocated (3:2 ratio, due to potentially higher drop-out in the intervention group than in the CG) to THG ($n = 41$) and CG ($n = 26$). THG underwent a 16-week recreational team handball intervention involving two to three 60-min sessions per week. CG was instructed to continue with their habitual daily PA. THG was also instructed to continue with their habitual PA in addition to the PA related to the intervention programme.

2.3. Measures and test procedures

All the participants were evaluated at baseline and at 16 weeks post intervention. The evaluations were performed on two separate days. The participants were instructed to have a light meal before the evaluations, except before the blood sampling, which was performed in the morning after an overnight fast (at least 8 h). No exhausting PA was allowed in the 48 h before testing. PA levels aside from those related to the exercise intervention were measured using the International Physical Activity Questionnaire [19].

2.3.1. Evaluation day 1

Body mass, stature and body composition were measured with the participants in light clothes and without shoes. Stature (rounded to the nearest 0.1 cm) was measured with a portable stadiometer (Seca 213, Hamburg, Germany) with the participant in an upright position, quiet, facing forwards with their arms hanging freely [20]. Body mass (kg), body fat (%) and lean mass (kg) were determined by whole-body dual-energy X-ray absorptiometry (DXA; Hologic Explorer QDR, Hologic Inc., Belford, MA, USA) following standard procedures. Lumbar spine and dominant femur BMD and BMC were determined by regional scanning.

Cardiorespiratory fitness was assessed using a standardised incremental treadmill (H/PHCosmos, Quasar, Germany) protocol [21]. Oxygen uptake and respiratory exchange ratio (RER) were determined by pulmonary gas exchange measurements (Oxycon Pro Metabolic Cart, Jaeger, CareFusion, Germany). VO_{2peak} was considered as the highest 15-s mean value. During the test, the participants' heart rate (HR) was continuously monitored with a heart-rate monitor (Polar Wearlink, Kempele, Finland). Age-predicted maximal HR (HR_{max}) was determined by the formula 208 – (age x 0.7) bpm [21]. The test stopped at the participant's voluntary exhaustion and the results were considered as VO_{2peak} if two of the following criteria were met: RER $\geq$1.1; $HR_{max} \geq$ 85% of age-predicted HR_{max}; failure of oxygen consumption to increase with increased exercise intensity [21].

2.3.2. Evaluation day 2

To assess the plasma concentration of biochemical bone turnover markers, blood samples were drawn by a trained technician. A 6-mL blood sample was collected in a tube containing ethylenediaminetetraacetic acid (EDTA) and centrifuged. Plasma was pipetted and frozen at −80 °C for subsequent analysis of osteocalcin (OC), procollagen type-1 amino-terminal propeptide (P1NP) and carboxy-terminal type-1 collagen crosslinks (CTX). The markers were analysed by a chemiluminescence method using a fully automated immunoassay system, (iSYS; Immunodiagnostic System Ltd., Boldon, UK). Assay performance was verified using the manufacturer's control specimens. The intermediary precisions expressed as coefficients of variation for CTX were 5.3% (at CTX concentration 213 ng/L), 3.4% (869 ng/L) and 3.5% (2,113 ng/L) for iSYS. For P1NP, the intermediary precisions were 5.4% (18.96 μg/L), 6.5% (48.48 μg/L) and 6.1% (122.10 μg/L) for iSYS. For OC, the intermediary precisions were 3.0% (8.73 μg/L), 3.6% (27.6 μg/L) and 3.5% (68.7 μg/L).

After the blood was drawn, the participants had their regular breakfast. Nearly 30 min later, they performed a single-leg flamingo test to assess postural balance [22]. In this test, the participants had to stand on their dominant leg on a 3-cm-wide and 5-cm-high bar for 1 min. Every time the participant lost their balance, the time was paused until balance was regained. The non-dominant leg was flexed at the knee joint. The number of falls during the defined time was recorded.

Afterwards, the participants performed the Yo-Yo intermittent endurance test level 1 (YYIE1), preceded by a 10-min warm-up of running at different velocities with changes of direction. HR during the test was assessed [23].

2.4. Exercise programme

THG performed two to three weekly sessions of a recreational team handball-based exercise programme for 16 weeks, with a rest period of at least 48 h between sessions. Each session lasted 60 min and consisted of a standardised warm-up (including running, coordination, strength, flexibility and balance exercises) and three 15-min periods of recreational team handball matches played as small-sided games (4v4, 5v5 or 6v6). The training sessions were performed on an indoor team handball court (40 × 20 m) adjusted to give an area of 34–36 m^2 per player. Some exceptions to official team handball rules were applied, namely: no exclusions; no substitutions; no dribbling; the participants rotated positions every 3 min in a random order, including the goalkeeper; the ball was immediately put back in play by the goalkeeper after a goal. To avoid injuries, no hard tackles and physical contact were allowed. The balls used were lighter than for conventional team handball and made of a soft material. All sessions were supervised by a physical education professional with good knowledge of the rules of the sport. Heart rate (Firstbeat Technologies Ltd., version 4.7.2.1, Jyväskylä, Finland) and rating of perceived exertion (RPE), 0–10 scale [24], were monitored in all training sessions. Individual HR_{max} was determined as the highest value reached during the VO_{2max} test, the YYIE1 or the training sessions [23].

2.5. Statistical analyses

Results are presented as mean ± standard deviations (SD) and 95% confidence intervals (95% CI). Group and intervention effects were analysed with two-way analysis of covariance (ANCOVA) with Bonferroni post hoc tests, with sedentary behaviour as the covariate to bone health, balance and body composition variables. Group and intervention effects for habitual PA were analysed with two-way analysis of variance (ANOVA) with Bonferroni post hoc tests. To analyse differences in pre-post delta values between the groups, a student's unpaired *t*-test was performed. A Pearson correlation was used to analyse associations in absolute and relative changes between osteogenic bone turnover markers. Practical significance was assessed by calculating Cohen *d* and interpreted as trivial (<0.2), small (0.2–0.5), medium (0.5–0.8) and large (>0.8) [25]. Statistical Package for the Social Sciences (SPSS Inc., version 25) was used for data analysis. Statistical significance was set at $p \leq 0.05$.

3. Results

3.1. Training sessions

The participants' mean training attendance was 1.9 ± 0.4 (0.9–2.9) sessions per week, with a total of 31 ± 7 (15–47) training sessions. Mean HR during matches was 128 ± 16 bpm (76 ± 6%HR_{max}), with peak values of 149 ± 17 bpm (88 ± 6%HR_{max}). HR was >80%HR_{max} for 44 ± 20% (18 ± 9 min) of total match duration, with 34 ± 14% of the time spent at 80–90%HR_{max} and 11 ± 9% of the time spent at >90%HR_{max}. Average RPE during match-play was 4.8 ± 1.9 (0.1–9.3).

3.2. Osteogenic response

A time x group interaction was shown for lumbar spine BMD and BMC ($p \leq 0.002$). THG increased lumbar spine BMD by 1.5% (0.892 ± 0.129 to 0.905 ± 0.130 g/cm^2; $p < 0.001$; 95% CI: 0.62–2.31; $d = 0.586$) and lumbar spine BMC by 2.3% (50.1 ± 10.1 to 51.2 ± 10.3 g; $p < 0.001$; 95% CI: 0.98–3.53; $d = 0.593$). An increase of 2.2% (25.3 ± 3.6 to 25.8 ± 3.5 g; $p = 0.004$; 95% CI: 0.90–3.48; $d = 0.502$) was also observed in femur BMC in THG (Table 1; Fig. 2).

A time x group interaction was shown for P1NP ($p = 0.017$) and OC ($p = 0.008$). At 16 weeks, THG showed significant higher P1NP levels than CG (67.5 versus 43.1 μg/L; $p = 0.014$). From pre to post intervention, THG increased CTX (375.7 ± 212.4 to 436.3 ± 198.5 ng/L; $p = 0.017$; 95% CI: 9.26–46.70; $d = 0.529$), P1NP (49.9 ± 18.9 to 67.5 ± 28.8 μg/L; $p < 0.001$; 95% CI: 17.82–57.33; $d = 1.300$) and OC (18.8 ± 7.1 to 27.7 ± 14.2 μg/L; $p < 0.001$; 95% CI: 29.28–54.57; $d = 2.807$) concentrations by 28%, 38% and 42%, respectively (Table 1; Fig. 3). A correlation between absolute ($r = 0.433$; $p = 0.015$) and relative ($r = 0.444$; $p = 0.012$) femur BMC and P1NP delta values was shown. Additionally, a correlation between relative femur BMC and OC delta values ($r = 0.381$; $p = 0.034$) was also observed.

3.3. Postural balance

A time x group interaction was observed for postural balance ($p = 0.010$). At post intervention, THG had decreased the number of falls by 7%, corresponding to five falls less than at baseline (38 ± 13 to 33 ± 14 falls; $p = 0.011$; 95% CI: −20.46–5.98; $d = 0.474$) (Table 1; Fig. 4).

3.4. Body mass, body fat and lean mass

A time effect was observed for body fat ($p = 0.008$). THG decreased body mass by 1.1% (66.9 ± 9.7 to 66.2 ± 9.4 kg; $p = 0.007$; 95% CI: −1.85; −0.27; $d = 0.423$) and body fat percentage by 1.1%-point (41.3 ± 5.3 to 40.2 ± 5.1%; $p < 0.001$; 95% CI: −3.58; −1.46; $d = 0.795$). CG decreased body fat percentage by 0.8%-points (40.3 ± 6.8 to 39.5 ± 6.6; $p = 0.019$; 95% CI: −3.87; −0.57; $d = 0.432$). No significant differences were observed for lean mass in either group or between groups after 16 weeks (Table 1).

3.5. Habitual physical activity

No significant differences ($p > 0.05$) between or within groups were observed with regard to total PA, vigorous PA, moderate PA and walking

Table 1
Body mass, body composition, blood bone markers and postural balance at baseline and after 16 weeks of small-sided recreational team handball training or a continuation of usual lifestyle, with baseline habitual physical activity as the covariate.

Variables	Team handball group ($n = 41$)				Control group (n = 26)				Two-way ANCOVA		
	Baseline	16 weeks	Δ (abs)	Δ (%)	Baseline	16 weeks	Δ (abs)	Δ (%)	Time p	Group p	Interaction p
Bone health											
Lumbar spine BMD (g/cm^2)	0.892 ± 0.129	0.905 ± 0.130*	0.013 ± 0.022	1.5 ± 2.7	0.899 ± 0.126	0.893 ± 0.124	−0.006 ± 0.014#	−0.6 ± 1.6#	0.442	0.731	0.001
Lumbar spine BMC (g)	50.1 ± 10.1	51.2 ± 10.3*	1.1 ± 1.8	2.3 ± 4.1	49.5 ± 8.1	49.1 ± 7.9	−0.4 ± 1.2#	−0.7 ± 2.4#	0.492	0.909	0.002
Femoral neck BMD (g/cm^2)	0.718 ± 0.098	0.724 ± 0.097	0.006 ± 0.025	0.9 ± 3.6	0.693 ± 0.125	0.693 ± 0.131	−0.000 ± 0.019	−0.2 ± 2.8	0.547	0.841	0.302
Femoral neck BMC (g)	3.3 ± 0.5	3.3 ± 0.5	0.0 ± 0.2	1.6 ± 8.0	3.2 ± 0.6	3.2 ± 0.7	−0.0 ± 0.2	−0.6 ± 5.9	0.660	0.758	0.595
Femur BMD (g/cm^2)	0.833 ± 0.101	0.838 ± 0.098	0.004 ± 0.019	0.6 ± 2.3	0.826 ± 0.111	0.828 ± 0.117	0.003 ± 0.018	0.3 ± 2.2	0.223	0.474	0.674
Femur BMC (g)	25.3 ± 3.6	25.8 ± 3.5*	0.5 ± 1.0	2.2 ± 4.1	25.7 ± 4.0	25.8 ± 4.0	0.1 ± 1.2	0.6 ± 4.8	0.100	0.494	0.153
CTX (ng/L)	375.7 ± 212.4	436.3 ± 198.5*	60.6 ± 115.2	28.0 ± 40.0	309.1 ± 245.4	338.6 ± 249.3	29.5 ± 50.2	16.6 ± 38.3	0.367	0.232	0.568
P1NP (μg/L)	49.9 ± 18.9	67.5 ± 28.8*	17.7 ± 16.6	37.6 ± 42.4	38.0 ± 27.5	43.1 ± 28.4#	5.1 ± 6.3#	18.1 ± 27.2	0.003	0.028	0.017
Osteocalcin (μg/L)	18.8 ± 7.1	27.7 ± 14.2*	8.9 ± 7.8	41.9 ± 27.0	16.6 ± 13.1	18.8 ± 13.1	2.1 ± 2.1#	16.9 ± 16.7#	0.003	0.157	0.008
P1NP/CTX	156.9 ± 64.8	162.4 ± 42.9	5.5 ± 64.3	14.5 ± 37.0	166.0 ± 68.0	181.8 ± 97.4	15.8 ± 83.6	11.7 ± 43.2	0.240	0.508	0.952
Osteocalcin/CTX	57.3 ± 18.2	65.7 ± 22.0	8.4 ± 22.1	20.5 ± 43.4	75.5 ± 38.5	82.9 ± 57.1	7.4 ± 43.2	10.8 ± 40.9	0.223	0.114	0.794
Physical fitness											
Postural balance (n)	38 ± 13	33 ± 14*	−5 ± 10	−7 ± 37	35 ± 13	38 ± 12	3 ± 8#	16 ± 41#	0.902	0.909	0.010
Body composition											
Body mass (kg)	66.9 ± 9.7	66.2 ± 9.4*	−0.7 ± 1.8	−1.1 ± 2.5	63.5 ± 9.3	63.2 ± 9.6	−0.3 ± 1.3	−0.5 ± 2.2	0.200	0.450	0.301
Body fat (%)	41.3 ± 5.3	40.2 ± 5.1*	−1.1 ± 1.4	−2.5 ± 3.4	40.3 ± 6.8	39.5 ± 6.6*	−0.8 ± 1.8	−1.6 ± 5.5	0.008	0.806	0.487
Lean mass (kg)	37.2 ± 4.1	37.4 ± 4.1	0.3 ± 0.9	0.8 ± 2.4	35.7 ± 3.5	36.0 ± 3.8	0.3 ± 1.3	0.9 ± 3.8	0.230	0.329	0.890

Data is presented as mean ± SD.
BMD: bone mineral density; BMC: bone mineral content; CTX: carboxy-terminal type-1 collagen crosslinks; P1NP: procollagen type-1 amino-terminal propeptide.
* Significantly different from baseline ($p \leq 0.005$).
# Significantly different from the team handball group ($p \leq 0.005$).

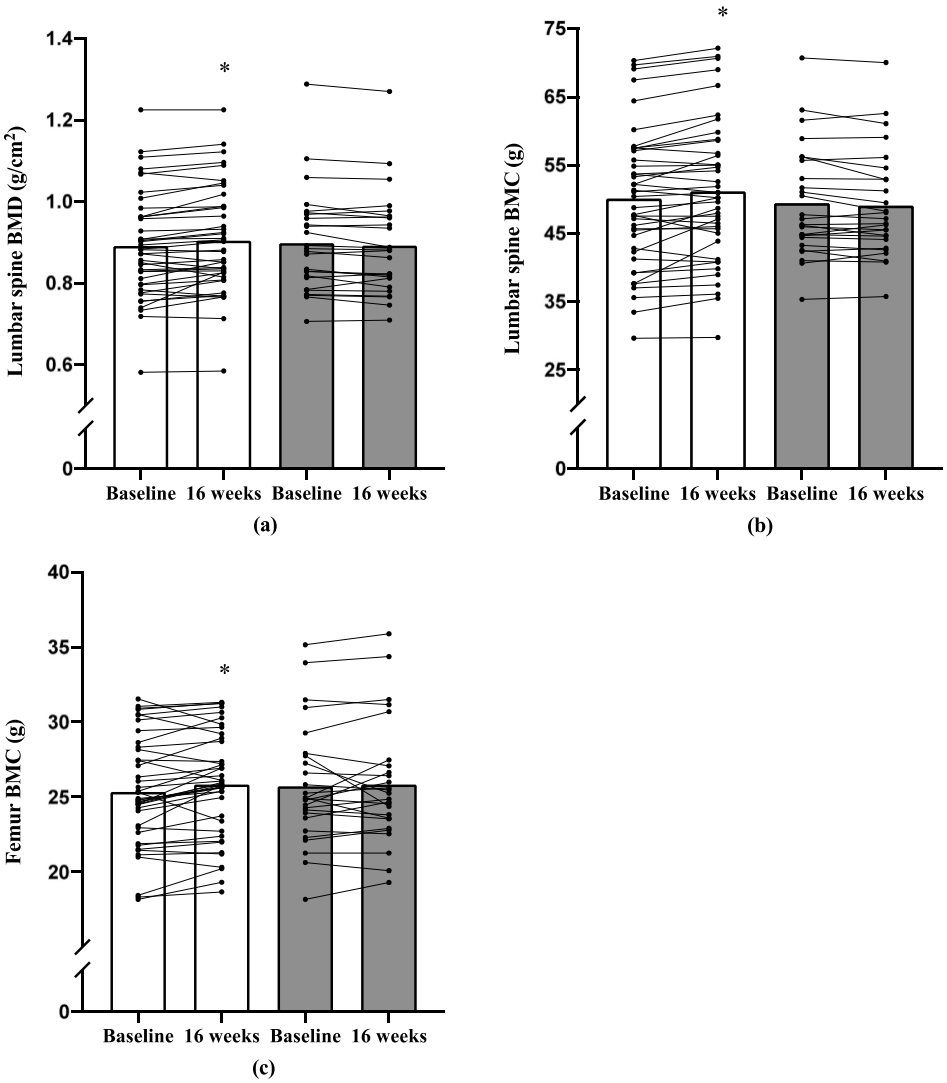


Fig. 2. Lumbar spine BMD (a), lumbar spine BMC (b) and femur BMC (c) at baseline and after 16 weeks of team handball training (THG, $n = 41$: white bars) or a continuation of usual lifestyle (CG, $n = 26$: grey bars). *Significantly different from baseline ($p \leq 0.005$).

between baseline and 16 weeks (Table 2). Although CG reported less sedentary behaviour than THG at baseline (142 vs 245 min/week; $p = 0.004$) and at 16 weeks (137 vs 195 min/week; $p = 0.041$), only THG had decreased sedentary behaviour at follow-up (245 to 195 min/week; $p = 0.011$).

4. Discussion

This is the first study to analyse the effects of a short-term (16 weeks) recreational team handball-based randomised controlled exercise programme on bone health, postural balance and body composition in inactive postmenopausal women without previous experience of the sport. The main findings were that 16 weeks of recreational team handball training, performed as small-sided games, induced an osteogenic response as well as improvements in postural balance and body mass.

4.1. Osteogenic response

THG increased lumbar spine BMD and BMC, and femur BMC, by 1.5, 2.3 and 2.2% ($p \leq 0.004$), respectively. It has been reported that during the first few years after menopause, BMD in lumbar spine and femur decreases 2.0% and 1.4% per year, respectively [26]. Thus, the present findings are of particular interest, since recreational team handball practice may counteract the normal BMD loss in this population. Additionally, bone remodelling to repair microfractures and replace old and fragile bone tissue with new bone is of the utmost importance for osteoporosis prevention [27]. For this, bone remodelling needs to take place through osteoclastic and osteoblastic activity [28]. Even though this process occurs irrespective of age and health, after menopause there is a greater increase in osteoclastic resorption than in osteoblastic activity [27], leading to a negative net bone balance. After 16 weeks, THG increased P1NP (37.6%), OC (41.9%) and CTX (28.0%). THG showed higher absolute delta values for biochemical bone formation markers

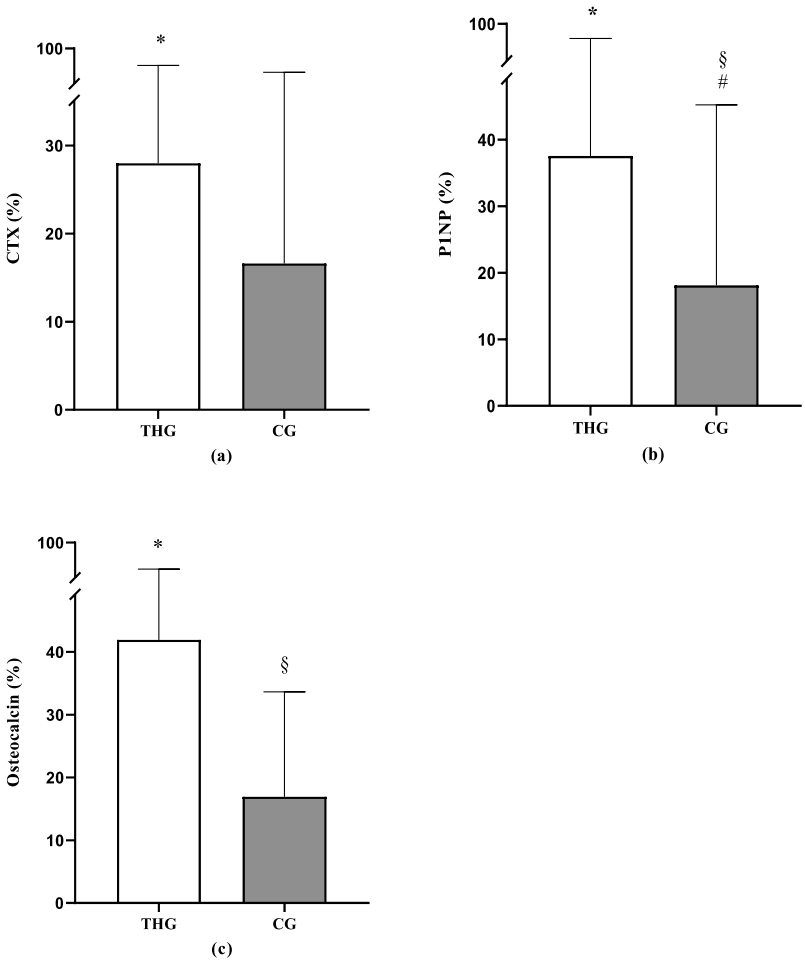


Fig. 3. CTX (a), P1NP (b) and osteocalcin (c), presented as delta values (%) between baseline and 16 weeks of team handball training (THG, n = 41) or a continuation of usual lifestyle (CG, n = 26). *Significant differences between baseline and 16 weeks ($p \leq 0.005$); #Significant difference between groups at 16 weeks ($p \leq 0.005$); §Significant differences in change score between groups ($p \leq 0.005$).

than CG (P1NP: 17.7 vs 5.1 μg/L; OC: 8.9 vs 2.1 μg/L, $p \leq 0.009$). Even though recreational team handball training for postmenopausal women resulted in an increase in the bone resorption marker CTX (375.7 ± 212.4 to 436.3 ± 198.5 ng/L; $p = 0.017$), it was accompanied by an increase in the osteoblastic activity markers P1NP and OC, which seems to indicate an overall osteogenic change in bone turnover.

In a previous study, after 4 months of recreational football practice comprising two to three 45–60-min sessions per week, increases of 1.0 and 1.1% in right and left femur BMD, respectively, were shown in older men (mean age 68.2 years) [29]. Additionally, after a year of intervention, right and left femur BMD increased by 5.4% and 3.8%, respectively. The authors suggested that the osteogenic response may take more time in older than in younger populations. Longer-term interventions may be required to understand whether recreational team handball is effective for improving femur BMD, since a 16-week intervention may not be enough to promote any significant change in this region. Indeed, the increase in biochemical bone markers may indicate a forthcoming alteration in bone structure. Moreover, it would be of interest to understand whether extending recreational team handball practice beyond 16 weeks induces additional improvements in lumbar spine BMD and BMC. Studies analysing the effect of team sports-based exercise interventions on lumbar spine BMD and BMC are scarce, even though both lumbar spine and femur are the areas for osteoporosis diagnostics [30]. Osteocalcin and P1NP were shown to increase by 41 and 45% respectively, with no change in CTX at the end of the fourth month of recreational football practice in older men [29]. An increase in P1NP (40%) was observed in postmenopausal women after 12 weeks of twice-weekly 60-min sessions of floorball practice, with no changes in CTX or OC [31]. However, after 15–16 weeks of recreational football training, an increase was shown in P1NP, OC and CTX in middle-aged women close to menopause (52%, 37% and 42%, respectively) [32], and in 61-year-old men and women (52%, 23% and 38%, respectively) [33].

Increases in femur BMD (0.8 and 2.0%), P1NP (33 and 65%), OC (56 and 45%) and CTX (34 and 25%) were observed in 20–30-year-old women and men, respectively, after a 12-week recreational team handball intervention involving two to three sessions per week, which accords with the findings of this study [15,16,34].

Improvements in bone health can contribute to the prevention of osteoporosis, which is associated with cardiovascular mortality, morbidity and atherosclerosis [4], highlighting a possible multiple-health approach of this exercise mode for preventing the deleterious effects of menopause.

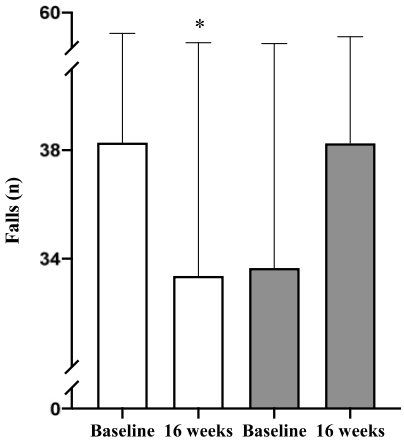


Fig. 4. Postural balance, evaluated as the number of falls in a flamingo balance test, at baseline and after 16 weeks of team handball training (THG, n = 41: white bars) or a continuation of usual lifestyle (CG, n = 26: grey bars). *Significantly different from baseline ($p \leq 0.005$).

4.2. Postural balance

The consequences of falls include fractures, bruises, other injuries and physiological effects, including morbidity and even death [6]. Thus, the prevention of falls and improvement of postural balance are paramount, particularly for postmenopausal women, who are at higher risk than men of experiencing fractures [35]. Recreational team handball practice resulted in an improvement (7%) in postural balance after 16 weeks. Greater postural balance improvements were shown in two team sport interventions involving men (27%, 42.3 years) and women (29%, 36.5 years) using team handball [17] and football [36], respectively. Indeed, better results were shown in the flamingo balance test in a younger (32.4 years) than in an older population (70.5 years) [37]. Additionally, long-term exposure to training is also a key factor in balance performance, with trained older men (69.6 years) reporting the same number of falls as untrained young men (32.4 years) [37].

A limitation of this study was not to have recorded the number of falls before, during and after the intervention, in daily life activities and during the training sessions. In future studies, it would also be of interest to analyse the fall pattern.

4.3. Total body mass, body fat and lean mass

THG reduced body mass by 0.7 kg, corresponding to 1.1%, though no changes were observed in lean mass. Curiously, both groups decreased body fat, THG by 1.1%-point and CG by 0.8%-points. In recreational team sports, changes in fat and lean mass were observed in several studies, namely using floorball for postmenopausal women [31,38], team handball for young men and women [15,16,34], and football for men of the same mean age as this study participants [39]. The decrease in body fat in THG is in accordance with previous training studies with team handball for young women (1.0%) [16] and overweight premenopausal women (1.4%) [34] playing recreational team handball twice a week for 12–16 weeks. In these studies, however, no changes were observed in body mass. Body mass decreases are of practical importance due to the association with health risks at older ages. Weight loss, even in small amounts, could be beneficial, namely for preventing obesity and its consequences [40]. It should be taken into account, though, that weight loss could induce loss of muscle mass, besides body fat, which is of particular concern in the older population [40].

4.4. Injuries

In order to minimise the risk of injury, no hard tackles or physical contact were allowed. Additionally, the balls used were made of soft material and the participants were continuously instructed how to hold, throw and catch the ball. During the 16 weeks, only one finger subluxation was reported, though this did not prevent the completion of the intervention by the participant. Thus, the overall incidence was 0.8 injuries per 1000 h of exposure. No severe injuries occurred during the programme, which is in accordance with previous studies [15,16].

A previous study in this population had already reported the efficiency of recreational team handball for improving aerobic performance and cardiorespiratory fitness, thus showing the positive cardiovascular health effect of this team sport practice in postmenopausal women [18]. However, this is the first RCT to analyse the effects of recreational team handball on bone health, balance and body composition in this population.

After the 16-week intervention, significant changes were shown in lumbar spine BMD and BMC, femur BMC, P1NP, OC, CTX, balance and body mass, though no alterations were shown in lean mass and femur BMD. This could be related to the duration of the intervention (16 weeks) being insufficient to induce significant alterations in these markers, and thus the effect of extending the intervention's duration on additional increases in BMD should be studied.

The increases in BMD, BMC and bone turnover could contribute to better skeletal mass and, together with the improvement in balance, reduce the risk of falls and fractures, which are associated with increased risk of mortality and morbidity. Taken together, data from the present study suggest that recreational team handball can be introduced as a high-attendance, high-intensity and low-risk exercise mode for improving bone density, content and metabolism, as well as postural balance.

Table 2
Daily physical activity at baseline and after 16 weeks of small-sided recreational team handball training or a continuation of usual lifestyle.

	Team handball group ($n = 41$)		Control group ($n = 26$)		Two-way ANOVA		
	Baseline	16 weeks	Baseline	16 weeks	Time p	Group p	Interaction p
Total PA (MET-min/week)	3051 ± 2834	3038 ± 1936	2458 ± 2364	3002 ± 2685	0.459	0.545	0.438
Vigorous-intensity PA (MET-min/week)	657 ± 1435	1194 ± 1127	859 ± 1775	947 ± 1554	0.218	0.934	0.374
Moderate-intensity PA (MET-min/week)	1085 ± 1395	827 ± 1039	761 ± 1162	1143 ± 1491	0.753	0.988	0.109
Walking (MET-min/week)	1309 ± 1140	1017 ± 886	838 ± 786	911 ± 747	0.447	0.134	0.204
Sedentary behaviour (min/day)	245 ± 161	195 ± 127*	142 ± 81#	137 ± 69#	0.083	0.005	0.146

Data is presented as mean ± SD.
PA: physical activity.
* Significantly different from baseline ($p \leq 0.005$).
# Significantly different from the team handball group ($p \leq 0.005$).

5. Conclusion

Short-term recreational team handball practice is effective for improving bone health and postural balance in postmenopausal women without previous experience of the sport, and hence may potentially be helpful for counteracting the elevated risk of falls, fractures and associated comorbidities in this population.

Acknowledgments

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CRediT authorship contribution statement

All authors read and approved the final version of the manuscript. RP conducted the training, testing, data collection and analysis, interpreted the study results and drafted the manuscript. JM and CC contributed to the study design, interpreted the study results and edited the manuscript. EC, RS and EWH interpreted the study results and edited the manuscript. NRJ carried out the analysis of the biochemical bone turnover markers and interpreted the study results. SP and PK conceived the study design, applied for the funding, interpreted the results and edited the manuscript.

Declaration of competing interest

The authors do not have any conflicts of interest to declare.

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Original Study IV

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Multicomponent recreational team handball training improves global health status in postmenopausal women at the long term – A randomised controlled trial

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ABSTRACT

We studied the long-term effects of a multicomponent exercise training protocol (recreational team handball training, RTH) on global health status in inactive postmenopausal women. Participants (n = 45; age 65 ± 6 years, stature 157 ± 6 cm, body mass 66.2 ± 9.4 kg, fat mass 41.4 ± 5.5%, VO_{2peak} 25.7 ± 3.6 mL/min/kg) were randomised into a control group (CG; n = 14) and a multicomponent exercise training group (EXG; n = 31, performing two to three weekly 60-min RTH sessions). Attendance was 2.0 ± 0.4 sessions/week (first 16 weeks) and 1.4 ± 0.5 (following 20 weeks) and mean heart rate (HR) loading was 77 and 79% of maximal HR (p = .002) for the first 16 and the following 20 weeks, respectively. Cardiovascular, bone, metabolic health, body composition and physical fitness markers were evaluated at baseline, and after 16 and 36 weeks. An interaction ($p \leq .046$) was shown for the 2-h oral glucose tolerance test, HDL, Yo-Yo intermittent endurance level 1 test (YYIE1) and knee strength, in favour of EXG. At 36 weeks, YYIE1 and knee strength were higher ($p \leq .038$) for EXG vs CG. Also, within-group improvements ($p \leq .043$) were observed after 36 weeks for EXG in VO_{2peak}, lumbar spine bone mineral density, lumbar spine bone mineral content, P1NP, osteocalcin, total cholesterol, HDL, LDL, body mass, android fat mass, YYIE1, knee strength, handgrip strength and postural balance. At 36 comparatively to 16 weeks, EXG showed an increase ($p \leq .036$) in fasting blood glucose, HDL, knee strength and handgrip strength, and a decrease ($p \leq .025$) in LDL. Collectively, this multicomponent exercise training (RTH) induces beneficial changes in global health status in postmenopausal women.

Highlights

- We evaluated the long-term effects of a recreational team handball-based multicomponent training on broad-spectrum health and physical fitness markers of inactive postmenopausal women.
- Improvements in VO_{2peak} and aerobic performance achieved after 16 weeks of training were maintained at 36 weeks.
- The 20-week extension of the training intervention resulted in further improvements in lipid profile markers and physical fitness variables.
- Recreational team handball could be suggested as an effective and safe strategy to counteract postmenopausal health-related constrains.

KEYWORDS

bone metabolism; fitness; lipid profile; menopause; team sports; VO_{2max}

1. Introduction

Women's global health is deteriorated during menopause (El Khoudary et al., 2019). Indeed, cardiovascular risk factors such as elevated blood pressure and metabolic markers such as triglycerides (TRG) and low-density lipoprotein cholesterol (LDL) are adversely

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changed in postmenopausal compared to premenopausal women (Pu et al., 2017). Moreover, bone mineral density (BMD) (Greendale et al., 2012) and muscle mass (Juppi et al., 2020) decrease during menopause transition. Loss of muscle mass can lead to physical disability and increased risk of falls (Thomas et al., 2021) and low bone mass is a risk factor for fractures (Uusi-Rasi et al., 2019). Thus, lowering cardiovascular risk factors and improving bone mass and reducing falls are important strategies for preventing fractures and reducing morbidity and mortality (Teo & Rafiq, 2021; Uusi-Rasi et al., 2019).

Feasible and efficient exercise training regimes targeting global health status have been suggested to counteract the deleterious menopause-related effects (Grindler & Santoro, 2015). Combined or multicomponent exercise training (combining endurance, resistance and balance training) (World Health Organization, 2020) has shown to be more effective in improving cardiometabolic health status, which has been associated with bone health upregulation (Milanović et al., 2022), than single-component modalities (Batrakoulis et al., 2022). Recreational team sports, an example of multicomponent exercise training (Krustrup et al., 2010a), have demonstrated to be feasible and broad-spectrum health-enhancing exercise options for middle-aged and elderly participants, and to assure exercise adherence over the short-term (Castagna et al., 2020a; Milanović et al., 2019). In fact, cardiovascular, metabolic and musculoskeletal improvements, similar to those obtained by conventional exercise programmes, are achieved with low doses of exercise (2×60-min sessions/week) (Krustrup et al., 2010a). Additionally, these are highly motivating activities (Milanović et al., 2019), thus overcoming the main barriers to exercise (i.e. lack of time and motivation) (European Comission, 2022). In fact, team sports practice results in lower levels of negative affects (such as angry, sad, anxious, ashamed, guilty, annoyed and worried) than individual sports practice, which can increase motivation to exercise (Barbry et al., 2021).

Nonetheless, apart from football, there is a lack of studies assessing the broad-spectrum health effects and adherence to other recreational team sports-based exercise programmes beyond the frequently used 12-to-16-week period (i.e. short-term), particularly in the elderly. Indeed, only two studies have analysed the long-term effects of this particular multicomponent training. In elderly men, enhanced bone health, as well as attenuated age-related effects were shown for maximal oxygen consumption (VO_{2max}) and glycated haemoglobin (HbA1c) after more than two years of floorball training (Pedersen et al., 2018). Moreover, 40 weeks of floorball for postmenopausal women were able to preserve body composition, cardiovascular and bone health, and physical fitness enhancements achieved after an initial 12-week period, as well as improved blood glucose regulation (Seidelin et al., 2017). Nevertheless, a 50% dropout was observed in the subgroup assessed at 40 weeks (Seidelin et al., 2017), confirming that long-term exercise adherence is particularly demanding in older populations (Findorff et al., 2009; Rivera-Torres et al., 2019).

Recreational team handball (RTH) has also been assessed as a global health promotion strategy (Castagna et al., 2020a; Pereira et al., 2021). The health effects of 16 weeks of RTH training were analysed in postmenopausal women, showing improvements on cardiorespiratory and physical fitness, bone health, body composition and lipid profile markers (Pereira et al., 2020; Pereira et al., 2021). Nonetheless, resting heart rate (HR), blood glucose regulatory markers, proximal femur and femoral neck BMD, and lean mass showed no changes. Thus, the role of exercise volume (total intervention duration) was put into perspective for future research. In fact, previous studies showed that an increase in leg BMD and in bone mineral content (BMC), both in the legs and in the whole-body, were observed only after 1 year and 40 weeks of football and floorball training, respectively, but not after 12 weeks (Randers et al., 2010; Seidelin et al., 2017). Extending the duration of the interventions beyond 16 weeks was suggested to ascertain if an enhancement in health status would only occur with longer durations, as well as further improvements after those shown after the short-term (Pereira et al., 2020; Pereira et al., 2021). Moreover, since the postmenopausal status is a permanent condition in women's life, the long-term adherence to exercise programmes, namely to this exercise mode, is of interest.

This study aimed at determining the long-term (36 weeks) adherence and the health and physical fitness effects of multicomponent training (RTH) for postmenopausal women without previous experience with the sport, and at comparing them with the alterations shown after the first 16 weeks (short-term).

We hypothesised that long-term RTH would result in positive health and physical fitness adaptations, and that the adherence to this exercise mode would be maintained over the 36 weeks (long-term) compared to the first 16 weeks (short-term). We also hypothesised that the health and physical fitness improvements (VO_{2max}, BMD and BMC, bone turnover markers, lipid profile, fat mass, aerobic performance, and postural balance) shown after the first 16 weeks would be maintained or further improved at the long-term.

2. Methods

2.1. Participants and study design

Recruitment started one month before the beginning of the trial. Eighty participants met the inclusion criteria (i.e. inactive postmenopausal women aged +55 years or younger if with menopause for at least three years) and were invited to participate in the study (Figure 1). Exclusion criteria was to present any medical contraindication for performing moderate-to-vigorous physical activity (PA). Two participants were on hormonal therapy. Some participants were taking antihypertensive ($n = 13$) and cholesterol-lowering ($n = 16$) drugs for more than one year before the starting of the intervention. The participants were asked to inform the research team if they changed their medicine intake or started a new medicine therapy. Nine participants dropped out for personal reasons (three before baseline evaluations and six subsequently). Seventy-one participants were stratified by VO_{2peak} and randomly allocated (3:2 ratio) to a multicomponent exercise training group (EXG) or a control group (CC). Unequal sample sizes (3:2 ratio) were used since a higher dropout was expected in intervention group than in the control group due to exercise-related injuries. An independent researcher generated the allocation sequence (computer-generated random numbers), enrolled, and assigned the participants to the groups. No significant between-groups differences were observed at baseline (data not shown). EXG performed 36 weeks of a RTH-based exercise programme, while the CG was instructed to keep their regular daily PA. Both groups were asked not to change their dietary habits during the time of the intervention. Evaluations were performed at baseline, 16 and 36 weeks. Before the 16-week evaluations, two participants in the CG dropped out for personal reasons, one participant was excluded because started a new exercise programme and one participant in the EXG was excluded because did not complete the 16 weeks of the exercise programme, resulting in sixty-seven participants being evaluated. After the 16 weeks evaluations, twelve participants in the CG dropped out, namely ten that did not want to continue to be involved in the study and two for medical issues. Additionally, ten participants of EXG dropped out for personal reasons (2), medical issues (5) and injuries (one shoulder pain and two finger subluxations). Only the finger subluxations were related to the exercise programme; the shoulder pain occurred previously to the enrolment in the exercise programme, however, it was further aggravated during the intervention. At 16 weeks, the dropout rate was 5.6% (1.4% EXG and 4.2% CG) and 36.6% at 36 weeks (15.5% EXG and 21.1% CG). Thus, forty-five participants completed the additional 20 weeks of the intervention and were evaluated at that time point.

After being informed in verbal and written form about the purpose, potential risks, and benefits of the study, and that they could withdraw at any time without penalty, the participants signed a written informed consent. This study was conducted in accordance with the Declaration of Helsinki and ethical approval was provided by the local Ethics Committee. This study was registered at clinicaltrials.gov (identifier: NCT05292261).

Peak oxygen uptake (VO_{2peak}) was the primary outcome of this study since cardiorespiratory fitness is associated with a lower risk of cardiovascular disease (Kodama et al., 2009), which is the major cause of morbidity and mortality in postmenopausal women (Baber et al., 2016). Bone health, metabolic health, body mass, body composition and physical fitness, as well as the other cardiovascular health markers were considered as secondary outcomes.

Sample size estimation for the main outcome (VO_{2peak}) was performed for a sample power of 95% with an effect size of 0.25 at a significance level of 5% and for a dropout rate of 20%, resulting in 72 participants to be recruited.

2.2. Exercise programme

Briefly, EXG performed 2–3 × 60-min/week supervised training sessions, with 48 h of rest in-between, for 36 weeks. Each session was performed on an indoor team handball court (40 × 20 m; 34–36 m^2/player) and started with a standardised warm-up [low intensity running and coordination exercises, combined with articular movements, strength (namely squats, lunges, push-ups and planks), flexibility (upper body stretching), and balance exercises (stand in one leg and hold the position)], followed by three 15-min periods of RTH matches, interspersed by 2-min breaks, played as small-sided games (4v4, 5v5 or 6v6). Other adaptations were made to the official team handball rules: no body contact was allowed, and softer and lighter team handball balls than the official ones were used, as this population had no experience with this sport, and to avoid potential injuries. Other exceptions to the official team handball rules included: no exclusions; no substitutions; no dribbling; the participants rotated positions every 3 min in a random order, including the goalkeeper; and the ball was immediately put back in play by the goalkeeper after a goal. According to procedures previously described (Pereira et al., 2020; Pereira et al.,

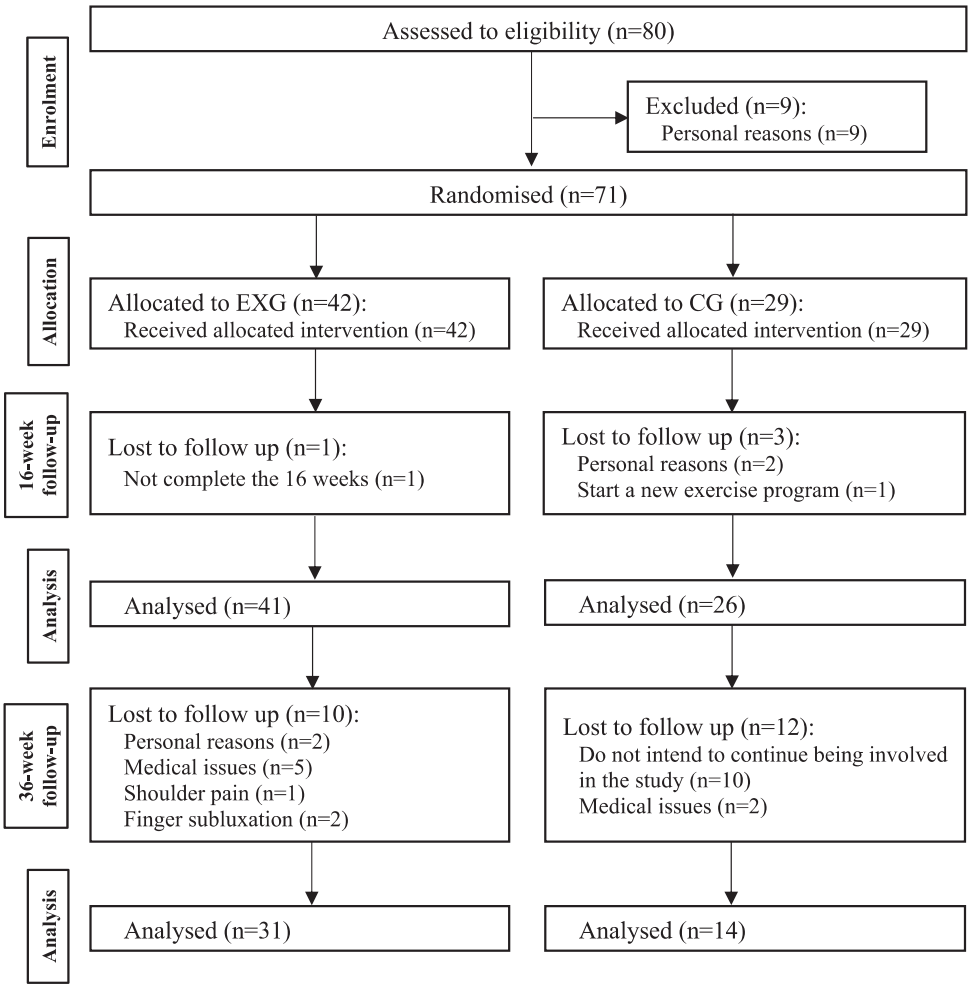


Figure 1. Flow chart showing the number of participants enrolled, randomised and evaluated.

2021), HR (Firstbeat Technologies Ltd., version 4.7.2.1, Jyväskylä, Finland), rating of perceived exertion (RPE), and fun levels (Grant et al., 1999), 0–10 scale, were monitored in all training sessions and maximal HR (HR_{max}) was determined.

2.3. Measures and test procedures

All the participants were evaluated on two separate days (distanced two to four days apart) at baseline and at the end of 16 and 36 weeks (Faculty of Sport, University of Porto, Portugal, facilities). No exhausting PA was allowed in the 48 h before testing. The participants were instructed to have a light meal not earlier than 3 h before the evaluations. Blood sampling was performed in the morning after a minimum 8-h overnight fasting. On the first evaluation day, resting HR evaluation, dual-energy X-ray absorptiometry (DXA) scans (body, fat and lean mass and BMD and BMC included), isometric knee extension peak torque and rate of force development (RFD) tests and a standardised treadmill incremental protocol to assess VO_{2peak} and time to exhaustion (TTE) were performed, in that order. On the second evaluation day, blood sampling for metabolic [blood glucose, insulin, total cholesterol (TC), high-density lipoprotein cholesterol (HDL), LDL, TRG] and bone turnover markers [sclerostin, carboxy-terminal type-1 collagen crosslinks (CTX), procollagen type-1 amino-terminal propeptide (P1NP) and osteocalcin] determination was performed. After a light breakfast, physical fitness [Yo-Yo Intermittent Endurance level 1 test (YYIE1) performance, handgrip strength (handgrip dynamometer, Takei TKK 5401, Niigata, Japan) and postural balance (single-leg flamingo test)] were evaluated.

The PA levels were measured using the International Physical Activity Questionnaire (Craig et al., 2003).

Sclerostin was measured in plasma using the TECO-Medical Sclerostin HS EIA assay (Quidel Corporation, San Diego, CA). The sample aliquots were kept frozen at −80°C until further analysis. The analysis was performed immediately after thawing the samples using one single batch of the assay. Assay performance was verified using the manufacturers' control and the intra-assay precision was 10% at both the 0.2 and 1.9 ng/mL levels.

Isometric knee extension peak torque and RFD of the dominant leg were measured on a Biodex isokinetic dynamometer (Biodex System 4 Pro, Shirley, NY, USA) following standard procedures. The participants were instructed to sit on the isokinetic dynamometer chair and hold on the chair handles, with their upper body (i.e. torso and waist) and with the dominant leg tightly stabilised by Velcro straps. Before the test, the participants performed a 3-min warm-up in a cycle ergometer at a work rate of 60 rpm and 0.5 Kp. A familiarisation test was performed by all participants that were instructed to exert a submaximal contraction against the pad. After a 1-min rest period, one maximum contraction of 5 s was performed. Participants received verbal encouragement to achieve their maximum effort and were instructed to stop immediately if they felt any pain or discomfort (Gray et al., 2016). Peak toque (Newton-meters, Nm) was recorded. The RFD (N/s) was calculated as the maximum slope of the force–time curve (force/time).

The detailed description of the assessment of the other markers was described elsewhere (Pereira et al., 2020; Pereira et al., 2021).

2.4. Statistical analyses

Results are presented as mean ± standard deviations (*SD*) and 95% confidence intervals (95% CI). To analyse between-group differences and intervention effects, a two-way analysis of variance (ANOVA) for repeated measures with Bonferroni *post hoc* tests was performed. Differences in absolute and relative between-groups changes were analysed using a Student's unpaired *t*-test. Differences in training intensity, RPE and fun levels between the two time points were analysed using a student's paired *t*-test. Practical significance was assessed by calculating Cohen *d* and interpreted as trivial (<0.2), small (0.2–0.5), medium (0.5–0.8) and large (>0.8) (Cohen, 1988). The Shapiro–Wilk test was used to test the normality of the data. Statistical Package for the Social Sciences (SPSS Inc., version 26) was used for data analysis. Statistical significance was set at $p \leq .05$.

3. Results

3.1. Chronological age, anthropometric characteristics, cardiorespiratory fitness and habitual physical activity

Chronological age, anthropometric characteristics and cardiorespiratory fitness of the participants are presented in Table 1. Habitual, vigorous and moderate PA, walking and sedentary behaviour at baseline and after 16 and 36 weeks are presented in Table 2. No differences ($p > .05$) were observed either between- or within-groups.

Cardiovascular, bone, metabolic health, body mass, body composition and physical fitness markers at baseline, after 16 and 36 weeks of the participants in exercise training and control groups are presented in Table 2.

3.2. Cardiovascular health

A time effect was shown for VO_{2peak} and TTE. EXG improved VO_{2peak} after 36 weeks by 9% ($p < .001$; 95% CI: 5.74–12.95; $d = 1.07$), with no differences between 16 and 36 weeks.

3.3. Bone health

A time effect was shown for lumbar spine BMC. EXG increased lumbar spine BMD (1.4 ± 3.5%; $p = .043$; 95% CI: 0.13–2.71; $d = 0.44$) and BMC (2.6 ± 5.1%; $p = .011$; 95% CI: 0.66–4.49; $d = 0.57$) after 36 weeks.

A group effect was shown for P1NP and a time effect was shown for P1NP and osteocalcin. P1NP values at 16 weeks were higher in EXG vs CG ($p = .014$). P1NP relative delta values from 16 to 36 weeks were lower in EXG than CG (−6.2 ± 23.2 vs 37.6 ± 35.2%; $p = .006$). EXG increased P1NP by 34% after 36 weeks vs baseline ($p = .023$; 95% CI: −2.94–71.26; $d = 0.75$). Absolute delta values (16–36 weeks) were lower in EXG vs CG (−4.3 ± 7.4 vs 0.6 ± 2.2 µg/L; $p = .039$). In EXG, osteocalcin was 26.9 ± 13.9 µg/L at 36 weeks, which was 29% higher than baseline ($p = .028$; 95% CI: 7.03–51.70; $d = 0.99$). Absolute

Table 1. Chronological age, anthropometric characteristics and cardiorespiratory fitness of the participants in exercise training and control groups.

Variables	Exercise training group (n = 31) mean ± *SD*	Control group (n = 14) mean ± *SD*
Age (years)	64 ± 7	67 ± 5
Stature (cm)	158 ± 7	157 ± 4
Body mass (kg)	66.9 ± 9.7	64.5 ± 8.8
Fat mass (%)	41.4 ± 5.5	41.6 ± 4.4
VO_{2peak} (mL/min/kg)	25.8 ± 3.9	25.2 ± 2.5

VO_{2peak}: peak oxygen uptake.

Table 2. Cardiovascular health, bone health, metabolic health, body mass, body composition, physical fitness and daily physical activity at baseline, after 16 and 36 weeks of the participants in exercise training and control groups.

	Exercise training group ($n = 31$)			Control group ($n = 14$)			Two-way ANOVA		
Variables	Baseline mean ± *SD*	16 weeks mean ± *SD*	36 weeks mean ± *SD*	Baseline mean ± *SD*	16 weeks mean ± *SD*	36 weeks mean ± *SD*	Time *p*	Group *p*	Interaction *p*
Cardiovascular health									
VO_{2peak} (mL/min/kg)	25.8 ± 3.9	27.4 ± 4.0*	28.1 ± 4.2*	25.2 ± 2.5	25.8 ± 3.3	25.8 ± 3.2	0.004	0.302	0.145
Time to exhaustion (s)	656 ± 122	722 ± 119*	708 ± 151	595 ± 133	643 ± 120	719 ± 131	0.009	0.291	0.245
Resting heart rate (bpm)	68 ± 9	65 ± 9	66 ± 7	63 ± 8	64 ± 7	64 ± 9	0.789	0.259	0.414
Bone health									
Lumbar spine BMD (g/cm^2)	0.897 ± 0.143	0.908 ± 0.145*	0.909 ± 0.146*	0.895 ± 0.161	0.890 ± 0.160	0.898 ± 0.162	0.121	0.833	0.999
Lumbar spine BMC (g)	50.99 ± 10.67	52.04 ± 10.87*	52.30 ± 11.31*	48.28 ± 9.77	47.96 ± 9.39	49.17 ± 10.08	0.006	0.350	0.131
Femoral neck BMD (g/cm^2)	0.719 ± 0.100	0.725 ± 0.102	0.726 ± 0.102	0.673 ± 0.122	0.669 ± 0.130	0.671 ± 0.124	0.919	0.152	0.431
Femoral neck BMC (g)	3.33 ± 0.50	3.33 ± 0.50	3.33 ± 0.51	3.26 ± 0.66	3.19 ± 0.72	3.25 ± 0.67	0.591	0.599	0.524
Proximal femur BMD (g/cm^2)	0.828 ± 0.105	0.835 ± 0.105	0.837 ± 0.106	0.803 ± 0.089	0.805 ± 0.093	0.805 ± 0.090	0.241	0.388	0.477
Proximal femur BMC (g)	25.09 ± 3.49	25.74 ± 3.51*	25.70 ± 3.60	25.50 ± 3.14	25.59 ± 3.04	25.48 ± 2.75	0.132	0.990	0.209
Sclerostin (µg/L)	0.81 ± 0.26	0.80 ± 0.29	0.77 ± 0.25	0.68 ± 0.15	0.76 ± 0.08	0.69 ± 0.08	0.188	0.491	0.326
CTX (ng/L)	445.9 ± 216.5	497.8 ± 203.5	512.3 ± 277.3	422.4 ± 315.5	459.7 ± 312.1	413.1 ± 348.7	0.656	0.722	0.717
P1NP (µg/L)	54.4 ± 20.8	75.6 ± 30.0*	69.6 ± 28.8*	32.2 ± 23.9	34.0 ± 25.9†	40.7 ± 24.6	0.011	0.028	0.076
Osteocalcin (µg/L)	20.6 ± 7.0	31.2 ± 14.9*	26.9 ± 13.9*	14.9 ± 8.3	17.1 ± 9.6	17.7 ± 8.3	0.007	0.106	0.103
P1NP/CTX	140.12 ± 63.53	158.68 ± 43.48	160.18 ± 71.41	149.36 ± 88.50	107.68 ± 18.45	165.51 ± 72.14	0.274	0.718	0.196
Osteocalcin/CTX	51.81 ± 16.26	65.48 ± 23.48	59.52 ± 22.35	71.25 ± 54.21	58.11 ± 26.67	75.77 ± 43.50	0.585	0.510	0.103
Metabolic health									
Fasting blood glucose (mmol/L)	5.0 ± 0.9	4.9 ± 0.9	5.3 ± 0.8#	4.9 ± 0.8	4.8 ± 0.5	5.1 ± 0.9	0.011	0.632	0.764
2-h OGTT blood glucose (mmol/L)	5.8 ± 1.8	6.1 ± 2.1	5.5 ± 1.4	4.7 ± 0.8	5.7 ± 0.9	5.9 ± 1.8	0.135	0.595	0.046
Fasting plasma insulin (µmol/L)	55.6 ± 29.9	53.8 ± 35.2	55.7 ± 30.6	48.8 ± 26.3	50.1 ± 16.3	42.0 ± 17.1	0.538	0.410	0.305
2-h OGTT plasma insulin (µmol/L)	309.5 ± 109.5	312.1 ± 201.7	271.3 ± 159.1	245.2 ± 164.3	300.9 ± 200.6	252.0 ± 170.2	0.314	0.613	0.629
Total cholesterol (mmol/L)	5.7 ± 0.9	5.5 ± 0.8	5.4 ± 0.9*	5.8 ± 1.1	5.5 ± 0.9	5.6 ± 1.4	0.031	0.792	0.622
HDL cholesterol (mmol/L)	1.5 ± 0.4	1.5 ± 0.4	1.6 ± 0.4*#	1.6 ± 0.5	1.6 ± 0.5	1.6 ± 0.4	0.092	0.672	0.028
LDL cholesterol (mmol/L)	3.6 ± 0.9	3.5 ± 0.8	3.2 ± 0.8*#	3.7 ± 0.9	3.5 ± 0.7	3.5 ± 1.0	0.005	0.690	0.208
Total/HDL cholesterol	4.09 ± 1.42	3.97 ± 1.17	3.47 ± 1.11*#	3.81 ± 1.01	3.64 ± 0.91	3.61 ± 0.85	0.003	0.683	0.101
Total/LDL cholesterol	1.60 ± 0.20	1.60 ± 0.18	1.71 ± 0.21*#	1.57 ± 0.19	1.61 ± 0.13	1.60 ± 0.11	0.018	0.444	0.056
LDL/HDL cholesterol	2.67 ± 1.26	2.57 ± 1.03	2.12 ± 0.94*#	2.51 ± 0.92	2.31 ± 0.74	2.29 ± 0.67	0.002	0.801	0.112
Triglycerides (mmol/L)	1.2 ± 0.4	1.2 ± 0.4	1.1 ± 0.4	1.0 ± 0.3	1.0 ± 0.4	1.0 ± 0.6	0.818	0.173	0.339
Body mass and body composition									
Body mass (kg)	66.9 ± 9.7	66.0 ± 9.3*	65.5 ± 9.3*	64.5 ± 8.8	64.0 ± 9.2	64.3 ± 9.1	0.064	0.552	0.247
Fat mass (%)	41.4 ± 5.5	40.3 ± 5.2*	40.0 ± 5.8	41.6 ± 4.4	40.9 ± 5.1	41.2 ± 5.1	0.066	0.700	0.463
Android fat mass (kg)	2.3 ± 0.9	2.2 ± 0.8*	2.1 ± 0.8*	2.2 ± 0.5	2.0 ± 0.6	2.1 ± 0.6	0.030	0.645	0.195
Gynoid fat mass (kg)	4.5 ± 1.1	4.3 ± 1.0	4.3 ± 0.9	4.3 ± 0.9	4.2 ± 0.9	4.2 ± 0.9	0.123	0.685	0.493
Lean mass (kg)	37.0 ± 4.0	37.2 ± 3.7	37.1 ± 3.7	35.7 ± 3.6	35.8 ± 4.1	35.7 ± 3.8	0.804	0.272	0.975
Physical fitness									
YYIE1 (m)	259 ± 119	417 ± 232*	443 ± 248*	173 ± 75†	191 ± 82†	178 ± 92†	0.002	0.004	0.007
Peak torque (Nm)	115.1 ± 25.7	116.5 ± 23.4	123.1 ± 25.2*#	111.6 ± 15.8	106.4 ± 14.1	106.2 ± 16.6†	0.381	0.169	0.015
RFD (N/s)	312.8 ± 166.5	326.1 ± 148.6	357.0 ± 201.8	321.6 ± 217.4	252.3 ± 87.2	240.6 ± 64.3	0.787	0.354	0.310
Handgrip strength (kg)	24.0 ± 3.9	24.9 ± 4.4	26.5 ± 4.1*#	23.3 ± 3.4	23.4 ± 3.3	24.4 ± 3.5	0.010	0.248	0.485
Postural balance (n)	39 ± 12	35 ± 14	31 ± 12*	34 ± 13	38 ± 11	31 ± 13	0.011	0.841	0.108
Daily physical activity									
Total PA (MET-min/week)	2879 ± 2728	3201 ± 1965	2705 ± 2990	3185 ± 2959	3489 ± 3178	2942 ± 1509	0.670	0.638	0.998
Vigorous-intensity PA (MET-min/week)	604 ± 1423	1240 ± 1219	561 ± 1858	1430 ± 2435	1487 ± 2062	1127 ± 1092	0.414	0.105	0.766
Moderate-intensity PA (MET-min/week)	939 ± 1301	931 ± 1129	895 ± 1290	820 ± 1419	970 ± 1252	677 ± 753	0.828	0.725	0.890
Walking (MET-min/week)	1337 ± 1076	1031 ± 883	1250 ± 912	935 ± 940	1033 ± 894	1139 ± 1345	0.725	0.488	0.600
Sedentary behaviour (min/day)	241 ± 164	208 ± 124	223 ± 148	145 ± 70	136 ± 85	164 ± 83	0.473	0.055	0.651

*Significantly different from baseline ($p \leq .005$).
#Significantly different from 16 weeks ($p \leq .005$).
†Significantly different from the exercise training group ($p \leq .005$).
BMD: bone mineral density; BMC: bone mineral content; CTX: carboxy-terminal type-1 collagen crosslinks; HDL: high-density lipoprotein cholesterol; LDL: low-density lipoprotein cholesterol; OGTT: Oral glucose tolerance test; P1NP: procollagen type-1 amino-terminal propeptide; PA: Physical activity; RFD: rate of force development; VO_{2peak}: peak oxygen uptake; YYIE1: Yo-Yo intermittent endurance level 1 test.

P1NP/CTX delta values (16–36 weeks) were lower in EXG vs CG (1.5 ± 38.0 vs 57.8 ± 60.0; $p = .050$).

3.4. Metabolic health

A time-by-group interaction was observed for the 2-h oral glucose tolerance test (OGTT), though no within- or between-groups differences were found. Relative and absolute ($p = .008$) delta values were lower in EXG vs CG from baseline to 36 weeks (−3.5 ± 22.3 vs 26.0 ± 31.7% and −0.4 ± 1.2 vs 1.2 ± 1.5 mmol/L, respectively).

A time-by-group interaction was observed for HDL with EXG showing an increase at 36 weeks vs baseline (12%; $p = .005$; 95% CI: 5.30–18.31; $d = 0.62$) and vs 16 weeks (12%; $p < .001$; 95% CI: 7.08–17.14; $d = 0.79$). Additionally, relative ($p = .036$) and absolute ($p = .028$) HDL delta values were higher in EXG than CG from 16 to 36 weeks (12.1 ± 13.7 vs 1.1 ± 16.3% and 0.17 ± 0.22 vs −0.01 ± 0.23 mmol/L, respectively).

A time effect was shown for fasting blood glucose, TC, LDL and TC/HDL, TC/LDL and LDL/HDL ratios. EXG increased fasting blood glucose by 8% after 36 weeks vs 16 weeks ($p = .004$; 95% CI: 3.85–12.77; $d = 0.66$). EXG decreased TC (−5%; $p = .025$; 95% CI: −8.45; −2.05; $d = 0.64$), LDL (−10%; $p = .002$; 95% CI: −15.38; −5.58; $d = 0.84$), TC/HDL (−13%; $p < .001$; 95% CI: −18.51; −8.48; $d = 0.97$) and LDL/HDL (18%; $p = .001$; 95% CI: −24.59; −10.74; $d = 0.97$) and increased TC/LDL (7%; $p = .002$; 95% CI: 3.45–10.50; $d = 0.68$) after 36 weeks vs. baseline. Moreover, EXG decreased LDL (−8%; $p = .025$; 95% CI: −13.15; −3.57; $d = 0.62$), TC/HDL (−12%; $p < .001$; 95% CI: −16.60; −8.16; $d = 1.101$) and LDL/HDL (−17%; $p < .001$; 95% CI: −22.71; −11.57; $d = 1.165$) and increased TC/LDL (7%; $p < .001$; 95% CI: 4.30–9.28; $d = 1.02$) after 36 weeks vs. 16 weeks. Higher relative ($p = .012$) and absolute ($p = .009$) TC/LDL delta values (16–36 weeks) were observed in EXG vs CG (6.79 ± 6.79 vs 0.04 ± 8.84% and 0.11 ± 0.11 vs −0.01 ± 0.14, respectively).

Higher relative delta values (16–36 weeks) were observed in EXG vs CG for fasting plasma insulin ($p = .039$; 11.6 ± 37.3 vs −14.9 ± 28.6%).

3.5. Body mass and body composition

A time effect was observed for android fat mass with EXG showing a decrease at 36 weeks vs baseline (−7.0%; $p = .019$; 95% CI: −12.70; −1.28; $d = 0.46$), that was not different from week 16. Relative ($p = .030$) and absolute ($p = .025$) delta values from 16 to 36 weeks were higher in EXG vs CG (−3.2 ± 14.4 vs 4.0 ± 6.5% and −0.1 ± 0.3 vs 0.1 ± 0.1 kg, respectively).

A within-group decrement was observed in EXG for body mass after 36 weeks vs baseline (−2.0 ± 4.2%; $p = .027$; 95% CI: −3.56; −0.40; $d = 0.45$). The reported change was not different from week 16.

3.6. Physical fitness

A time-by-group interaction was shown for YYIE1 performance. YYIE1 values at baseline ($p = .050$), 16 ($p = .007$) and 36 weeks ($p = .004$) were higher in EXG vs CG. EXG improved YYIE1 performance by 78% ($p < .001$; 95% CI: 48.55–107.81; $d = 1.33$) after 36 weeks but was not different from 16 weeks. Relative and absolute delta values were higher in EXG than CG from baseline to 36 weeks (78.2 ± 77.9 vs 11.0 ± 45.3%; $p = .019$ and 183 ± 183 vs 4 ± 68 m; $p < .001$, respectively).

A time-by-group interaction was found for isometric knee extension peak torque. At 36 weeks, peak torque values in EXG were higher vs CG ($p = 0.038$). Baseline to 36 weeks relative and absolute increases were higher in EXG vs CG (8.2 ± 14.2 vs −4.3 ± 11.7%; $p = .010$ and 8.0 ± 13.9 vs −5.4 ± 13.3 N; $p = .007$, respectively). At 36 weeks, EXG increased peak torque by 8% and 6% vs baseline ($p = .008$; 95% CI: 2.89–13.45; $d = 0.579$) and vs 16 weeks ($p = .036$; 95% CI: 1.33–11.32; $d = 0.432$), respectively.

A time effect was observed for handgrip strength ($p = .010$) with EXG showing an increase at 36 weeks vs baseline (12%; $p = .004$; 95% CI: 3.38–20.66; $d = 0.67$) and 16 weeks (8%; $p = .023$; 95% CI: 2.22–13.13; $d = 0.544$).

Also, a time effect was shown for balance ($p = .011$). At 36 weeks, 31 ± 12 falls were registered for EXG, corresponding to eight less falls vs baseline ($p < .001$; 95%CI: −32.53;−2.94; $d = 0.87$), but it was not different from 16 weeks.

3.7. Training sessions' attendance, intensity and fun

The participants' mean training attendance was 2.0 ± 0.4 (1.9–2.2) sessions/week during the first 16-week period. In the following 20 weeks, the mean attendance decreased ($p < .001$) to 1.4 ± 0.5 (1.2–1.6) sessions/week. Cardiovascular training intensities and RPE for 16 and 36 weeks are presented in Table 3. There was an increase in mean HR and RPE ($p \leq .002$) between the 16 and 36-week periods, respectively. Fun levels were 8.3 ± 1.5 and 8.7 ± 1.1 (0–10, AU), for 16 and 36 weeks, respectively, with no differences between the time points.

4. Discussion

This randomised controlled trial (RCT) evaluated the effects of a 36-week recreational team handball-based

multicomponent training intervention on broad-spectrum health and physical fitness markers of inactive postmenopausal women. In general, although improvements in cardiorespiratory fitness (i.e. VO_{2peak}), aerobic performance (i.e. YYIE1) and in most of the health-related variables achieved after 16 weeks of training were maintained at 36 weeks, the 20-week extension of the training intervention resulted in further improvements in lipid profile markers and other physical fitness-related variables, besides YYIE1, compared to the short-term (16 weeks). Interestingly, these improvements were obtained despite a decrement in weekly training frequency from 2.0 to 1.4 sessions, during the last 20 weeks.

An interaction was shown for YYIE1 performance, isometric knee extension peak torque, 2 h OGTT blood glucose and HDL in favour of team handball training. As no changes were observed in daily PA and sedentary behaviour during the 36-week period for the exercise training group, the observed positive effects on health and fitness profile are related to the multicomponent training *per se*.

YYIE1 performance increased after 16 weeks and was maintained at 36 weeks in EXG, that showed higher values than the CG at both time points. Similar aerobic performance results were shown in postmenopausal women after playing floorball for 12 and 40 weeks (Seidelin et al., 2017) and in 20- to 43-year-old men playing football after 12 and 64 weeks (Randers et al., 2010), despite the decrease in training frequency from 12 to 40 weeks, supporting the positive effect of recreational team sports practice in aerobic performance in different populations. Being YYIE1 largely associated to VO_{2max} in untrained individuals (Castagna et al., 2020b), the increase in this aerobic performance-related parameter is of most importance, as VO_{2max} is inversely related to the risk of cardiovascular disease and all-cause mortality (Kodama et al., 2009), and low levels of physical fitness are one of the most important risk factors for cardiovascular diseases (Warburton et al., 2006).

Table 3. Cardiovascular training intensity and rating of perceived exertion during 16 and 36 weeks of intervention.

Variables		16 weeks mean ± *SD*	36 weeks mean ± *SD*
Mean heart rate	bpm	130 ± 14	134 ± 13*
	%	77 ± 15	79 ± 4*
Peak heart rate	bpm	151 ± 15	150 ± 14
	%	88 ± 4	88 ± 5
Time >80%HR_{max}	min	18 ± 9	17 ± 8
	%	46 ± 21	46 ± 22
Time >90%HR_{max}	min	5 ± 4	3 ± 4
	%	11 ± 10	9 ± 11
Rating of perceived exertion	Global	5.1 ± 1.7	6.6 ± 1.4*
	Respiratory	4.9 ± 1.4	6.9 ± 1.6*
	Muscular	4.8 ± 1.4	6.7± 1.6*

*Significantly different from 16 weeks ($p \leq .005$).
HR_{max}: maximal heart rate.

Regarding isometric knee extension peak torque, our data showed that 36 weeks of RTH not only prevented putative aging-related strength loss but, more importantly, increased lower body strength in postmenopausal women compared to the pre-training condition. Nonetheless, quadriceps RFD was unchanged, what is in accordance with results shown after one-year of football training for 68-year-old men (Sundstrup et al., 2016). Additionally, a decrease in lower body strength was observed in the CG (Pedersen et al., 2018; Sundstrup et al., 2016), which reinforces the role of recreational team sports in preventing aging-related strength loss. Moreover, an increase in isometric hamstring strength and RFD was observed in the football training group, which could be related with the nature of the high-intensity actions that stimulate this muscle (e.g. sprints) that occur in this sport (Sundstrup et al., 2016). Therefore, exploring the impact of RTH practice in strength improvement of different muscle groups, could also be of interest. Besides obvious benefits related to strength improvement on functional ability and decreased risk of falls, our data are important as lower muscle strength, but not muscle mass, is a predictor of mortality in older adults (Newman et al., 2006). As a decrease in muscle mass during menopause transition is reported in postmenopausal women, the increase in muscle strength promoted by RTH, irrespectively of an increase in muscle mass, seems to be extremely crucial. In fact, muscle strength, more than muscle mass, is considered the key factor for sarcopenia diagnosis, which is a muscle disease highly prevalent at older ages (Cruz-Jentoft et al., 2019), and so postmenopausal women at any time point. Interestingly, the combination of improved cardiorespiratory fitness and muscle strength, as opposed to the isolated improvement of each, is suggested as the most effective strategy to reduce all-cause and cardiovascular mortality risk (Kim et al., 2018). Moreover, the related increase in physical fitness would lead to improvements in global health status (Warburton et al., 2006).

Menopause might lead to serious changes in metabolism, predisposing women to diabetes, insulin resistance, and corresponding increased risk of impaired glucose tolerance over the years (Lambrinoudaki et al., 2022; Wu et al., 2001). Moreover, postmenopausal women are prone to increased TC and LDL and reduced HDL concentrations, which ultimately let them more susceptible to cardiovascular diseases (Saha et al., 2013). Thus, the interaction effect observed in some metabolic variables resulting upon this exercise programme must be highlighted. In fact, although low

HDL, high waist circumference as well as elevated fasting glucose levels are associated to metabolic syndrome, which has an increased prevalence after menopause (Marchi et al., 2017), the increase in HDL, together with a decrease in android fat mass observed in within-group differences (abdominal fat) might help to counteract and prevent this cluster of risk factors associated to cardiovascular diseases.

Within-group, but not between-group differences, were also shown in VO_{2peak}, lumbar spine BMD and BMC, P1NP, osteocalcin, fasting blood glucose, TC, LDL, body mass, android fat mass, handgrip strength and postural balance after 16 weeks, but without further improvements at 36 weeks of RTH. This lack of additional improvements at 36 weeks may indicate a need for higher training frequency, as 97% of the participants complied with two to three weekly sessions over the short-term, but only 42% complied with at least two sessions over the long-term. Nevertheless, it is important to note that the improvements obtained after 16 weeks were maintained at 36 weeks, which suggests that just one weekly 60-min session was sufficient to maintain the beneficial effects attained after two weekly training sessions over 16 weeks. This finding is of the most importance, since lack of time is one of the main barriers to exercise (European Comission, 2022). Therefore, further studies addressing the dose–response effects of RTH on physical and health-related outcomes may optimise training prescription regimens. Besides the potential impact of training frequency, intensity has also been considered an important physiological parameter associated to distinct outcomes in postmenopausal women (Kistler-Fischbacher et al., 2021). In fact, in recreational football practice, which working demands are similar to RTH, mean HR was >80% of HR_{max} and at least 10% of total time was spent >90% HR_{max} (Krustrup et al., 2010b), which is slightly higher that our study values. Short- and long-term recreation football-based interventions resulted in improvements in VO_{2max}, BMD, bone turnover markers, LDL, fat mass, and physical fitness, compared to a non-exercise group (Milanović et al., 2015; Milanović et al., 2019; Milanović et al., 2022). Therefore, higher exercise volume and/or intensity or eventually a higher sample sized (namely in the CG), might have been necessary to reach group differences in our study.

Volume and programme adherence are limitations of this study as training attendance decreased from 16 to 36 weeks (2.0 to 1.4 sessions/week) and the dropout in the CG was 21%. This clearly demonstrates the difficulty of keeping middle-aged/elderly participants in the interventions, especially in the CG. Nonetheless, the overall dropout in the EXG was only 16%, which is much lower than that observed in other exercise interventions (Milanović et al., 2019) and a potential evidence of the motivational advantage of RTH.

Taken together, data from this RCT study responds to the scarcity of long-term interventions using team sports apart from football and adds relevant knowledge to the literature on recreational team sports health-related outcomes. Moreover, it allowed to access health and physical fitness changes after long-term exposure to RTH, which was put in perspective in previous short-term studies using this exercise mode and population. Considering the injury incidence during the intervention (0.8 injuries/1000 h), RTH could be suggested as a safe and effective strategy to counteract postmenopausal health-related constrains. Our data only partially confirmed our hypothesis. In fact, only some, but not all or even most of the health and physical fitness improvements obtained after the first 16 weeks were further improved at the long-term (i.e. 36 weeks). Therefore, maybe due to the distinct "biological nature" of the physiological outcomes in analysis, still several issues should be put into question, regarding the definitive and optimal dose–response equation that would prompt adequate and sustainable general outcomes.

In conclusion, although we cannot be completely assertive regarding the truly impact of the exercise programme, due to the lack of between-group differences in some parameters after 36 weeks, the participants engaged in the programme improved physical fitness and lipid profile compared to the CG. Therefore, RTH may be considered a beneficial multicomponent exercise mode over the long-term for postmenopausal women.

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CHAPTER V

General Discussion

General Discussion

The main aims of this thesis were to describe the physiological and physical demands of RTH and to evaluate the effects of this exercise modality on health and physical fitness in inactive postmenopausal women without previous experience with the sport. The results of the original studies showed that RTH is a high-demanding exercise mode (original study I), that is able to induce positive adaptations in cardiometabolic (original studies II and IV) and bone health, in body composition (original studies III and IV) and in physical fitness (original studies II-IV) in this population.

The postmenopausal status is characterized by deleterious physiological and physical changes, namely at cardiovascular, bone and metabolic level as well as in body composition (Greendale et al., 2012; Greendale et al., 2019; Marchi et al., 2017; Rosano et al., 2007), predisposing women to adverse health conditions such as osteoporosis and to the development of CVDs, which, in fact are preponderant after menopause (Baber et al., 2016; Ji & Yu, 2015). Nonetheless the undeniable effect of exercise in improving general health (B. K. Pedersen & Saltin, 2015), women within the postmenopausal age range show low PA levels (European Comission, 2017). Lack of motivation has been identified as one of the main barriers to exercise (European Comission, 2022), and thus, to increase PA levels, the proposed exercise options need to meet the populations' interests. Indeed, the prospect of women adhere to exercise, namely as a treatment mode, is related with the ability to choose according to their preferences (Stojanovska et al., 2014).

A study involving 1693 menopausal women aged 46-55 years, aiming to investigate exercise preferences in this population, concluded that walking was the main choice, followed by dancing and swimming (Daley et al., 2011). The reasons why walking is pointed out as the main exercise choice could probably be related to its popular use in health-related campaigns, and also with the fact that it does not require specialized equipment or technical experience, being possible to be performed independently in any time schedule (Daley et al., 2011). Jogging/running, racquet sports and, curiously, team sports were the least

preferred (Daley et al., 2011). Nonetheless, it is of note that 35.5% of the responders in this study reported to complete at least 30 min of exercise for less than 1 time per week and 34.4% only 1-2 times per week (Daley et al., 2011). Thus, the results of this study must be analyzed with caution.

Rhythmic activities using large muscle groups (such as walking, swimming and dancing) are recommended for individuals with metabolic diseases and CVDs risk factors (American College of Sports Medicine, 2018). However, these activities have none or limited effects in bone mass, in which, exercises involving high forces and high impacts seem to be the most effective (Guadalupe-Grau et al., 2009). Moreover, even though walking and running result in similar reductions in the risk for developing hypertension, hypercholesterolemia, and diabetes (CVDs risk factors) if the energy expenditure is similar between both the exercise modes, running practitioners present lower risk for the conditions above mentioned than walking practitioners (Williams & Thompson, 2013). In fact, a faster pace during the exercise was associated with a lower risk of CVDs risk factors, which suggests an influential role of exercise intensity in health improvement and in diseases prevention (Williams & Thompson, 2013). Therefore, the activities that most women prefer may not be demanding enough to induce overall health improvements. In fact, the PA guidelines for both adult and older people include moderate and vigorous aerobic PA in different doses, and muscle-strengthening for additional benefits. Moreover, multicomponent PA, underlining functional balance and strength training, is also recommended as part as the weekly PA of older adults (Bull et al., 2020).

RTH is a multicomponent PA, that combines characteristics of the aerobic, strength and balance exercise. In 45-min RTH matches, ~2 km are covered mainly by walking, but also jogging, fast running and sprinting, resulting in mean HRs of ~79% HR_{max} (i.e., vigorous intensity) (original study I). Moreover, high-demanding actions, such as jumps, throws, stops and changes of direction, that possess the load characteristics to potentially stimulate positive musculoskeletal adaptations (Guadalupe-Grau et al., 2009), and different movement patterns that elicit postural balance, are also present when postmenopausal women practice this exercise modality. Furthermore, although the casuistic nature of RTH, the

intensity is consistent across the training sessions (original study I). Thus, RTH (two weekly sessions of 45-min RTH matches) can be suggested as a viable exercise option to improve postmenopausal women's overall health and to meet the PA guidelines. Nonetheless, team sports were pointed out as the least preferred activity by menopausal women (Daley et al., 2011). The reasons for this are unknown. Possibly the unawareness of interesting and suitability of team sports for this populations could be the reason.

RTH holds, at least in part, the same conditions reported for walking to be considered an appealing activity for menopausal women. Additionally, the rules can be adapted, making the game simple to understand and play. In fact, RTH is an easy to learn sport at any age, that can be performed by running or walking, and in which the main abilities involve throwing and catching a ball. Moreover, the equipment required to play RTH is only a ball and two goals, and the playing field can be any delimitated area. In RTH-based exercise programs dribbling should be avoided, which fosters teamwork and increases exercise intensity as the player is only able to perform 3 steps with the ball, thus requiring the collaboration of the team mates to move the ball towards the goal. In accordance, the physiological and physical demands are high during this exercise mode, even though the rating of perceived exertion reported is low (5.5 out of 10, AU) and the fun level is high (8.4 out of 10, AU) (original study I). At last, the non-dependence of others and from a time schedule to exercise were pointed out as positive characteristics of walking as a PA modality, however, the opposite (i.e., dependence of others and a fixed schedule) has been reported as an important promotor of higher compliance with exercise (Ottesen, Jeppesen, & Krustrup, 2010). In fact, participants involved in a football-based exercise program reported that having a set time and the feeling of mutual obligation with the team were determinant to fit the exercise program in their daily routine and to keep playing after the end of the intervention. On the other hand, the participants of individual activities, that do not join a group after the end of the intervention program, found it more difficult to fit exercise in their daily life (Nielsen et al., 2014). This means that the commitment of the participant with the team can possibly enhances its own adherence to exercise. Additionally, besides RTH being a team sport, the

game format played can be adjusted in order to meet the number of participants present in the training session (ranging from 3v3 to 7v7), while maintaining high working demands (Carneiro et al., 2022; Stojiljković et al., 2020). Thus, RTH not only seems suitable to meet postmenopausal women's interests, but also presents characteristics to be consider as a promising beneficial health-related strategy. These features are similar to those reported for recreational football (Krustrup et al., 2010), which has been proven to have a positive overall health effect in 18-65-year-old women (Krustrup et al., 2018).

In accordance to the previously mentioned arguments, our original studies II and III clearly emphasize the beneficial effects of RTH on postmenopausal women's health, namely in body composition, bone and cardiometabolic health and in physical fitness. Indeed, after 16 weeks of RTH practice, the participants increased peak oxygen uptake (VO_{2peak}; +7%), BMD (lumbar spine: +1.5%), BMC (lumbar spine: +2.3%; femur: +2.2%), bone turnover markers (CTX: +28%; P1NP: +38%; osteocalcin: +42%), aerobic performance (+70%) and balance (-5 falls), and decreased body mass (-1%), total cholesterol (-2.6%) and LDL (-2.3%) (original studies II and III). Since some of these variables are closely related to CVDs and osteoporosis (Al-Mallah, Sakr, & Al-Qunaibet, 2018; DeFina et al., 2016; Ji & Yu, 2015; Tandon et al., 2010), these improvements after only 16 weeks are of the most importance. It should be highlighted that cardiorespiratory fitness (VO_{2peak}) and aerobic performance values at 16 weeks were 10% and 88% higher, respectively, in RTH group compared to the control group.

CVDs are the major cause of morbidity and mortality in postmenopausal women (Baber et al., 2016), while high cardiorespiratory fitness is associated with reduced CVDs and all-cause mortality (Al-Mallah et al., 2018). Thus, the improvement shown in VO_{2peak}, which is the main outcome of the present research, is an important finding (original study II). Moreover, as dyslipidemia is a CVDs risk factor for this population, the reduction in total cholesterol and LDL after the RTH-based exercise intervention (original study II) reinforces the potential of this exercise program against CVDs.

An association between increased cardiorespiratory fitness levels and reduced risk for low bone density at the femoral neck in postmenopausal women

was previously reported (DeFina et al., 2016). In original study III, no changes were observed in femoral neck and femur BMD, though an increase in lumbar spine BMD was reported in RTH group. Additionally, the change in lumbar spine BMD observed in the RTH group after 16 weeks was significantly different from the control group (+1.5 vs. -0.6%). This supports the effect of RTH practice as a potential strategy that not only mitigates, but also counteracts the expected bone loss observed in postmenopausal women (Greendale et al., 2012). The positive effects in bone health were also shown in BMC and in bone turnover markers. An increase in bone content due to increased bone formation is an important contributor to BMD. Additionally, bone resorption is needed to allow the replacement of the old and fragile bone. To maintain bone mass, a balance between osteoclastic and osteoblastic activity is required (Eastell & Szulc, 2017). However, at postmenopausal status there is a tendency for a higher osteoclastic than osteoblastic activity, which leads to bone loss (Tella & Gallagher, 2014). Thus, the results from original study III are of relevance for this population, as an increase was shown in bone resorption marker CTX (+28%), which was accompanied by an increase in bone formation markers P1NP (+38%) and osteocalcin (+42%). Moreover, at 16 weeks, P1NP concentrations were higher in the RTH group than in the control group, and the relative changes observed in both bone formation markers (P1NP and osteocalcin) were higher in the RTH group when compared to the control group. Taken together, the improvement shown in bone health markers, cardiorespiratory fitness and lipid profile, underline the combined effect of RTH in counteracting osteoporosis and CVDs, which are critical in the postmenopausal status (Baber et al., 2016; Ji & Yu, 2015).

Osteoporosis is closely associated with osteoporotic fractures (Chen et al., 2018), which in turn, are associated with morbidity and mortality (The North American Menopause Society, 2021). Prevention of falls has been pointed out as an important approach to avoid fractures (The North American Menopause Society, 2021). Multicomponent exercise programs, that combine muscle strength and balance, emerge as main options to target falls reduction (Bull et al., 2020). An improvement in balance in the RTH group indicated by a decrease in the number of falls after the 16-week RTH-based exercise program was shown

in original study III. The absolute and relative beneficial change in postural balance observed in the RTH group (-5 falls; -7%) was significantly different from the control group (+3 falls; +16%). Thus, the combined effect of the RTH exercise program in improving BMD and balance is of the most importance.

An increase of 70% in aerobic performance evaluated by the YYIE1 was observed after 16 weeks of RTH training in postmenopausal women, resulting in a value 88% superior to that shown by the control group (original study II). YYIE1 performance has been shown to be associated with VO_{2max} in untrained recreational football players (Castagna, Krustrup, & Póvoas, 2020b). Cardiorespiratory fitness and balance, as well as flexibility and strength are components of physical fitness (Caspersen, Powell, & Christenson, 1985), which in turn, is associated with better health-related quality of life in postmenopausal women (Moratalla-Cecilia et al., 2016). Physical fitness declines from premenopause and from perimenopause to postmenopause status, however, women with high levels of PA have higher physical fitness compared with women with low PA levels, independently of the menopausal status (Bondarev et al., 2018). Thus, the combined improvement in physical fitness (namely aerobic performance and balance) and in the other health-related conditions already reported in postmenopausal women, after a short-term period of RTH practice, is of value.

Since the menopausal condition represents a significant part of women's lifetime, regular exercise practice at long-term is crucial. However, the long-term adherence to lifestyle-based health promotion interventions is challenging, and the engagement in regular exercise is not an exception (Middleton, Anton, & Perri, 2013). A 2-year study, with over 70-year-old women and based on an intervention involving walking and balance exercises, concluded that 71% of the participants regularly exercised during this period; however, less than 30% of the participants complied with the prescribed exercise program (≥150 min/week of walking and/or ≥2 days/week of balance exercises) (Findorff, Wyman, & Gross, 2009). In original study IV, that aimed to analyze the long-term adherence and health and physical fitness effects of RTH practice, 76% of the participants in the RTH group completed the 36-week intervention. The mean attendance

decreased from 2.0 ± 0.4 in the first 16 weeks to 1.4 ± 0.5 times/week in the following 20 weeks, which is below the instructed 2 times/week; however, 42% of the participants kept attending at least 2 sessions per week in the additional 20 weeks. The dropout and the attendance were limitations of this study. Nonetheless, this study showed that the positive cardiovascular and bone adaptations attained at 16 weeks were maintained at 36 weeks (VO_{2peak}: +9%; lumbar spine BMD: +1.4%; lumbar spine BMC: +2.6%; P1NP: +34%; osteocalcin: +29%; YYIE1: +78%; body mass: -2%; android fat mass: -7%; comparing to baseline), despite the decrease in attendance. Moreover, an improvement comparing to the 16 weeks was observed in HDL (+12%), LDL (-8%), peak torque (+6%) and handgrip strength (+8%). Considering that lack of time is the main barrier to exercise (European Comission, 2022), the results achieved after the additional 20 weeks with a decrease in mean attendance are of the most importance. However, it cannot be assumed that these results would be obtained without an initial 2 times/week period. In fact, a 16-week study aiming to analyze the dose-response health effects (1, 2 or 3 times per week) of a RTH exercise-based program in over 50-year-old-men, concluded that the volume of training seemed to be the main contributor for the health benefits, with greater improvements being observed in the 2 and 3 times/week exercise groups (Carneiro, Krustrup, Castagna, Mohr, et al., 2023; Carneiro, Krustrup, Castagna, Pereira, et al., 2023).

Apart from the health improvements, the risk of adverse events and the potential harms of participating in these exercise programs must also be addressed. In fact, the risk of injuries is also reported as a barrier to exercise (8% of the European population), particularly in 55-year-old or older people (13%) compared to younger populations (<25 years; 4%) (European Comission, 2022). Determining the safety of exercise programs for postmenopausal women is crucial, namely to prevent fractures related to fragile bones, typical in this population, and enhanced by falls (The North American Menopause Society, 2021). Albeit the nature of RTH (i.e., runs, changes of direction, jumps, among other high-intensity and impact actions) may suggest some potential fall and injury risk, it is also necessary for the improvement of cardiovascular and bone

health (American College of Sports Medicine, 2018; Guadalupe-Grau et al., 2009). Notwithstanding, no fractures or other severe injuries were reported during the exercise intervention in the present thesis. The number of falls resulting from RTH practice during the intervention would be of interest to analyze, however it was not registered, which represents a limitation of our study. During the first 16 weeks of the program, only one finger subluxation was reported, which even so, allowed the participant to complete the 16-week intervention. Thus, the injury incidence at 16 weeks was 0.8 injuries per 1000 h of exposure. During the additional 20 weeks, one participant suffered a finger subluxation and one participant reported shoulder pain. The shoulder pain occurred previously to the enrolment in the exercise program, however, it was aggravated during the practice. Taken together, this resulted in the dropout of the three participants due to injury during the additional 20 weeks of the exercise program. Nonetheless, the injury incidence remained at 0.8 injuries per 1000 h of exposure during the additional 20-week period. The use of a softer and lighter ball instead of a regular one, the continuous instructions on how handle the ball and the modified rules (such as no physical contact) could have potentiated the safety of the exercise program. Other aspects, such as a proper warm-up, a slow and progressive start-up period with adapted settings, such us fewer participants and smaller areas than the official version of the game, which were implemented during this intervention, were reported as possible enablers of injury risk reduction in a team sports-based exercise intervention (M. T. Pedersen et al., 2017). Therefore, these results seem to sustain the safety of this exercise program, which are in line with previous studies using RTH as exercise mode (Hornstrup et al., 2019; Hornstrup et al., 2018).

Unfortunately, it was not possible to compare the incidence of injuries in the present study with other using recreational team sports for postmenopausal women, as these data were not reported (Nyberg et al., 2014; Seidelin et al., 2017). A review aiming to analyze the exercise-related effect on bone markers in postmenopausal women and considering different exercise interventions (resistance training, impact training, combined resistance and impact training, low load weight bearing training, walking and water-based exercise) reported 11% of

injuries, expressed as the number of injuries/number of participants, related to the interventions implemented in 25 studies (Kistler-Fischbacher, Weeks, & Beck, 2021). Nevertheless, these data did not consider the total exposure. The most reported harms were muscle or joint pain and exacerbation of pre-existing joint pain. Our RTH intervention showed lower rate of injuries (2 and 7%, at 16 and 36 weeks, respectively). Another review aiming to analyze the exercise effect on health-related fitness in postmenopausal women considered 28 studies and reported ≤8% of injuries in only walking programs, ≤6% of injuries in most of the studies using aerobic exercise, 13% of injuries in low-intensity aerobic exercise and 23% of injuries in high-intensity aerobic exercise (one study), ≤3% of injuries in resistance programs, though 33% of injuries in a resistance-based exercise program lasting 1 year, and ≤19% of injuries in combined exercise programs (Asikainen et al., 2004). Even though these results provide some information about the injury incidence in exercise programs for postmenopausal women, it is not possible to compare the results, as the intervention duration and volume (weekly frequency) are not being taken into account. Thus, the hours of exposure must be considered in future studies, when reporting injuries. Moreover, note that in team sports the exposure is usually low (2-3 times/week of 40-60 min) (Castagna et al., 2020a; Milanović et al., 2022; Milanović et al., 2019) and taking the results of this thesis as example, it would be needed 12 years (2 sessions/week of 60 min, all year round) to sustain an injury.

Seven years after the end of the intervention program, 22 participants still play RTH regularly. A qualitative study aiming at examining the factors related to women's adherence to exercise after completing a structured exercise program, concluded that motivation, need for support and enjoyment were some of the most reported factors (Huberty et al., 2008). A study with a similar purpose (i.e., to explore why participants continued to exercise after completing a structured exercise intervention), involving middle-aged and older men, concluded that being part of a group encourages participants to continue to exercise regularly after the end of the intervention, suggesting the superiority of team sports over individual exercise in this matter (Nielsen et al., 2014). Factors such as the playful and enjoyable environment, skill development, social interaction and network

were associated to football practice as key aspects for continued participation (Nielsen et al., 2014). Additionally, participants in team sports-based interventions expressed higher levels of intrinsic motivation than participants engaged in individual exercises programs (e.g., running, CrossFit and resistance training), which seem to rely more on extrinsic motivation (e.g., expectation of improved health) (see Nielsen et al., 2014; M. T. Pedersen et al., 2017). Even though extrinsic motivation was referred as very important to start an exercise program, intrinsic motivation was indicated as a more important key factor to keep the participants engaged on it (Nielsen et al., 2014). The nature of team sports relies on social interaction (and to some extent, in peer support) and occurs in an enjoyable environment, both factors reported as contributors to motivation to exercise and thus assembling two of the reasons reported by women to adhere to exercise and to keep engaged on it at the long-term (Huberty et al., 2008; White, Ransdell, Vener, & Flohr, 2005). Taken together, this could explain why more than half of the initial group of the participants in our study (22 out of 41) still keeps playing RTH regularly after the end of the intervention and supports the argument that team sports are able to promote long-term adherence to exercise and emphasizes the suitability of team sports-based exercise programs as a powerful tool to counteract physical inactivity at the long-term in this population.

The studies comprised in this thesis are part of the Handball4Health project, which aims to describe the physiological and physical demands of RTH in different contexts; to determine the effects of RTH regular practice on the prevention and treatment of diseases related to inactive lifestyles in participants of different ages, both sexes, with and without previous experience with the sport; to promote, disseminate and implement this exercise modality as a means to promote health, physical fitness, and well-being in several populations; and to promote knowledge transfer, increasing awareness and understanding of the positive role of PA in health (http://www.panaf.gov.pt). The Handball4Health project was selected by the Intersectoral Commission for the Promotion of Physical Activity as one of the 21 first national-level initiatives to be included in "The Portuguese National Action Plan for the Promotion of Physical Activity", in

the Health area, that aims at increasing the PA levels of the Portuguese population (http://www.panaf.gov.pt).

The conclusions of these studies provide an important contribution to the scientific knowledge. The postmenopausal status is an inevitable condition in women's life, that once established is permanent. Additionally, the young women of today, will be the postmenopausal women of the future, and even though the ongoing efforts and action plans to decrease physical inactivity, the current scenario shows that the levels of physical inactivity are increasing and that also increase with aging (European Comission, 2017, 2022). Thus, this population group may well develop adverse health conditions associated to life-long inactivity, decrease of estrogen levels, and aging. Previous research also showed the positive effect of RTH practice in younger women's health (Hornstrup et al., 2020; Hornstrup et al., 2018), and thus, that playing RTH is advantageous also at an earlier stage of women's life. After the starting of this thesis, more research was developed in the context of RTH for health, namely the study of the effects of its practice in over 50-year-old men's health (Carneiro, Krustrup, Castagna, Mohr, et al., 2023; Carneiro, Krustrup, Castagna, Pereira, et al., 2023). Taken together, the research with young men and women, adult/middle-aged men, over 50-year-old men and postmenopausal women supports that RTH practice promotes health, and that it appears to be feasible and effective for broad range of participant groups, across age and gender.

CHAPTER VI

Conclusions

Conclusions

The results of the original studies in the present thesis led to the following conclusions:

1. RTH is a high-intensity and high-demanding exercise modality, with mean and peak HRs of 76-79%HR_{max} and 88%HR_{max}, respectively, and high demanding actions such as, throws, stops, changes of direction, accelerations, and decelerations. The rating of perceived exertion is reported as hard to very hard, ranging from 4.8 to 6.6 (AU; 0-10 scale), while the fun is high (8.4 AU; 0-10 scale). These characteristics point out the potential of this exercise mode to induce cardiovascular, metabolic and musculoskeletal adaptations, and to enhance physical fitness in postmenopausal women, and to promote long-term adherence to PA.

2. Short-term (16 weeks) RTH training was able to improve cardiovascular (VO_{2peak}), metabolic (total cholesterol, LDL), and skeletal health profile (lumbar spine BMD and BMC, femur BMC, CTX, P1NP and osteocalcin) and physical fitness (aerobic performance and postural balance) in inactive postmenopausal women without experience with the sport.

3. After an additional period of 20 weeks, most of the results previously achieved at 16 weeks were maintained (VO_{2peak}, lumbar spine BMD and BMC, P1NP, osteocalcin, aerobic performance), whereas lipid profile (HDL and LDL) and strength (isometric knee extension peak torque and handgrip) were further improved.

4. RTH was shown to be an effective, feasible and safe exercise mode to improve the general health profile and physical fitness in postmenopausal women and to keep them engaged in exercise at the long-term.

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