POTENTIAL BENEFITS OF STRENGTH TRAINING FOR PEOPLE LIVING WITH OBESITY

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A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of

Doctor of Philosophy

In the Graduate Academic Unit of Interdisciplinary Studies

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This Dissertation is accepted by the
Dean of Graduate Studies

THE UNIVERSITY OF NEW BRUNSWICK

December 2022

Abstract

Being physically active is linked to health benefits no matter what size one is and regardless of weight loss for people living with obesity. Many barriers exist to meeting the physical activity guidelines and even more, if living with obesity. Compared with aerobic activities, such as walking, the health benefits of muscle-strengthening activities or the combination of both modes of activities may offer unique benefits for individuals living with obesity regardless of weight loss. However, sex differences are not well understood, and strategies to encourage people living with obesity to regularly participate in aerobic and muscle-strengthening activities need to be tested. The objectives of this thesis include threefold. First, we aimed to test the benefits of meeting the muscle-strengthening activity guidelines in people living with obesity and the role of sex in body fat percentage and mortality using a secondary study involving 3915 people living with obesity. We reported that meeting muscle-strengthening activities guidelines was associated with lower body fat (β: -0.78) ($p<0.001$) but not mortality (Hazard Ratio: 0.911) ($p=0.615$) in people living with obesity; however, it did not affect men and women differently. Second, we tested if a 12-week circuit strength training program performed in a fitness facility could reach moderate aerobic intensity for a single session and explore the potential benefits, for individuals living with obesity. We reported that participants reached moderate intensity ($40\% \leq$ heart rate reserve), regardless of the indicator used to quantify the intensity. Finally, we tested if the same circuit strength training program offered online without specialized equipment could increase adherence to both components of physical activity guidelines (aerobics and muscle-strengthening) in men living with obesity compared with a control group after 46 weeks. Our results indicated that a 12-week online circuit program led a

significant proportion of men living with obesity (36.8%) to adhere to both components of physical activity guidelines after 46 weeks. However, expected improvements in physiological outcomes were not observed. Altogether, this dissertation highlights some benefits of muscle-strengthening exercises for both men and women living with obesity.

Dedication

To My Homeland, **IRAN**

Acknowledgements

I would like to sincerely thank you, ***Dr. Danielle Bouchard*** for all of your endless supports throughout the entire program. Great advice and the thoughtful discussions you provided inside and outside of research. Thank you for answering my email in April 2017, giving me the chance to change my life, for being my teacher.

Special thanks to you ***Hassan***, for all your supports and being a reliable life friend.

And you, ***Keara Grey***, I was very fortunate that I met you in my life, thank you for everything.

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CHAPTER 1: INTRODUCTION

1.1 Physical activity

Physical inactivity is a key challenge for public health in the 21st century [Blair 2009] and a primary cause of most chronic diseases [Booth, Roberts and Laye 2012]. The number of global death caused by chronic diseases increased from 28 million in 1990 to 36 million in 2008 and 39 million in 2016 [Anderson and Durstine 2019]. According to the World Health Organization (WHO) 2020 guidelines, health and other key sectors must increase their investment and priority in services that promote physical activity [Bull et al. 2020]. To achieve a comprehensive and coherent public health action, WHO recommends all countries set national guidelines on physical activity targets.

1.1.1 Physical activity recommendations

International health organizations such as the American College of Sports Medicine (ACSM) and the Canadian Society for Exercise Physiology (CSEP) regularly present evidence-based position statements for physical activity guidelines. The goal is to offer clinical practice recommendations to customize physical activity prescriptions for individuals of different ages and conditions. In Canada, the current physical activity guidelines for adults were developed to reduce premature death, coronary heart disease, stroke, hypertension, colon cancer, breast cancer, type 2 diabetes, osteoporosis, and improve fitness, body composition, and mental health indicators [Tremblay et al. 2011]. The new Canadian 24-hour movement guidelines represent an integrated recommendation for physical activity, sedentary behaviour, and sleep. In terms of physical activity, the recommendation is to complete a minimum of 150 minutes weekly of moderate to vigorous intensity of aerobic activities in addition to a minimum of two days of muscle-

strengthening activities; However, several hours of light physical activities, including standing, are also recommended [Ross et al. 2020]. Specific to older adults (65+), the guidelines were developed to maintain functional independence. It is recommended to add mobility activities if judged needed. In the United States, new guidelines were released in 2019 after an extensive literature review. Generally, the guidelines recommend adults do at least 150 minutes (2 hours and 30 minutes) to 300 minutes (5 hours) of moderate-intensity aerobic activities in a week plus two or more days of strengthening exercises targeting major muscle groups. For older adults (65+), multicomponent physical activity, including balance training, is recommended [NIH 2019].

According to the evidence, muscle-strengthening activities and aerobic activities are included in physical activity recommendations due to their unique and/or cumulative health benefits [Garber et al. 2011]. Aerobic activities mainly lower the risk of cardiovascular disease [Lee et al. 2012], diabètes [Aune et al. 2015], colon/breast cancer [Moore et al. 2016], depression [Mammen and Faulkner 2013] and cognitive decline [Beckett, Ardern and Rotondi 2015]. In comparison, there are fewer data available on the epidemiology of muscle-strengthening activities, which is correlated with increased muscle strength and bone health [Zehnacker and Bemis-Dougherty 2007], ability to perform daily living activities/ reduced risk of falls [Liu and Latham 2009] and improved glucose/lipid metabolism [Ashton et al. 2020].

1.1.2 Measurement of physical activity

There are different ways to capture the amount of physical activity. An objective measure is an impartial measurement with less bias, which results in greater accuracy [Kowalaki et al. 2012]. On the other side, a subjective measure is influenced by personal

judgement of how the measurement is performed; therefore, open to interpretation or opinion [Boisvert et al. 1988]. A subjective measure is usually in the form of a questionnaire. Self-reported physical activity is one of the most popular forms of collecting information on physical activity obtained in large samples [Prince et al. 2008]. Although not highly correlated and less reliable than objective measures, the benefits of this form of data collection include ease of administrating and low-cost value [Prince et al. 2008].

The self-reported questionnaire is the most commonly used method to collect information on an individual's muscle-strengthening activities. Muscle-strengthening activities tend to be a single question in a questionnaire normally asked: "Over the past days, how often did you do exercises especially to increase muscle strength or endurance, such as lifting weights or push-ups?" [NHANES 2013]. Exercise intensity classification is also an issue when administering a questionnaire; participants' high, moderate, and low resistance is not well understood, which can result in inaccurate classification [Shephard 2003]. Despite the problems associated with questionnaires, there is value in this method of testing muscle-strengthening activities; for example, in showing where increased activity would be beneficial and in monitoring changes in physical activity populations.

1.1.3 Mode of physical activities

The two main categories of exercise are aerobic and strength training. Both aerobic and strength training promotes significant health benefits [Dishman 1988]; however, the benefits are often different. Aerobic training is more important in terms of cardiopulmonary improvements, such as $\dot{V}O_{2max}$, and effectively modifies cardiometabolic risk factors [Pollock and Evans 1999]. On the other hand, strength training improves neuromuscular adaptations that increase absolute strength, even without significantly changing $\dot{V}O_{2max}$

[Lambert and Evans 2005]. Metabolic responses to strength training, such as stimulation of metabolic rate, fat oxidation after exercise, and the enhancement of muscular protein balance, may justify the benefits of strength training on body composition [Villareal et al. 2017]. Pollock et al. (2000), in a review paper endorsed by the ACSM, compared the effectiveness of aerobic training and strength training in a variety of physiological benefits [Pollock et al. 2000] (Table 1-1).

Table 1-1. Comparing the effects of aerobic training and strength training [Pollock et al. 2000]

Variable	**Aerobic**	**Strength**
% Fat mass	↓↓	↓
Lean body mass	↔	↑↑
Muscle strength	↔	↑↑↑
Bone mineral density	↑↑	↑↑
Insulin sensitivity	↑↑	↑↑
Basal insulin levels	↓	↓
High-density lipoprotein	↑↔	↑↔
Low-density lipoprotein	↓↔	↓↔
Systolic blood pressure	↓↔	↔
Diastolic blood pressure	↓↔	↓↔
Cardiorespiratory fitness	↑↑↑	↑↔
Basal metabolism	↑	↑↑

↑ Indicates values increase; ↓, values decrease; ↔, values remain unchanged; ↑ or ↓, small effect; ↑↑ or ↓↓, medium effect; ↑↑↑ or ↓↓↓, large effect

As shown in Table 1-1, it seems the most significant difference between aerobic training and strength training adaptations include fat mass, lean body mass, muscle strength, $\dot{V}O_{2max}$, and resting metabolic rate.

Studies indicate that adherence to both aerobic activities and muscle-strengthening activities reduces the risk of mortality compared with meeting only one component of the guidelines [Stamatakis et al. 2018, Tarasenko, Linder and Miller 2018]. Bennie et al. (2020) reported that meeting both aerobic and muscle-strengthening activities guidelines were associated with better cardiometabolic outcomes than meeting either of those in a sample of ~10,000 Korean adults. Although both aerobic activities and muscle-strengthening activities are globally recommended, few public health surveillance data are available on the epidemiology of meeting both aerobic activities and muscle-strengthening activities guidelines as opposed to just meeting aerobic activities guidelines. For example, estimates from 2016 National Health Interview Survey data in the U.S. [Katzmarzyk et al. 2017] reported that fewer than 22% of adults meet both aerobic activity and muscle-strengthening activity guidelines. The compliance was even lower for people living with obesity in the U.S. (13.5%) [Harris et al. 2013].

1.1.3.1 Circuit strength training

Over recent years, a new method of strength training named "circuit strength training" has played a significant role in clinical research. Circuit strength training is a type of exercise that combines aerobic and muscle-strengthening activities to reap all possible benefits. Although there are many forms of circuit strength training, common characteristics include the performance of a high volume of repetitions with light resistance and little, if any, rest between exercises [Trynecki 1999]. Circuit strength training is a physiologically demanding exercise [Gotshalk, Berger and Kraemer 2004]. Circuit strength training can lead to a variety of physiological adaptations and benefits. Based on the scientific evidence, the most cited physiological adaptations resulting from circuit

strength training are improving body fat % [Bocalini et al. 2012], muscle strength [Romero-Arenas et al. 2013], cardiorespiratory adaptations [Brentano et al. 2008, Takeshima et al. 2004] and cardiometabolic markers [Hazley et al. 2010, Nash et al. 2001, Paoli et al. 2013]. Considering physiological responses, circuit strength training could be a single form of exercise that fulfills standard recommendations for both aerobic and strength training [Gettman and Pollock 1981, Jacobs, Nash and Rusinowski 2001, Kaikkonen et al. 2000].

1.1.3.2 Online-delivered exercise programs

As internet access has increased and many telecommunication devices (e.g. smartphones, tablets) have become more omnipresent, health programs delivered through the internet have multiplied over the past two decades [Srikesavan et al. 2019]. Numerous studies have indicated that web-based health programs improved health outcomes for people with chronic conditions, including cardiovascular disease, diabetes, chronic obstructive pulmonary disease, and cancer [Nunan et al. 2013, Robinson et al. 2019, van Beugen et al. 2014].

In March 2020, the World Health Organization declared the Covid-19 disease pandemic. As a result, countries responded by introducing public health measures such as lockdowns, quarantine and social distancing [Nussbaumer-Streit et al. 2020]. According to the statistics, in 2020, the general population's recreational physical activities were significantly reduced during the Covid-19 pandemic [Stockwell et al. 2021]. This is significant, considering the low rate of physical activity levels in developed countries even before the pandemic [Finger et al. 2017] and the fact that physical activity plays a key role in reducing risk factors for chronic conditions [Booth et al. 2017].

Before the beginning of the Covid-19 pandemic, online programs were already appealing as they are cost-effective [Nobis et al. 2013] and time-efficient [Mitchell et al. 2018]. People's interest in online programs grew even more during the pandemic as they can be implemented in a private space with no risk of Covid-19. A survey of 10,433 participants (age 38.4±8.4; women 58.9%) indicated that over 68% of respondents were interested in web-based exercise programs during the Covid-19 pandemic [Wilke et al. 2020]. In a cross-sectional study, Parker et al. 2020 examined the relationship between digital platforms and meeting physical activity guidelines among Australian adults and adolescents during the Covid-19 pandemic. Digital platforms included streaming services, live/recorded exercise classes, active electronic games and subscriber fitness programs. Their findings showed that, when access to facilities is limited, adherence to the guideline related to aerobic activity and muscle-strengthening was higher among digital platform users (odds ratio (OR) = 2.7, 95% CI 2.0-3.8) relative to their non-user counterparts [Parker et al. 2021]. Online-delivered programs that could even be performed at home/workplace could address barriers to engaging in physical activity programs as they are effective, flexible, and cost-effective [McGuire et al. 2019]. The benefits of digital programs could be even greater for people living with obesity as they could address their specific barriers, such as weight stigma [Thedinga, Zehl and Thiel 2021].

1.1.4 Barriers

There are reasons why people do not engage in regular exercise as they need or wish. Low personal priority, lack of confidence, lack of knowledge and difficulty finding time are among the reasons referred to as perceived exercise barriers [Lox, Martin and Petruzzello 2003]. Barriers can be defined as objective (e.g., disease, injury, inaccessible

facilities for physically disabled persons) or perceived (e.g., lack of time) [Pender, Murdaugh and Parsons 2006]. Barriers can have direct (e.g., lack of exercise facilities in the community) and indirect effects on positive behaviour change, primarily by reducing motivation or commitment [Pender, Murdaugh and Parsons 2006]. Barriers play an important role in engaging in physical activity programs [Buckworth and Dishman 1999].

Among all individuals, those who are living with obesity are at increased risk of cardiometabolic diseases [Zalesin et al. 2008], show high levels of inactivity [Adams et al. 2003] and experience many barriers to participating in regular physical activity [Joseph et al. 2019]. Considering the growing trends of obesity worldwide [WHO 2021], researches in the past decades have focused on the benefits of physical activity for individuals living with obesity.

1.2 Why targeting people living with obesity?

1.2.1 Obesity

The Obesity Medicine Association defines obesity as "a chronic, relapsing, multifactorial disease where an excessive amount of body fat causes adipose tissue dysfunction and could result in chronic metabolic, biomechanical, and psychological impairments" [Fitch and Bays 2022, page 1). Obesity has reached epidemic proportions, spreading globally within a short period of time [Kopp 2019]. Worldwide, the United States showed the most significant increase in the rate of obesity from 1999–2000 through 2017–2018, increasing from 30.5% to 42.4% in the adult population [NCHS 2020]. Between 1975 and 2016, the worldwide prevalence of obesity almost tripled, with over 650 million people over the age of 18 years living with obesity [NCHS 2020].

In Canada, significant changes in the rate of obesity have taken place too. In 2018, over 26% (about 7.3 million) of the Canadian adult population was classified as living with obesity [Statistics Canada 2018]. An additional 9.9 million adults (36.3%) were classified as overweight – bringing the total population with increased health risks due to excess weight to 63.1% [Statistics Canada 2018]. Among provinces of Canada, New Brunswick had the highest obesity rate; in 2017, Statistics Canada released annual estimates showing that 38% of adults in New Brunswick were classified as living with obesity; as a consequence, 61% of New Brunswickers are reported to have at least one obesity-related chronic health conditions I[Statistics Canada 2018]

1.2.1.1 Atheology of obesity

It is well-accepted that obesity results from an energy imbalance caused by multiple factors, including a lack of physical activity and increased energy intake [Shah and Cheung 2019]. The contribution of energy intake to a positive energy balance is emphasized in the atheology of obesity [Mattes 2014]. On the other hand, regular physical activity and diet are recognized as strategies for obesity management [Volek, VanHeest and Forsythe 2005].

Studies show sociodemographic elements, such as household income, education, and occupational status, play an extensive role in obesity prevalence [Fowler-Brown et al. 2010, Wang and Zhang 2006]. A low socioeconomic status can impact someone's behaviour and, thus, may result in a greater prevalence of obesity [Drewnowski 2009, Sobal and Stunkard 1989]. The community environment can have an impact on obesity prevalence. Areas with a cluster of shops, coffeehouses, perhaps galleries and bookstores, which encourage walking and exploring, could be an advantage when it comes to physical activity [Cerin et al. 2007]. Walkable neighbourhoods encourage physical activity, and,

subsequently, residents are likely to have a lower BMI [Moudon et al. 2006, Rundle et al. 2007, Saelens et al. 2003].

Age and genetics affect body weight throughout a lifetime [Hughes et al. 2002]. The rate of obesity increases with age, peaking in the sixties, then begins to decrease [El-Hazmi and Warsy 2002]. A decline in energy expenditure due to age has partially explained this increase [Lovejoy, Sainsbury and Group 2009]. Hormonal imbalance contributes to obesity and could derive from gene impairment and health conditions [Butler 2016].

Some health conditions and certain medications, such as anti-depressants [Schwartz et al. 2004], can dysregulate hormones and result in weight changes and obesity [NIH 2012]. According to clinical cohort studies, other lifestyle factors, such as stress, emotional factors, and poor sleep, can also impact weight [Jääskeläinen et al. 2014, Vgontzas et al. 2014]. It should be noted that all factors contributing to the atheology of obesity influence either energy intake and/or expenditure [Mattes 2014].

1.2.1.2 Common conditions associated with obesity

Diabetes mellitus. Obesity is associated with an increased risk of insulin resistance and therefore type 2 diabetes or diabetes mellitus. Most individuals with obesity have an impaired adipose tissue function, leading to adipocyte hypertrophy, hypoxia, stresses, and inflammatory processes within adipose tissue [Blüher 2009]. In people living with obesity, adipose tissues tend to increase glycerol levels, pro-inflammatory cytokines, non-esterified fatty acids, and some hormones, all contributing to insulin resistance [Kahn, Hull and Utzschneider 2006]. Insulin resistance along with beta- cells dysfunction, could fail to

regulate blood glucose levels and ultimately lead to type 2 diabetes [Kahn, Hull and Utzschneider 2006].

Cardiovascular diseases. Obesity contributes to mechanical failure of the cardiac system through different pathways. Hormonal dysregulation and increased systematic inflammation due to obesity lead to insufficient ejection fraction (the amount of blood the left ventricle pumps out with each contraction) and, ultimately, heart failure [Glezeva and Baugh 2014]. Excessive regional adipose tissue affects myocardial perfusion through capillary ramification, potentially contributing to myocardial infraction [Pandey et al. 2018]. Moreover, a high amount of regional adipose tissue, such as visceral adipose tissue in people living with obesity, seems to impact exercise tolerance and increases the risk of heart failure during physical activity [Haykowsky et al. 2018].

Hypertension, a common chronic condition in people living with obesity [Zhang et al. 2019], is another cardiovascular disease resulting from excessive body weight [Sun et al. 2007]; the influence depends on the history of obesity and fat distribution [Hall et al. 2015]. The mechanism of obesity-related hypertension results from several endothelial, hormonal and inflammatory alternations, leading to hypertension [Seravalle and Grassi 2017]. Although not well studied as cardiovascular diseases and diabetes, evidence shows that obesity can contribute to damage to the musculoskeletal system [Godziuk et al. 2018]. Obesity is associated with the progression of musculoskeletal disorders such as low back pain [Shiri et al. 2010], gait disturbance [Cau et al. 2014], osteoporosis [Roy et al. 2016], and fibromyalgia [Cheema, Chang-Miller and Aslam 2019]. Both metabolic and mechanical factors play a role in developing obesity-related musculoskeletal disorders [Wearing et al. 2006].

A high load on the musculoskeletal system could lead to stress in connective structures such as bones, joints, and soft tissues [Wearing et al. 2006]. Metabolic factors, on the other hand, can play a role in musculoskeletal disorders; for example, excessive adipose tissue as a result of obesity is a source of proinflammatory cytokines [Kang et al. 2016]. Proinflammatory cytokines alongside extra mechanical load resulting from obesity may contribute to the pathogenesis of osteoarthritis [Gualillo 2007]. Abnormally elevated inflammation as a result of high levels of proinflammatory cytokines can increase the risk of obesity-related cancer [Harvey, Lashinger and Hursting 2011]. Epidemiological studies show that obesity increases the risk of several cancers, including colon, endometrium, postmenopausal breast, kidney, pancreas and liver [Fund and Research 2007, Lichtman 2010]. Excessive body weight can increase the risk of obstructive sleep apnea, a common sleep disorder in which breathing repeatedly stops and starts overnight. Obstructive sleep apnea is associated with obesity [Gami, Caples and Somers 2003]. Episodes of hypoxemia/apnea can drop the oxyhemoglobin saturation from 95% to 80%, depending on the length of the period of apnea [Jehan et al. 2017]. Obesity has also been associated to many mental disorders; however, obesity-related psychological distress are relatively less explored compared to physical conditions. In a systematic review, Rajan and Menon (2017) reported that depression was the most significant psychological issue associated with obesity; these effects were mediated by gender. Mechanisms suggested for obesity-induced depression would be partially related to negative self-perceptions and weight stigma [Zhao et al. 2009].

1.2.2 Importance of physical activity regardless of weight loss

There are many studies suggesting that regular physical activity could attenuate obesity health consequences despite having extra body weight – termed the 'fit and fat' concept [McAuley et al. 2009, McAuley and Blair 2011, Wei et al. 1999]. In a study by Dankel et al. (2016), the data of 11,057 adults in the U.S. were evaluated. There were eight groups in the study based on physical activity and BMI categories. After adjustments for potential confounders, only inactive groups were at significant risk for all-cause mortality independent of their weight status. Their evidence supports the fact that clinicians need to promote physical activity among all individuals regardless of body mass status [Dankel, Loenneke and Loprinzi 2016].

In addition, there is evidence showing that exercise without weight loss significantly improves health outcomes such as aerobic capacity, blood pressure, waist circumference, and positive mood [King et al. 2012]. To be clear, it is possible to achieve a significant weight loss by exercising more, without diet modification; however, it is simply harder than the popular belief. For example, Ross et al. (2000) and Ross et al. (2004) reported that for both males and females, significant weight loss could be achieved by walking 45 to 60 minutes per day, seven days a week for three months as much as cutting 500 kcal per day for the same period [Ross et al. 2000, Ross et al. 2004]. Still, the effort is commendable but not realistic for most people living with obesity [Ross et al. 2004]. Miller et al. (1997) conducted a meta-analysis of 25 years of weight loss research and indicated that caloric restriction appears to have a more significant and consistent effect on weight loss than physical activity alone, potentially because of the greater possibility of creating an energy deficit. . One potential reason why the diet could be more important than exercise to

achieve significant weight loss could be because people tend to eat more after exercising (i.e., compensatory response), and therefore reduce the net energy spent. It seems there are physiological, psychological and behavioural factors that play a role in the association between exercise and appetite [King et al. 2012]. In a systematic review, Riou et al. (2015) indicated a significant variability in energy compensation after exercise, ranging between 18% ± 93%. Their analysis showed that 48% of the variability of energy compensation could be explained by initial fat mass, age and duration of exercise interventions, while sex, frequency, intensity and dose of exercise were not significant predictors of energy compensation. Furthermore, the mode of exercise might also be important when using exercise as a strategy for weight loss. For example, implementing a high dose of weekly aerobic physical activities could significantly reduce BMI in individuals living with obesity [Donnelly et al. 2013, Irwin et al. 2003, Jakicic et al. 1999, King et al. 2008, Ross et al. 2000, Ross et al. 2004], but the same might not happen for people utilizing strength training as the mode of exercise [Church et al. 2010, Schmitz et al. 2007].

The ACSM position stand states that between 150 and 250 minutes of moderate to vigorous physical activity per week is required to prevent weight gain; however, this amount of time for people attempting to lose weight and those who want to avoid weight gain after weight loss is between 225 and 420 minutes and 200 and 300 minutes per week, respectively [Swift et al. 2014]. According to these guidelines, engaging in a minimum level of recommended exercise (150 min/week) would not be a plausible way for weight loss aimed at treating obesity. People living with obesity are asked to perform exercise regardless of weight loss for health reasons. The following table (Table 1-2) below

summarizes recommendations and suggestions for weight loss/maintenance using weekly exercise as an only intervention.

Table 1-2. Amount of aerobic physical activity and expected weight loss Adapted from ACSM [Swift et al. 2018]

Aerobic physical activity amount	Weight loss amount (8 weeks)
<150 min per week	No weight loss or minimal weight loss
150-225 min per week	Weight loss of 2 to 3 kg
225-420 min per week	Weight loss of 5 to 7.5 kg
200-300 min per week	Weight maintenance after weight loss

According to the international physical activity guidelines, strength training does not play a significant role in weight loss [Swift et al. 2014]. It appears that strength training alone is unlikely to lead to enough negative energy balance to result in a significant weight loss compared to aerobic exercise [Willis et al. 2012]. Potential gains in lean mass because of strength training also might attenuate weight loss [Olson et al. 2007, Willis et al. 2012]. People living with obesity who only participate in strength training may see favourable changes in body composition [Schmitz et al. 2007] and other health benefits [Schjerve et al. 2008], but not necessarily weight loss. In a review paper, Swift et al. (2018) reported the data evaluating the impact of types of physical activities on reducing weight. According to Swift et al. (2018), it is important to underline health outcomes resulting from exercise in people living with obesity rather than weight loss [Swift et al. 2018]. As suggested by [Ross and Janiszewski 2008], many health benefits such as waist circumference, visceral fat and cardiometabolic risk factors are associated with exercise regardless of weight loss.

Table 1-3. Expected weight loss different types of exercise programs [Swift et al. 2018]

Exercise type	Expected weight loss	Obese to non-obese status
Aerobic exercise training only	0 to 3%	Possible, but only with high exercise volumes
Strength training only	0 to 1%	Very unlikely
Aerobic and Strength training	0 to 3%	Possible, but only with high volumes of aerobic exercise training

1.2.2.1 Circuit strength training for people living with obesity

The evidence for potential health benefits and practical applications of circuit strength training suggests that circuit strength training can be offered as a potential training method for people living with obesity. There is limited literature about the benefits of circuit strength training for people living with obesity. In a meta-analysis, Seo et al. (2019) evaluated the effectiveness of circuit strength training programs on weight loss in adults. A total of nine randomized controlled trials with primary bodyweight outcomes were included in their study. The weighted mean difference was estimated using the random-effect model with a 95% confidence interval. Circuit strength training programs significantly affected body weight (−3.81 kg 95% CI 5.60 -2.02 kg); however, further analysis indicated that programs led to significantly reduced weight only in individuals living with obesity (MD = −5.15 kg, 95% CI −8.81 to −1.50) but not healthy weight (MD = −2.38 kg, 95% CI −7.07 to 2.32). Programs consisting only of circuit strength training significantly reduced weight (MD = −5.12 kg, 95% CI −7.11 to −3.12) compared to circuit training combined with other lifestyle programs (MD = −2.17 kg, 95% CI −4.82 to 0.47).

Previous studies from Dr.Bouchard's laboratory have indicated that strength training can be designed to increase moderate aerobic intensity based on heart rate [Bharti et al. 2017, Hrubeniuk et al. 2014]. Individuals with BMI ≥25 kg/m^2 could reach about 90% of the exercise time at moderate aerobic intensity while performing strength training using weight machines [Bharti et al. 2017]. Although these findings could provide a rationale for using strength training-based exercise programs to contribute to aerobic activities for individuals who are overweight, there is currently a lack of research investigating accurate measures for aerobic intensities while performing circuit strength training in individuals living with obesity; for example, the association between heart rate and oxygen consumption has been questioned in the past [Fletcher et al. 2001, Jansen, Schmidtbleicher and Cabri 2007], which could be important as health benefits are achieved due to an increase in cardiorespiratory fitness [Knuttgen 2007]. Overall, considering the benefits of circuit strength training could potentially play a significant role in obesity management not only by addressing some potential barriers to engaging in exercise in individuals living with obesity but also by meeting the physiological benefits of both aerobic activities and muscle-strengthening activities.

1.2.2.2 Enablers and barriers to exercise for people living with obesity

Among the numerous enablers and barriers related to exercise adherence for the general public, weight stigma, personal organization, physical capacity, and social support [Dugdill, Graham and McNair 2005, Williams et al. 2007, Williams 2009] are amplified for people living with obesity and perhaps are different for men and women. Although obesity prevalence is high for both men and women, more lifestyle modification studies have been conducted in women living with obesity. Therefore, more knowledge is

available in this population [Gavarkovs, Burke and Petrella 2016]. This is mainly driven by the lack of interest in programs for men [Wirth et al. 2014] or barriers such as gender preferences [Ross et al. 2012]. It seems consistent factors play a role in men's adherence to lifestyle and exercise programs. Psychosocial aspects and past experiences, along with using men-designed program features and men-specific recruitment strategies, are among the most cited elements.

The location and setting of a weight management program can act as a "hook" to catch men. Based on men's experiences of workplace-based programs, performing the program in a workplace could be attractive [White, Conrad and Branney 2008]. This idea is supported by Burton, Walsh and Brown (2008), who investigated Australian men's preferences for a health promotion program and reported that they would be most interested if the program was organized in their workplace. Morgan et al. (2011) also examined the impact of a workplace-based weight management program for men living with obesity doing shift work. After 14 weeks, the participants in the intervention group experienced a significant decrease in body weight, waist circumference, blood pressure, physical activity, resting heart rate, consumption of sweetened beverages, and physical activity-related cognitions [Morgan et al. 2011].

Throughout the Covid-19 pandemic that began in 2020, moving workstations from offices/sites to homes has dramatically increased, and some positions have become permanently remote even after the initial outbreak [Bick, Blandin and Mertens 2021]. Many studies have indicated the importance/benefits of developing home-based exercise programs due to the lack of fitness facilities accessible during the Covid-19 pandemic [Chaabene et al. 2021, Ghram et al. 2021, Holland et al. 2020, Shariat, Cleland and

Hakakzadeh 2020]. Therefore, the fact that home-based exercise programs could also be considered as workplace-based programs could potentially be more helpful for men living with obesity to adhere to such programs.

The literature also indicates that weight management programs in a positive environment with a certain masculine culture could be successful, such as programs in partnership with sports clubs [Gill et al. 2016, Hunt et al. 2014]. An example is the Football Fans in Training, an extended program that implemented a weight management program for football fans living with obesity in Scotland. The program included 12 sessions of a weight loss program delivered by community coaching staff held weekly at a Scottish football club. Each 90-minute session combined advice on a healthy diet with physical activity. The authors reported that the program was highly acceptable and effective among the participants [Gray et al. 2013].

Alongside the mentioned components of a program, such as participants and location and setting, the way that a weight management program is advertised or presented in public for men could impact its success [Segar et al. 2012]. Delivering a program straightforwardly and nonjudgmentally, such as simply listing the local services or risk factors related to good health, would be the most successful [Coles et al. 2010]. McDonald et al. (2020), investigated the best ways to recruit men, specifically those living in disadvantaged areas, for weight management interventions. Two recruiting strategies were studied, including community outreach (venue information stands and word of mouth) and GP letters, targeting disadvantaged areas. Compared to community outreach, those who were recruited through GP letters were older (57 vs 48 years); more likely to report obesity-related health issues (87% vs 44%), and less educated (degree educated 11% vs 41%);

however; both methods were successful strategies for recruiting participants to a men-only weight management trial [McDonald et al. 2020].

In addition to recruitment strategies, some program features of a weight management program can play a role in drawing men into a program. Indeed, the nature of a weight management program could affect men's participation. Hooker et al. (2011) investigated the effect of eight weeks of physical activity programs for middle-aged African American men; sessions included gaining social support, setting goals, tracking progress, and integrating into one's lifestyle. Selecting a weekly "Most Valuable Person" was used as a social model and provided a friendly competition among the participants. The authors reported significant improvements in physical activity, self-efficacy, goal setting, self-regulation and fitness components. Moreover, in a study by Griffith et al. (2014), weekly meetings addressing barriers to physical activity for men incorporated activities that promoted flexibility, strength, balance, and conditioning. After ten weeks, promoting healthy competition helped increase social support, group identity, and cohesion among men [Griffith et al. 2014]. Elliot et al. (2020) examined men living with obesity who attended either a group-based or one-to-one weight loss at local services. The authors listed some barriers – previously identified in the literature – including financial issues and busy lifestyles; however, the most significant theme among the participants were "female-dominated services" and "incompatibility" of existing services for men [Elliott, Gillison and Barnett 2020]. Taken together, the evidence suggests men's attitudes, experiences, expectations and feelings toward the nature of a program can be determinative for their participation [Elliott, Gillison and Barnett 2020].

In conclusion, different reasons have been highlighted to explain the lack of engagement in lifestyle programs for men living with obesity and focused on what motivates participants in existing programs. It is important to consider this information specifically when building exercise programs for men. Some of these barriers/enablers, such as location, advertisement, and gender-specific programs, were considered when designing a program in the current thesis (Study #3).

In addition to gender differences that exist in participation in exercise programs among people living with obesity, sex and gender could also impact on the prevalence of obesity [Agha and Agha 2017], obesity-related chronic diseases [Rajan and Menon 2017] and preference of mode of exercise [Harris et al. 2013]. As a result, it is imperative to pursue the research to understand better the implications of sex and gender in health outcomes in order to have tailored recommendations if needed.

1.3 Why a focus on sex and gender?

Because both 'sex' and 'gender' are considered in this dissertation, it is important to define these terms. According to the Canadian Institutes of Health Research, sex refers to "a set of biological attributes in humans and animals, primarily associated with physical and physiological features. Gender is defined as "the socially constructed roles that influence how people perceive themselves and each other" [CIHR 2021]. Efforts to integrate sex and gender throughout all phases of health research have increased in the past decade [Mazure and Jones, 2015]. Many national health research agencies are putting pressure on researchers to consider the role of both sex and gender in health outcomes [Clayton 2016] in order to prevent sample bias and result in guidelines that do not represent the majority of the population [Bottorof et al. 2011].

Gender may influence physical activity adoption and maintenance differently. For example, traditional gender roles may have created differences in post-retirement physical activity levels of older adults such that men are highly sedentary but more physically active, while women are less sedentary and less physically active [van Ballegooijen, van der Ploeg and Visser 2019]. Research also suggests that women may require social support for long-term adherence and prefer lighter intensity or group activities than men [Amireault, Baier and Spencer 2019]. Thus, programs targeting specific groups may not adequately meet the needs of older men and women.

In 2013, the Centers for Disease Control and Prevention (CDC) in the U.S. indicated a significant sex difference in adherence to the meeting muscle-strengthening activities guidelines (≥ 2 times/wk) [Harris et al. 2013]. The CDC's report showed that 34.4% of males and 24.5% of females (N = 469,312) met recommended guidelines for muscle-strengthening activities [Harris et al. 2013]. In 2020, Nuzzo aimed to investigate population-level surveys on meeting muscle-strengthening activities guidelines to clarify whether a gender difference in participation exists. Sixteen studies from six different countries were included and the results showed that more men than women met recommendations for muscle-strengthening activities in all the studied countries except Australia, where no sex difference was observed. Nuzzo concluded that although there is a gender difference in meeting muscle-strengthening activities guidelines, low participation rates in both genders should encourage participation for both [Nuzzo 2020].

Although studies show that strength training improves body composition in adults [Ho et al. 2012, Lynch et al. 2020, Willis et al. 2012], it is still unknown whether there is any sex difference in the benefits of strength training in individuals living with obesity.

According to the previous studies (systematic reviews), there are sex differences in strength adaptations [Roberts, Nuckols and Krieger 2020, [Jones et al. 2021]. For example, the literature reports the role of sex in the effect of strength training on skeletal muscle morphology [Frontera et al. 2000, Singh et al. 1999, Staron et al. 1990, Trappe et al. 2000]. Men, despite their age, experience a greater hypertrophic response after strength training than women [Hubal et al. 2005] and also seem to have a higher degree of muscle loss with detraining [Melnyk, Rogers and Hurley 2009]. Not only gender and sex can influence the practice of exercise, the obesity status as well.

Obesity prevalence has increased more in males than females in the past decades. Based on the current trends, it is predicted that, In Europe, 60% of males and 50% of females will be living with obesity by 2050 [Lobstien and Leach, 2007]. Sex differences in trends of the prevalence of obesity were reported in different regions of the world. For example, in Canada, (69.4% of males vs. 56.7% of females in 2018) [Statistics Canada 2018], and in the UK (67.7% of males vs 60.1% of females in 2018) were living with overweight or obesity [Conolly, Craig and Gebert 2019].

Clinical studies show that the prevalence of obesity-related diseases is also significantly higher in males. A European-wide study [White and Cash 2004] assessed males' health in 17 European countries, including 19,050,000 participants and reported that males had a higher rate of major chronic conditions such as heart disease, lung cancer, liver disorders, and stroke than females. The higher rates of obesity in males can be partly explained by their less interest in weight management and lifestyle programs because of the context in which they are offered [Robertson et al. 2014].

Although obesity increases the risk of death for both sexes, it is unclear whether obesity results in chronic conditions in males and females to a different extent. Some studies have suggested that visceral fat distribution could be more associated with cardiometabolic outcomes in females than males, but other studies did not support this conclusion [Lind, Ärnlöv and Lampa 2017, Rost et al. 2018, Wannamethee et al. 2010]. A study including more than 500,000 people aged between ages 40 and 69 years [Censin et al. 2019] showed that for both males and females, obesity was associated with coronary artery disease, stroke, chronic obstructive pulmonary disease, lung cancer, diabetes mellitus, non-alcoholic fatty liver disease, chronic liver disease, and renal failure. Interestingly, their results showed that a higher BMI represents more risk of type 2 diabetes in females than males, and waist measures were a better predictor of pulmonary diseases and renal failure in males than females. Although both males and females living with obesity are at risk of obesity-related mental disorders, the odds are higher in women, suggesting a gender effect [Rajan and Menon 2017]. Overall, it seems that sex and gender can play a role in the atheology of obesity, not only physiologically, such as the influence of hormones on body composition and metabolism, but also through behavioural and socio-cultural factors [Lovejoy, Sainsbury and Group 2009].

1.4 Gaps in the literature

Although it is recommended that people of all genders engage in muscle-strengthening activities, it is still unknown whether men and women living with obesity could get similar benefits from regular participation in such activities. It is also unclear if individuals living with obesity can achieve moderate intensity and experience health benefits by practicing a circuit-designed muscle-strengthening training. A variety of reasons have been reported

for men's underrepresentation in lifestyle programs. Based on the literature and our findings, strength training and, more specifically, an online-delivered circuit strength training could provide a potentially effective option, especially for men living with obesity, to increase exercise adherence and associated health benefits.

1.5 Research aims

Based on the review of the literature, the aims of this dissertation were threefold. First, to investigate the benefits of meeting muscle- strengthening activities guidelines in people living with obesity in terms of body fat percentage and mortality and further explore whether sex moderates those outcomes. It was hypothesized that meeting the muscle-strengthening activities guideline correlates with a lower body fat percentage and mortality, and sex is a significant moderator in those correlations.

Second, we explored whether circuit strength training could reach the moderate intensity and bring health benefits to individuals living with obesity. It was hypothesized that individuals living with obesity could reach moderate aerobic intensity by practicing circuit strength training and experiencing health benefits.

Third, using a randomized controlled trial to investigate if an online-delivered muscle strength circuit training could increase adherence to both components of the physical activity guidelines (≥150 min of moderate to vigorous aerobic exercise + ≥ two sessions of muscle-strengthening activities) by addressing barriers to engage in regular exercise in men living with obesity and improve health outcomes compared to the control group. It was hypothesized that the online delivered muscle strengthening circuit program could help men living with obesity adhere to the two components of the physical activity guidelines 46 weeks after baseline compared to the control group.

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CHAPTER 2: MANUSCRIPT ONE

Examining the role of sex on the benefits of muscle-strengthening activities for people living with obesity: A cross-sectional study

(Health & Science Report. Status: Published)

Keshavarz Mohammad, Sénéchal Martin, Dombrowski U Stephan, Meister Daniel, Bouchard R Danielle. *Examining the role of sex on the benefits of muscle-strengthening activities for people living with obesity: A cross-sectional study*. Health Science Report, 2022 5(4); 720-*727*

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2.1 ABSTRACT

Objective: To investigate the correlations between meeting the muscle-strengthening activities guideline, body fat % and mortality for individuals living with obesity and to explore if these correlations are moderated by sex.

Materials and Methods: Data from 3915 adults (51.9% women; 48.1% men) living with obesity (Body fat % ≥25 for men and ≥35 for women) from two cycles of the National Health and Nutrition Examination Survey (NHANES 2003-04 / 2005-06) were analyzed. Muscle-strengthening activities were self-reported via a questionnaire, body fat % was measured via Dual Energy X-ray, and mortality was obtained via administrative data for an average of 10 years.

Results: 18.7% of men and 15.2% of women living with obesity met the muscle-strengthening activities guideline ($p = 0.021$). Sex was correlated with body fat %; (β (S.E.) = 11.34 (0.18); $p \leq 0.001$) and risk of mortality (H.R. (95%CI) = 0.36 (0.24-0.54); $p \leq 0.001$), once adjusted for confounders (weekly aerobic activities, ethnicity, education, household income, smoking, and the sum of chronic conditions). The interaction between sex and meeting the muscle-strengthening activities guideline was not significantly correlated with the studied outcomes.

Conclusion: Performing muscle-strengthening activities a minimum of two times per week does not impact body fat % or risk of mortality (over ten years) differently in men or women living with obesity.

2.2 INTRODUCTION

Obesity is a complex and costly disease [Bray 2004]. Regardless of an individual's obesity status, physical activity is essential to health and weight management [Jakicic and Otto 2006]. International physical activity guidelines state that adults should accumulate a minimum of 150 minutes of aerobic activities at moderate intensity and two sessions of muscle-strengthening activities per week [WHO 2020] because of the multiple health benefits correlated with this practice [Bennie, Shakespear-Druery and De Cocker 2020]. Despite decades of promotion and evidence of the benefits of regular physical activity, the proportion of adults meeting both components of the guidelines (using self-reported measures) is low. For example, in the United States, only 23% meet both components [Bennie et al. 2019], with 30.2% of individuals meeting muscle-strengthening activities recommendation [Bennie et al. 2018] versus 52.6% meeting aerobic activities recommendation [Bennie et al. 2015]. The proportion for meeting both guideline components is even lower (9%) in individuals living with obesity [Bennie et al. 2015].

Individuals living with obesity may prefer muscle-strengthening activities over aerobic exercise to reap the benefits of exercise. Individuals living with obesity are often stronger than their leaner counterparts, perhaps because of greater absolute muscle mass [Gill et al. 2017]. Additionally, individuals living with obesity tend to report a lower rate of perceived exertion compared to aerobic activities at the same intensity, and may display greater self-worth compared to individuals without obesity when performing muscle-strengthening activities [Ten Hoor et al. 2016].

While muscle-strengthening activities are recommended for both men and women, evidence suggests that women are less likely to engage in muscle-strengthening exercises

than men throughout their lifetime [Strain et al. 2016]. Muscle-strengthening activities improve body composition in adults [Ho et al. 2012, Lynch et al. 2020, Willis et al. 2012], but the difference between men and women living with obesity is unknown. In two meta-analyses on sex differences in muscular adaptations following strength training, 31 studies [Jones et al. 2021] and 17 studies [Roberts, Nuckols and Krieger 2020] were analyzed. Their results showed that lower body and upper body strength gained following muscle-strengthening interventions are different in men and women, explaining sex-dependent adaptations. As suggested, sex and gender need to be explored as a moderator and not only as a confounder [Regitz-Zagrosek 2012].

This study aims to investigate the correlations between meeting the muscle-strengthening activities guideline, body fat % and mortality in people living with obesity and further explore if these correlations are moderated by sex.

2.3 METHODS

2.3.1 Study overview

This study used data collected from the National Health and Nutritional Examination Surveys (NHANES). NHANES is conducted bi-yearly by the U.S. Center for Disease Control and Prevention (CDC) to assess the U.S. population's health, dietary practices, and nutritional status. It includes questionnaires, medical examinations, and laboratory biomonitoring methods to determine the prevalence of diseases and environmental exposures in a sample of the non-institutionalized general U.S. population. Participants receive a health examination at mobile examination centers and are interviewed in their homes. Each cycle, the CDC collects data on a new group of participants.

Although NHANES is cross-sectional, the mortality status of participants is also tracked via administrative data. The 2003-2005 and 2005-2006 continuous NHANES cycles were combined and used in this study. These cycles were chosen because they contain data on body fat %, muscle-strengthening activity participation, and time spent in moderate to vigorous physical activity (MVPA) calculated using accelerometers.

2.3.2 Study sample

An initial sample of 20,470 participants was available from the 2003–04 and 2005–06 NHANES databases. The inclusion criteria were: age 19 or above and had data on muscle-strengthening activity participation, DXA calculated body fat %, and accelerometer measured MVPA levels. A total of 3915 participants were included in the current analysis once, removing people with no data on muscle-strengthening activities (N=6080); age 18 years old or younger (N=3813); missing body fat % (N=2062); not meeting the criteria for obesity (N=1862); not having a minimum of four days data of accelerometer wear time (N=2451); and missing data for smoking, household income, education and mortality (N=287). No difference was observed between the age of the selected sample between men and women (51.6 years men vs 52.0 years women p=0.373), but a difference was observed for sex with slightly more women (51.9% women vs. 48.1% men; p=0.016).

2.3.3 Exposure variables

Muscle-strengthening activities

Participants self-reported their muscle-strengthening activities by answering the following questions: (1) Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles, such as lifting weights, push-ups, or sit-ups? If a participant answered yes, then they were asked the second question,(2) Over the

past 30 days, how many times did you do these activities designed to strengthen your muscles, such as lifting weights, push-ups, or sit-ups? According to the most recent international physical activity guidelines [WHO 2020], it is recommended to perform muscle-strengthening activities a minimum of two times/week. As a result, the sample was divided into two groups: meeting the muscle-strengthening activities recommendation (≥8 times/30 days) or (8< times/30 days).

Obesity

Body composition was captured via DXA (Hologic, USA), and body fat percentage was estimated. Details of the DXA protocol are available on the NHANES website [NHANES 2013]. Based on the WHO definition, men having ≥ 25% and women having ≥35% body fat were classified as living with obesity [WHO 1995]. BMI was calculated following standardized procedures; weight (kg) divided by height (m) squared [Navalta, Stone and Lyons 2019]

Mortality rate

Mortality data was obtained via the National Death Index which is linked with the NHANES database [NHIS 2020]. The time to death was recorded in years based on the day of a participant's examination to the time of death or up to the end of follow-up. The average follow-up time for the sample was 10.2 ± 2.3 years.

2.3.4 Potential confounders

The following variables were selected as potential confounders based on relevance and availabilities. Demographic characteristics included age, ethnicity (Mexican American and other Hispanic; non-Hispanic white; non-Hispanic black; Others), education (below diploma grade 12; high school and some college degree; college graduate and above),

smoking behaviour (current smoker or non-smoker), and household income (under $20,000; between $20,000 and $74,999; $75,000 and above). The sum of chronic conditions was computed using five conditions that could influence the ability to perform muscle-strengthening activities: arthritis, cardiovascular diseases, diabetes, lung diseases and cancer. These conditions were self-reported using the question 'Did a doctor ever say you had_____?'; the possible answers being yes, or no. One score was given for each yes, and a sum out of five (either ≥ 2 or < 2) was used in the analysis. The Aerobic activities were also considered confounders, collected using the ActiGraph 7164 accelerometer (ActiGraph, Shalimar, FL). Participants were asked to wear an accelerometer for seven consecutive days. A minimum of four days of data and 10 hours per day of wear time was required to be included in the study [Troiano et al. 2008]. Moderate intensity cut-point for physical activity was defined as ≥5998 counts/min [Metzger et al. 2008]. Weekly time (minutes) of aerobic activities spent at moderate to vigorous intensity was calculated. Menopause was quantified using two available variables. The first variable came from a question asking whether the individual had a period in the past 12 months. The second variable asked the individual who responded no to the above question whether this was due to pregnancy, breastfeeding, menopause/hysterectomy, medical condition/treatment or other. Those who answered that their lack of a period in the last 12 months was due to menopause/hysterectomy were defined as being menopaused.

2.3.5 Statistical analysis

Descriptive data is reported as unweighted average ± standard deviation or N (%). The description of participation in aerobic activities and muscle-strengthening activities are presented by sex. Potential differences among groups were tested using chi-square tests or

T-tests. Weighted linear regression models were used to test if practicing muscle-strengthening activities (≥ two sessions/week) affects the body fat percentage of men and women living with obesity differently after adjusting for potential confounders. Kaplan Meier and Proportional hazard Cox regression were used to describe and determine if meeting the muscle-strengthening activities guidelines (≥ two sessions/week) was associated with mortality at a different rate for men and women, once weighted and adjusted for the same covariates. Statistical analyses were performed using R 4.1.1.1 and SPSS 21.0.

2.4 RESULTS

Descriptive data for the study sample are presented in Table 1. The average age, BMI and body fat % of participants was 51.8±16.4 years, 30.1±5.8 and 37.0±7.3 %, respectively. Participants spent an average of 138.6±146.4 minutes of MVPA in a week. The majority of the sample was non-Hispanic White (51.7%) and completed high school (54.2%). Among women with data for menopausal status (n=1183), 58.2% were categorized as menopausal. Only 28.8% of participants were categorized as having low household income (less than $20,000), and 18.8% reported as current smokers. About a fifth of the sample (12.2%) self-reported having a minimum of two of the five chronic conditions evaluated. A proportion of 18.7% of men and 15.2% of women ($p = 0.021$) met the muscle-strengthening activities recommendation.

The results of the regression model fully adjusted for potential confounders (MVPA, ethnicity, education, household income, smoking, sum of chronic conditions) showed that sex (being women) ($\beta=11.35$; $p \leq 0.001$) and meeting the muscle-strengthening activities guideline ($\beta=-0.77$; $p=0.004$) were significantly correlated with lower body fat %.

However, the interaction between sex and meeting muscle-strengthening activities guideline was not statistically significant (β=-0.14; p=0.681) (Table 2). The regression model results did not change with the absence of MVPA as a confounder.

The average follow-up for survival analysis was ten years ± 2.3, during which 644 deaths were recorded: 19.0% men vs women 12.0% ($p \leq 0.001$). The proportion of death was non-significantly lower for men meeting the muscle-strengthening activities guideline compared to men not meeting the guideline (15.0% vs.19.8%). Similar results were seen in women meeting the muscle-strengthening activities guideline compared to women not meeting the guideline (9.7% vs. 12.1%) (Figure 1).

Being a woman protected against death (HR (95% CI) = 0.36 (0.24-0.54); $p \leq 0.001$). However, meeting the muscle-strengthening activities guideline was not significantly correlated with mortality ($p = 0.44$) when fully adjusted for potential confounders (MVPA, ethnicity, education, household income, smoking, and sum of chronic conditions). The interaction between sex and meeting muscle-strengthening activities guideline was not statistically significant ($p = 0.36$) (Figure 2).

2.5 DISCUSSION

The main objective of the current study was to investigate the correlations between meeting the muscle-strengthening activity guideline, body fat % and mortality in people living with obesity and further explore if these correlations are moderated by sex. The results show that more men than women living with obesity meet the muscle-strengthening activities guideline. Meeting the muscle-strengthening activities guideline was correlated with a lower body fat % in both men and women. There was no interaction between sex

and meeting the muscle-strengthening activities guideline; meaning that practicing muscle-strengthening activities equally influences men and women living with obesity in terms of body fat % and mortality.

Although it is known that sex and gender influences body fat %, mortality and the preference for muscle-strengthening activities, this study is among the first attempts to understand the potential sex interaction for adults living with obesity reaching muscle-strengthening activities guideline or not. As observed before, women are less likely to engage in muscle-strengthening activities than men [Strain et al. 2016], and the same applies to adults living with obesity. Given the strength advantages that both men and women living with obesity have over lean people, tailored suggestions to both men and women living with obesity about the specific benefits of muscle-strengthening activities to them might be a useful addition to public health interventions.

Although systematic reviews with meta-analysis design [Jones et al. 2021, Roberts, Nuckols and Krieger 2020] included 40 studies have stated that men and women may gain relative lower body (95% CI 0.33, 0.10, $p = 0.0003$) and upper body (E.S. = 0.60 ± 0.16; $P = 0.002$) strength differently when performing muscle-strengthening activities, these studies almost exclusively focus on muscle strength and muscle size, but not on body fat % or mortality rate. However, using BMI cut-offs to classify obesity in two different cross-sectional studies found that meeting muscle-strengthening activities guideline was correlated with a lower rate of obesity in 400,000 US adults [Bennie et al. 2018] and 1.7 million U.S. adults [Bennie et al. 2020]. In a prospective cohort study, meeting the muscle-strengthening activities guideline was correlated with a reduced risk of developing obesity [Brellenthin et al. 2021]. Our findings could address the gap in the literature that sex does

not appear to significantly moderate body fat % in individuals living with obesity who are meeting muscle-strengthening activities guidelines.

Most studies on muscle-strengthening activities and mortality have focused on the correlation between muscle strength and mortality rather than participation in muscle-strengthening activities and mortality [Jochem et al. 2019, Malhotra et al. 2020, Nakamura et al. 2021, Ruiz et al. 2008]. Many beneficial outcomes can be obtained when performing muscle-strengthening activities besides muscle strength. For example, in a study [Shiroma et al. 2017], the authors reported a reduced risk of cardiovascular disease by 17% (H.R.: 0.83, 95% CI: 0.72, 0.96) and type 2 diabetes by 30% (H.R.: 0.70, 95% CI: 0.61, 0.80) in women who had any muscle-strengthening activities experiences in their life. Other outcomes, such as metabolic risk factors and anthropometrics have also been studied where an improvement was shown in cardiovascular (endothelium) function and waist circumference as a result of performing muscle-strengthening activities by 3% (95% CI: 1.5–4.5) and 1.4% (95% CI: −2.7 to −0.8) respectively [Stensvold et al. 2010]. Nonetheless, a meta-analysis of 11 prospective studies (370,256 participants; mean follow-up = 8.85 years) [Saeidifard et al. 2019] reported that performing muscle-strengthening activities was independently correlated with 21% lower risk of all-cause mortality (H.R.;95% CI, 0.79;0.69–0.91). Our results do not confirm the correlation between muscle-strengthening activities and mortality rate, and this can potentially be explained by the limitations in the current study, such as studied population and mortality timeline as the differences may become more pronounced over time (figure 1).

2.6 STRENGTH AND LIMITATIONS

The current study is strengthened by using the NHANES database, which is nationally representative and has an appropriately weighted sample. Using the DXA to measure body fat percentage reduced measurement errors and social desirability bias of reporting weight and height and avoided many of the issues that BMI measurements might present. As for limitations, the weighted analysis aimed to be used for the original sample; therefore, the final sample may not represent individuals living with obesity in the US. Participation in muscle-strengthening activities was self-reported and, therefore, potentially biased.

Using a self-reported questionnaire to report muscle-strengthening activity is a limitation of this study. However, as mentioned by Shakespear et al. (2021), there are limited surveillance instruments to assess muscle-strengthening activities beyond weekly frequency, and as opposed to aerobic activities, there is no standardized instrument for assessing muscle-strengthening activities in health surveillance [Shakespear-Druery et al. 2021]. In addition, although Ravelli et al. (2020) stated that self-reported dietary data should not be used for the study of energy intake/expenditure in individuals living with obesity [Ravelli and Schoeller 2020], we can still mention the lack of adjustment for dietary intake as a limitation of this study. Finally, meeting muscle strength activities guidelines was considered in four weeks (28 days), while the NHANES database is based on a month (30 days).

2.7 CONCLUSION

This study shows that meeting muscle-strengthening activities is associated with a lower body fat percentage, but no interaction was observed between sex and the two outcomes studied. Therefore, based on our results, performing muscle-strengthening activities a

minimum of two days per week does not impact body fat percentage or risk of mortality over 10 years in men and women living with obesity differently. The greatest addition to the literature of this study is that no significant interaction between sex and muscle-strengthening activities was observed for the studied outcomes. Therefore, regular participation in muscle-strengthening activities benefits both men and women living with obesity similarly.

Perspective

Performing muscle-strengthening activities reduces the risks associated with many chronic conditions, such as obesity. Men and women experience different barriers and facilitators when participating in muscle-strengthening activities. Little research has examined the health benefits of doing muscle-strengthening activities for individuals living with obesity, and whether those benefits are moderated by sex or not is unknown. The current study aimed to explore the relationships between meeting the muscle-strengthening activities guidelines, body fat percentage and mortality for people living with obesity and to investigate if these associations are moderated by sex. The results of the current study suggest that performing muscle-strengthening activities a minimum of two times per week improves body fat percentage but not mortality in men and women living with obesity similarly. These findings have implications on the use of muscle-strengthening activities in a clinical setting for health practitioners.

Table 1. Descriptive characteristics of the study sample

	Whole group N= 3915	Men N=1882	Women N=2033
Age (years)	51.8±16.4	51.6±16.5	52.0±16.2
BMI (kg/m^2)	30.1±5.8	29.8±4.9	30.4±6.5*
Body fat percentage (%)	37.0±7.3	30.9±4.0	42.7±4.5*
Weekly MVPA (min)	138.6±146.4	178.0±170.5	102.6±108.3*
Ethnicity (non-Hispanic white)	2126 (51.7)	1018 (54.0)	1008 (49.6) *
Education (high school or more)	2122 (54.2)	971 (51.5)	1151 (56.6) *
Household income (less than $20,000)	1129 (28.8)	483 (25.6)	646 (31.8) *
Current smoker (yes)	736 (18.8)	416 (22.1)	320 (15.7)*
Reporting ≥ 2 chronic conditions	450 (12.2)	362 (12.5)	812 (11.9)
Menopausal status	-	-	1183 (58.2)
Years of follow-up for mortality	10.3±2.3	10.0±2.6	10.5±2.0*

N (%) or average ± SD
MVPA: Moderate to Vigorous-intensity Physical Activity
* Significant difference between men and women

Table 2. Muscle-strengthening activities 2+/week and body fat %

	Model 1	Model 2	Model 3	Full model
Sex (women)	11.73 (0.15)	11.43 (0.18)*	11.41 (0.18)*	11.36 (0.18)*
Muscle-strengthening activities 2+/week	-1.03 (0.25)	-0.79 (0.25)	-0.70 (0.25)*	-0.78 (0.25)*
Muscle-strengthening activities 2+/week *sex	-0.13 (0.36)	-0.11 (0.35)	-0.16 (0.35)	-0.14 (0.35)

Data presented as B-value (S.E.). * Represents a p-value below 0.01.
Model 1 is unadjusted, Model 2 adjusted for age, aerobic activity (minutes of MVPA per week),
Model 3, further adjusting for ethnicity, education, household income, the fully adjusted model is further adjusted for smoking, sum of chronic conditions.

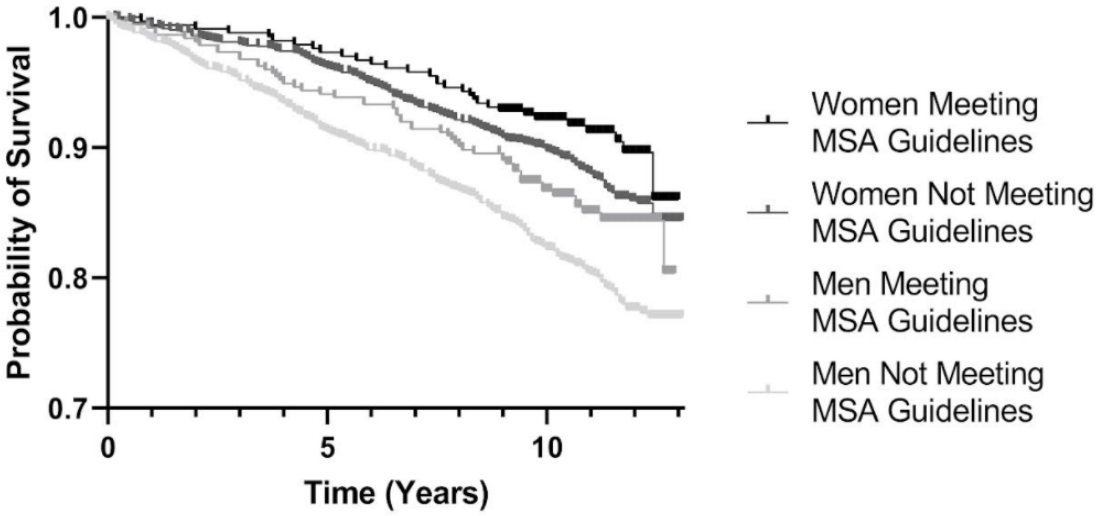

Figure 1. Probability of survival of men and women meeting the muscle strength activities guidelines

MSA guidelines=Muscle-strengthening activities 2X or more per week

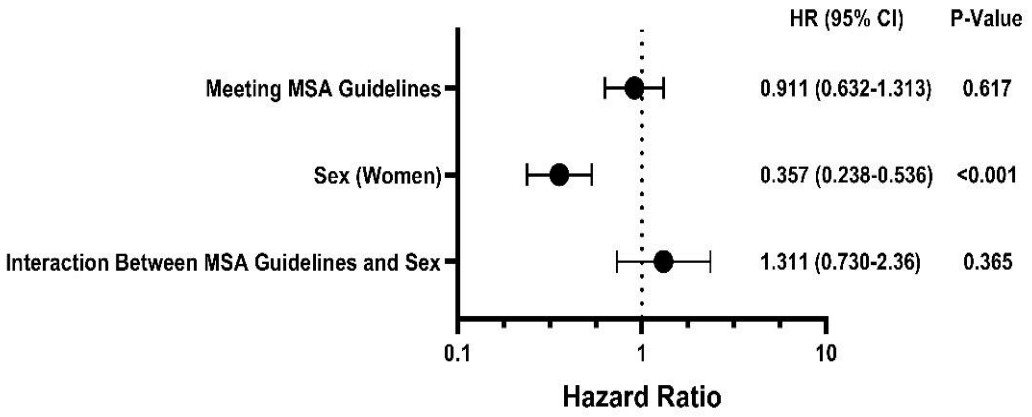

Figure 2. The association between selected variables and risk of death
MSA guidelines=Muscle-strengthening activities 2X or more per week

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CHAPTER 3: MANUSCRIPT TWO

Can a brief circuit resistance training meet aerobic and strength activities recommendations for people living with obesity?

(Submitted to Science & Sport. Status: Under Review)

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3.1 ABSTRACT

Objective: To explore if individuals living with obesity participate, have interest, and benefit from a brief circuit resistance training (RT+) program and evaluate if the RT+ reaches moderate intensity and the association between oxygen consumption and heart rate while performing RT+.

Methods: Ten inactive adults (men and women) living with obesity participated in the RT+ program for 12 weeks. Participants performed 150 minutes of the RT+ program using four exercises (squats, chest press, lunges and lat-pull down) for three sessions of 50 minutes each week. Measured outcomes included attendance, fitness, lipids, anthropometrics, and body composition. Oxygen consumption and heart rate were captured during a single session of the RT+ program using portable indirect calorimetry. Interest in the RT+ program was assessed via an exit interview.

Results: Participants (Age 55.5y; women 60%) attended 91% of offered sessions. A significant improvement was observed in the body mass index (BMI) -1.3 kg/m^2 ($p=0.03$). The RT+ program permitted participants to reach moderate intensity regarding the indicators used to establish moderate intensity: 3≤ metabolic equivalents (METs), 46 $\%VO_{2\ peak,}$ 40% $VO_{2\ reserve,}$ 64% heart rate max and 40% heart rate reserve). The association between heart rate and VO_2 while performing the RT+ program was ($r=0.27$; $P < 0.01$).

Conclusion: This study suggests that adults living with obesity show interest in and benefit from this brief program. The RT+ program could contribute to the aerobic portion of the guidelines and, therefore, reduce the weekly time required to meet the minimum exercise recommendations.

3.2 INTRODUCTION

International recommendations suggest performing a minimum of 150 minutes of moderate-intensity activities per week and a minimum of two resistance training sessions with no intensity recommendations [ACSM 2018, AHA 2018, CSEP 2020]. Resistance training is not typically considered to contribute to the aerobic portion of the guidelines as there is an uncertainty that oxygen consumption increases sufficiently to induce adaptations typically resulting from aerobic activities [Vilaça-Alves et al. 2016].

Individuals living with obesity may prefer resistance training over aerobic activities as they might show mobility issues [Fletcher et al. 2001], lower fitness levels [Schranz et al. 2014], and high rates of osteoarthritis [Messier et al. 1994, Messier et al. 2005]. A growing body of literature shows that resistance training is undervalued for people living with chronic conditions [Bennie, Shakespear-Druery and De Cocker 2020]. Previous studies of Dr. Bouchard's research group [Bharti et al. 2017, Hrubeniuk et al. 2014] have demonstrated that when a resistance training program is designed to increase the proportion of time spent at moderate intensity based on heart rate, individuals living with obesity can spend approximately 90% of the exercise time at moderate intensity. While these findings have provided a rationale for considering resistance training-based exercise programs as a contributor to aerobic activities for individuals living with obesity, there is currently a lack of research investigating resistance training capabilities to reach moderate intensity measured with oxygen consumption. The association between heart rate and oxygen consumption has been questioned in the past [Fletcher et al. 2001, Jansen, Schmidtbleicher and Cabri 2007]. It is important since health benefits are achieved because of an increase in cardiorespiratory fitness [Knuttgen 2007].

This study aimed to explore if individuals living with obesity participate, have interest, and benefit from RT+ program and evaluate if the RT+ reaches moderate intensity and the association between oxygen consumption and heart rate while performing the RT+.

3.3 METHODS

3.3.1 Participants

Ten inactive adults living with obesity between 19 and 64 years old were recruited. Recruitment took place via general advertisement (e.g., facebook, newspaper) throughout the community. Inclusion criteria included a BMI $\geq$ 30 kg/m^2, and reporting less than 150 minutes of aerobic activity at moderate to vigorous intensity per week. The Physical Activity Readiness Questionnaire (PARQ+) was used as a criterion for inclusion to ensure participants' safety [CSEP 2021]. If the PARQ+ deemed that a participant was considered high-risk, clearance from a physician was required to participate in the study. An ethical board approved the study, and informed consent was obtained. The study was performed in line with the Helsinki Declaration.

3.3.2 Outcomes

Anthropometrics and resting heart rate were measured following standardized procedures [Navalta, Stone and Lyons 2019]. Maximal heart rate was estimated using a known equation (206.9 – [0.67] × age) [Chewning 2010]. Body composition was assessed using a Bod Pod (Cosmed, Concord, CA). Cardiorespiratory fitness (VO_{2peak}) was assessed using indirect calorimetry (Parvo, U.S.A) with a protocol specifically designed for adults living with obesity [RW 1959]. A registered nurse took blood samples following a 12-hour fast (baseline and 24 hours after the last session of the program) and subsequently sent for analysis to establish a lipid profile (high-density lipoprotein, low-density lipoprotein).

3.3.3 Intervention

Participants exercised three times per week for 150 minutes (50 minutes per session) at the fitness facility located at the university. Each session consisted of participants completing circuits of four exercises that had been previously identified [Bharti et al. 2017]. These exercises included squats, lat pulldowns, lunges, and chest presses. Machines were used for the lat pulldown and the chest press, while free weights were used (if needed) for squats and lunges. Participants were instructed to complete as many circuits as possible safely in the 50 minutes to maximize the aerobic intensity. The load was fixed at 70% (10 reps) of the one resistance maximum (1-RM) as determined to be an optimal intensity to increase heart rate above moderate intensity with this population [Bharti et al. 2017]. 1-RM tests were done at baseline and repeated every four weeks to adjust the loads at 70% of 1-RM following an established protocol [ACSM 2013]. Participants were allocated a one-minute break in between each circuit and no break between exercises.

3.3.4 Exercise intensity

At week eight, oxygen consumption and heart rate were measured via a portable metabolic cart (Metamax, Quadromed, Montreal Qc) and a heart rate monitor (Polar RS800CXN, Lachine, QC), respectively, during a single session. Five intensity indicators were calculated : 3 METs, 40 %$VO_{2peak,}$ 40% $VO_{2reserve,}$ 64% heart rate max and 40% heart rate reserve) as recommended by previous literature [Swain and Franklin 2002] to identify the average heart rate and oxygen consumption were above these different thresholds.

3.3.5 Interest

Interest was measured based on attendance and drop-out rates. Once a participant completed the study or decided to drop out, an exit survey was sent via email and participants were offered to answer questions regarding the program.

3.3.6 Statistical analysis

As appropriate for small sample sizes, non-parametric analyses were used. Mann-Whitney tests were used to evaluate the changes pre-post. Wilcoxon tests were used to compare each intensity indicator to capture the moderate intensity. Spearman correlation tests were used to evaluate the association between heart rate and VO_2 during the RT+ session. All statistics were analyzed using SPSS version 25.

3.4 RESULTS

Of the 10 participants (60% women), one participant dropped out of the study. An average of 32.5 sessions out of 36 were attended (91%). As reported in Table 1, this study attracted people median aged 55 with a median BMI of 33.7 kg/m^2. All median changes observed were leaning towards improvements reaching significance for BMI.

Figure 1 presents the correlation between heart rate and VO_2 for participants during the tested RT+ session ($r= .27$; $P < 0.01$). Table 2 shows that participants who performed the RT+ program significantly surpassed the minimum threshold for moderate intensity for all five intensity indicators. The average energy expenditure during a session was calculated as 5.85 (Kcal/min), according to ACSM calorie expenditure equation using participants' average VO_{2max} and body mass data [Swain 2000].

The exit survey (Table 3) was completed by seven original participants (three men and four women). The median value of RT+ participants reported a confidence level of 9.2/10

when completing the exercise sessions. All participants perceived an improvement in their body weight and muscle strength. They indicated that the least favourite part of the program was the need to share the resistance training equipment with others in the fitness facility.

3.5 DISCUSSION

The current findings indicate that adults living with obesity could adhere to the RT+ program and potentially reach health benefits related to both aerobic and resistance training. This study suggests it is worth investigating if the RT+ leads to long-term adherence in this population using the appropriate study design.

Given this study's small sample size and pilot nature, the goal was not to observe significant differences in health outcomes. However, all measured variables related to metabolic health tended to improve, thus encouraging further trials.

Few studies have reported the average heart rate during a resistance training session, mostly done in non-overweight young adults [Bharti et al. 2017]. It has been suggested that an average of 50% heart rate reserve (above the 40% threshold for moderate-intensity) and spending 51.5% of the time exercising above or equal to 64% of predicted maximal heart rate considered moderate-intensity while doing circuit resistance training [Swain and Franklin 2002]. These studies showed that reaching moderate intensity while doing resistance training is feasible for adults with a "healthy" BMI. The current study builds on the previous studies by investigating the intensity response to resistance training in individuals living with obesity.

Based on the literature, it is supported that heart rate max is not strongly associated with VO_{2max} [Sarsan et al. 2006]. Some studies have reported that VO_2 does not increase linearly with heart rate while performing resistance training, in contrast to aerobic exercise

[Fletcher et al. 2001, Jansen, Schmidtbleicher and Cabri 2007]. For example, Jansen et al. (2007) reported an average of 61.0% heart rate while doing resistance training, compared to only 26.5% of VO_{2max} [Jansen, Schmidtbleicher and Cabri 2007]. Based on our findings, this would not be the case when doing a circuit resistance training session. Although heart rate and VO_2 were not strongly correlated when performing the RT+ (r=0.27), it is important to note that all moderate-intensity indicators were reached when doing the RT+. Our data showed that when heart rate increases, VO2 does not necessarily increase; however, heart rate and VO_2 do reach moderate intensity for the average resistance training session. It therefore, means that heart rate could be used to track aerobic intensity while performing resistance training.

A high participation rate in any exercise program with any population is a challenge [Patel, Doku and Tennakoon 2003]. This study proposes a novel resistance training program that is brief and repetitive. Participants demonstrated both high levels of participation and self-confidence throughout the program completion. These findings are similar to those of Schranz et al. (2014), who also highlighted an increase in self-confidence in individuals living with obesity while completing a resistance training-based exercise program [Schranz et al. 2014]. Based on the participation rate and a low drop-out rate, the following steps are, the following steps are to test the program on a longer term and have a proper design to test the health benefits and long-term adherence. Another important element is to develop a similar program using only callisthenics exercises that can be done outside a fitness facility.

3.6 LIMITATIONS

Although this pilot study proposes a novel exercise program that has shown great potential as a beneficial alternative to traditional exercise programs, it also poses some limitations. First, the current study was a pilot project, and a small sample size can influence results. Only one session was used to quantify oxygen uptake while performing the RT+ program.

3.7 CONCLUSION

This study suggests that adults living with obesity show interest and could benefit from this brief program. The RT+ program could contribute to the aerobic portion of the guidelines and, therefore, could reduce the weekly time required to meet the minimum exercise recommendations.

Table 1. Baseline characteristics and % change during the program

	Baseline characteristics	% Change
Age (years)	55.5 (52.8 - 59.0)	
Sex (men)	4 (40%)	
VO_{2peak} (ml/kg/min)	24.8 (24.4 - 27.6)	3.5 (-2.9 to 4.7)
Weight (kg)	83.2 (78.3 – 107.4)	-2.8 (-5.4 to -1.1)*
BMI (kg/m^2)	33.7 (30.9 - 37.5)	-1.3 (-3.5 to -0.8) *
Waist Circumference (cm)	102.8 (101.9 - 118.3)	-1.2 (-5.2 to 3.7)
Systolic Blood Pressure (mmHg)	134.5 (127.8 - 154.5)	-1.0 (-8.6 to 12.0)
Diastolic Blood Pressure (mmHg)	88.0 (76.8 - 99.5)	0.0 (-1.4 to 7.9)
Body Fat Percentage (%)	44.7 (41.3 - 49.4)	-2.3 (-5.6 to 3.6)
Fat-Free Mass (kg)	46.4 (44.3 - 56.2)	0.4 (-2.9 to 4.3)
High-Density Lipoprotein (mmol/L)	1.2 (1.1 - 1.9)	3.2 (-6.9 to 7.6)
Low-Density Lipoprotein (mmol/L)	3.6 (3.3 - 3.9)	-3.6 (-15.2 to 8.0)

Data presented as median (25th-75th percentile) or N (%)

Table 2. Intensity reached during the RT+ session

	Minimum moderate intensity	Resistance training + session
METs	3	4.7 (4.0-5.1) *
% $VO_{2\ peak}$	46	61.3 (56.0-70.0) *
% $VO_{2\ reserve}$	40	41.6 (37.8-46.8) *
% Heart rate $_{max}$	64	74.7 (71.1-80.1) *
% Heart rate $_{reserve}$	40	45.7 (41.5-48.1) *

Data are presented as median (25-75 percentile). * Represents significant difference vs. the minimum intensity to reach moderate intensity.

Table 3. Exit Survey

	RT+ program
Did you like the program? (Yes)	7 (100.0%)
On a scale of 1-10, what was your confidence in doing the program?	9.2 (8-10)
Do you think you lost any weight or had a change in your body composition? (Yes)	7 (100.0%)
Do you believe you made any strength gains in the gym? (Yes)	7 (100.0%)
What was your least favourite part of the program?	
Repetitive movements	2 (28.5%)
Sharing equipment	5 (100.0%)

Data presented as N (%) or median (range)

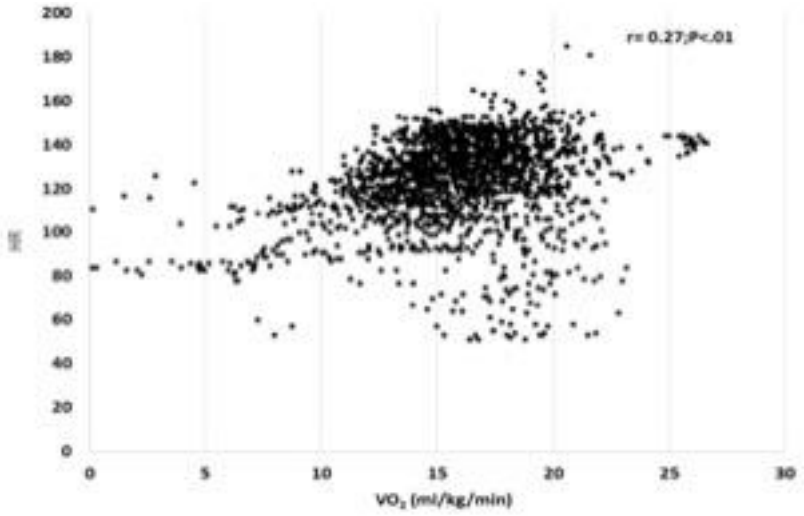

Figure 1. Correlation between heart rate and VO_2 for participants during a RT+ session during the program (r= .27; P < 0.01).

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CHAPTER 4: MANUSCRIPT THREE

The Impact of an Online-delivery Circuit Training and Adherence to the Physical Activity Guidelines: A Randomized Controlled Trial of Men Living with Obesity

(To be submitted to Obesity Journal)

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4.1 ABSTRACT

Objectives: To examine adherence to the weekly physical activity guidelines and health outcomes in men living with obesity 46 weeks after being offered an online muscle strengthening circuit program, compared with a control condition.

Methods: Sixty men (age ≥ 18 years; body fat % ≥ 25) were randomly assigned to the intervention group (N=30) or the control condition (N=30) for 12 weeks. The intervention group did the online delivered circuit training, three sessions in a week. Adherence to the weekly physical activity guidelines was evaluated 46 weeks after enrolling in the program using a heart rate tracker and an exercise log. Most variables (anthropometrics, body composition, resting heart rate, blood pressure, lipids profile, glucose) were measured at baseline and after 12, 24, and 46 weeks. Aerobic fitness and comfort with technology were measured at baseline. Perceived benefits/barriers of participation in exercise were captured at baseline and 12 weeks.

Results: More participants in the intervention group adhered to the physical activity guidelines compared to the control group at 46 weeks (intervention 36.8% vs control 5.3%; p=0.021). However, the intervention group did not improve their health outcomes after 12, 24, and 46 weeks. Fewer barriers were reported after 12 weeks for the intervention group (p=0.02).

Conclusions: The proposed program increased adherence to the physical activity guidelines after 46 weeks for men living with obesity; however, this did not translate into health improvement. More studies are needed to understand better how online delivery circuit training can lead to health outcomes in men living with obesity.

4.2 INTRODUCTION

The prevalence of adults reaching the physical activity recommendations in developed countries is low and leads to many chronic conditions such as obesity [Loyen et al. 2017]. There is an international consensus that adults should perform a minimum of 150 minutes of moderate-to-vigorous aerobic activities per week in addition to a minimum of two sessions of muscle-strengthening activities to reap health benefits [Piercy et al. 2018, Tremblay et al. 2011]. Only 14.3% of adults living with obesity reach these guidelines compared with 25.0% of their lean counterparts [Bennie et al. 2019a]. Many exercise programs have shown health benefits for people adhering to them [Picorelli et al. 2014]. Although obesity prevalence is high for both men and women, it has increased more in men than women over the last decades [Agha and Agha 2017]. More lifestyle modification studies have been conducted in women living with obesity; thus, more knowledge is available in this population [Gavarkovs, Burke and Petrella 2016], which is mainly driven by the lack of interest in programs for men [Wirth et al. 2014] or barriers such as gender preferences [Ross et al. 2012].

Although muscle-strengthening activities are recommended for both men and women, evidence shows that men are more likely to engage in such activities than women throughout their lifetime [Strain et al. 2016] and this is partially due to the masculine features of muscle-strengthening activities [Dworkin 2001, Howe, Welsh and Sabiston 2017, Salvatore and Marecek 2010]. Therefore, focusing on muscle-strengthening activities could be a strategy for men living with obesity as they are stronger than their lean counterparts [Gill et al. 2017], report a lower rate of perceived exertion compared to aerobic

activities at the same intensity, and may display greater self-worth compared to individuals without obesity when performing muscle-strengthening activities [Ten Hoor et al. 2016].

Among the methods of performing muscle-strengthening activities, circuit training is less time-consuming and can target outcomes typically associated with both muscle-strengthening activities and aerobic activities by sustaining a high heart rate [Hrubeniuk et al. 2014]. Previously, Dr. Bouchard's research group showed that adults living with obesity spent 92.5 % of their time during strength circuit training at moderate aerobic intensity [Bharti et al. 2017]. Recently, we showed that men living with obesity performing the same circuit training adapted for a home setting could also reach 90% of the total exercise time at moderate aerobic intensity [Keshavarz 2019]. Given that a muscle strength circuit program can lead to reaching both components of the physical activity guidelines, it is important to test the long-term adherence to such a program.

To increase long-term adherence, the main barriers to regular activity must be targeted [Brinthaupt, Kang and Anshel 2010]. The main barriers to exercise for adults included lack of time [Korkiakangas, Alahuhta and Laitinen 2009, Trost et al. 2002], costs [Resnick and Nigg 2003], and transportation [Resnick and Nigg 2003]. Additionally, people living with obesity report other barriers, such as the need for a minimum level of fitness [Gill et al. 2017], or technical skills [Kuriyan 2018], being ashamed of their bodies [Westermann et al. 2015] and the lack of gender-specific programs [Ross et al. 2012]. Offering a program in the home specific for men living with obesity could meet all these barriers, especially during the global Covid-19 pandemic that caused lockdowns, social interaction limitations [Killgore et al. 2020] and fitness centres closures [Kaur et al. 2020]. The primary objective of this study was to test if an online muscle strengthening circuit program offered for 12

weeks, leads to a greater proportion of men living with obesity adhering to the two components of the physical activity guidelines compared with the control group at 12 weeks, 24 weeks and 46 weeks after baseline. The second objective was to investigate if participants in the intervention group would improve anthropometric measures, body composition, and metabolic profile (resting heart rate, blood pressure, lipids/glucose) and benefits/barriers compared with the control condition. It was hypothesised that the online muscle strengthening circuit program could lead to a minimum of 26.3% of men living with obesity adhering to the two components of the physical activity guidelines and imprvoe antropometrics, body composition and metabolic profile, 46 weeks after baseline compared to the control group.

4.3 METHODS

4.3.1 Study design

The current study is a parallel randomized controlled trial comparing men living with obesity who were offered an online-based muscle strengthening circuit program for 12 weeks to a control condition (online resource to exercise on their own). Participants were randomly assigned in a 1:1 ratio to either the intervention or the control condition. Assessments were performed at baseline, 12 weeks (post-assessment), 24 weeks, and 46 weeks (Table 1). All participants were provided with an informed consent form, signed before participation. The Research Ethics Board approved the study of the University of New Brunswick (REB #2020-008).

Since this project was conducted during the global pandemic of Covid-19, amendments to the original protocol were made. First, we originally planned to measure cardiorespiratory fitness at all time points, but many participants did not accept wearing

the mask. As a result, this measure is only available at baseline. Also, the goal was to follow participants for a full year (52 weeks after enrollment), but we decided to reduce the follow-up time to avoid another wave of Covid-19 predicted after the Christmas period. As a result, a follow-up at 46 weeks was conducted.

4.3.2 Inclusion/exclusion criteria

Recruitment was done through flyers at the university and through Facebook. The focus was placed on the facts that this program was only offered to males, free performed at home without specialized equipment. Participants were eligible if they 1) characterized themselves as men, 2) were aged ≥19 years of age (self-reported), 3) displayed a body fat percentage greater or equal to 25% [WHO 1995] confirmed by a BodPod measurement (COSMED; Rome, Italy) at the baseline visit, and 4) had access to the internet at home to perform the online program. Participants were excluded if they reached the two components of the physical activity guidelines (150 min of moderate to vigorous aerobic activities + two sessions of muscle-strengthening activities per week) [WHO 1995] as measured by a heart rate tracker (Fitbit HR charge3) (California, US) [Thomson et al. 2019] and an exercise log over seven consecutive days. Men were also excluded if they reported any condition (e.g., severe knee arthritis) that could impact their ability to perform the program or take medications impacting heart rate.

4.3.3 Participant recruitment

A total of 132 individuals were screened, and 57 were excluded because they did not meet one of the inclusion criteria (Figure 1). Therefore, 75 participants completed baseline assessments, from which 15 were excluded because they were either meeting physical activity guidelines (N= 8), not meeting a minimum of 25% of body fat (N= 5), or declined

to participate in the study (N= 2). Finally, 60 participants were randomly assigned to the intervention group (n=30) and control condition (n=30), from which 11 dropped out in both groups by the end of the last follow-up (46 weeks). As a result, 19 in each group were analyzed. The baseline assessment started in September 2020, and the last follow-up assessment took place in December 2021. No significant difference was observed between participants in the intervention group who dropped from the program (N = 11) and completers (N = 19) on baseline measures, with the exception that a greater proportion (36.4%) of dropouts were meeting the aerobic guideline comparing with 0% of completers (p= 0.005).

4.3.4 Randomization

Randomization was done after obtaining informed consent from all participants and once the eligibility was confirmed. Participants were randomly assigned to either the intervention or control group to obtain a ratio of 5:5 for every 10 participants. An external person who had no role in the study did the randomization. Computer-generated random numbers created the randomization sequence via SPSS software 16.0. Allocation was done by a research assistant not involved in this project.

4.3.5 Intervention

Participants in the intervention group were asked to exercise three times per week while performing four basic bodyweight exercises in a circuit manner for 12 weeks while supervised online via the Microsoft TEAMs platform. The program was offered in different weekly periods to accommodate different work schedules. If a participant missed a session, there plenty of opportunities to participate in another session.

Before starting the 12-week intervention, each participant received a personal in-person educational session explaining exercises. Participants were eased into the program by completing 120 minutes of exercise in week one, 150 minutes in week two, and 180 minutes in the following weeks. Participants were supervised 3X/week for the first four weeks, then 2X/week for the next four weeks and 1X/week for the remaining four weeks. This strategy was used previously to increase participant autonomy before they started the unsupervised phase [Rowlands et al. 2004]. At each session (Figure 2), participants performed the four prescribed exercises (squats, tricep dips, lunges, and push-ups) for 45 seconds each, then switched immediately (15 seconds) to the next exercise, followed by one minute of rest at the end of each circuit. Following this exercise program, men living with obesity reached moderate intensity [Keshavarz 2019]. The circuit was repeated until the session was completed. Modifications were made if a participant had restrictions that prevented him from performing an exercise. Instructors checked the attendance list every session.

Participants allocated to the control group received an online exercise resource for a 12-week workout plan covering fitness components required to reach both components of the weekly physical activity guidelines on their own [Gold's Gym]. Before starting the program, each participant received a personal, educational session explaining the Gold's-gym workout plan. It was recommended to do a minimum of 150 minutes of moderate to vigorous aerobic activities and two sessions of muscle-strengthening activities using an online program. No supervision was offered, and no contact was permitted between the research team and participants from this group.

It should be noted that participants in both groups received their health/fitness assessment reports at 12 weeks, 24 weeks and 46 weeks.

4.3.6 Primary outcome

Adherence to the physical activity guidelines 46 weeks after baseline was the primary outcome (yes/no). It was also captured after 12 and 24 weeks. To be considered as meeting both components of the physical activity guidelines, a participant needed to accumulate a minimum of 150 minutes of aerobic activities at moderate to vigorous intensity (≥40% of heart rate reserve) [Daniel et al. 2004] tracked by a Fitbit charge 3 on the non-dominant wrist (California, US) [Thomson et al. 2019] and report a minimum of two sessions of muscle-strengthening activities (days, duration, setting) over seven consecutive days. Fitbit devices have been reported in a systematic review by [Fuller et al. 2020] as accurate devices for measuring steps and heart rate. Once participants returned the Fitbit, heart rate data was extracted using the Fitbit Javascript platform (https://dev.fitbit.com/) and recorded every five seconds. A minimum of four days (10 hours/day) was considered as a valid day. At 12, 24 and 46 weeks, completing the online muscle strength circuit program was considered as a muscle-strengthening session and counted for aerobic activity if reaching moderate to vigorous intensity was attained.

4.3.7 Secondary outcomes

In addition to the main outcome, some descriptive and health outcomes were measured at different time points. These included anthropometrics, blood pressure, and resting heart rate. They were all measured following CSEP protocols [CSEP 2021]. Body fat percentage and muscle mass (kg) was estimated using the BODPOD (COSMED; Rome, Italy) (Error ±1-2.7%). BMI was calculated by a person's weight in kilograms divided by height in

meters squared (kg/m^2) [WHO 2022]. Fasting lipid and glycemic profiles were measured at the fasting level using finger-prick blood samples and analyzed via an automated analyzer [Barrett, Huffman and Johnson 2011] (2300 StatPlus analyzer, Yellow Springs Industries, USA).

At baseline, additional information was collected to understand better the sample, including age, household income (≤$100,000) and education level (college or higher). Because the program was offered online, participants' comfort level with technology was measured using the Functional Assessment of Currently Employed Technology Scale (FACETS) questionnaire [Lepkowsky and Arndt 2018]. The FACETS is a score ranging from 0 to 50, and scores of +35 are classified as comfortable with technology. Cardiorespiratory fitness was evaluated using a modified version of the Balke and Ware treadmill test [Balke and Ware 1959]. Briefly, after one minute of continuous walking (3.4mph), the grade was increased to 7.0%, progressively increasing by 1.0% every minute thereafter until 15.0%. If the participant was not fatigued, the grade was maintained at 15.0%, and the speed increased by 0.5 mph each minute until volitional fatigue. The exchange of oxygen, carbon dioxide, and participants' heart rate were continuously gathered using a TrueOne 2400 Metabolic Cart and a Polar FT1 heart rate monitor (Polar, Kempele, Finland). Finally, the Exercise Benefits/Barriers Scale (EBBS) was used at baseline and again after the intervention to determine individuals' perceptions of the benefits and barriers to regular exercise. The EBBS Scores ranged from 43 to 172, with a higher score showing less barriers to exercise [Sechrist, Walker and Pender 1987]. The average intensity during an exercise session, captured at week six, was 48.0 ± 5.8% of heart rate reserve.

4.3.8 Statistical analysis

Sample size calculation was done based on the anticipated change in the proportion of individuals living with obesity to achieve the same proportion of their lean counterparts meeting the two components of the physical activity guidelines. It was hypothesized that the proportion of men living with obesity who meet physical activity guidelines in the intervention group would increase to 26.3% at 36 weeks after intervention [Bennie et al. 2019a] compared with a 0% increase for the control group. The alpha level and power of analysis were set at 0.05 and 80%, respectively, considering a dropout rate of 30% in each group. A total of 23 people per group were required, so we recruited 30 per group.

Shapiro–Wilk and Leven's tests were performed to test for normality and equality of variances among continuous data. Data are presented as average ± standard deviation, while categorical data are presented as N (%). Chi-square tests and independent sample T-tests were used to assess differences in categorical and parametric variables between the two groups, respectively. Wilcoxon signed-rank and Friedman tests (categorical data) and Paired T-tests (parametric data) were used to determine the significant changes in the studied outcomes of each group at different time points (baseline, 12 weeks, 24 weeks, 46 weeks). Statistical analyses were performed using SPSS version 26. A ($p \leq 0.05$) was considered significant.

4.4 RESULTS

Baseline data for the study sample are presented in Table 2. The average age of participants was 41.7 ± 11.4 years old. The majority of the participants made a yearly household income equal or less than $100,000, and the majority had a college or university degree. The average body fat % was 35.4 ± 5.8% at baseline. A third of the sample (31.6%)

met the aerobic recommendation at baseline, while 7.9% met the recommendation for muscle-strengthening activities, but only in the control group. All participants were classified as comfortable with technology, with a score of 35 or more for all participants and an average of 44.3 ± 4.9. The average score concerning benefits/barriers to exercise participation was 131.6 ± 12.9.

Out of the 24 supervised sessions, participants who completed the trial attended an average of 22.8 ± 1.3 sessions or 95% during the active phase of the intervention. Participants in the intervention group had a significantly higher adherence to both components of physical activity guidelines (150 min of aerobic activities + ≥2 sessions of muscle-strengthening) compared with the control condition at 12 weeks (intervention 56.6% vs control 5.0%; p= 0.001), 24 weeks (intervention 38.9% vs control 10.5%; p= 0.031) and 46 weeks (intervention 36.8% vs control 5.3%; p= 0.021). (Figure 3).

A higher proportion of participants in the intervention group reached the minimum guidelines for muscle-strengthening activities (≥2 sessions/week) compared with the control group at 12 weeks (intervention 84.2% vs control 22.2%; p<0.001), 24 weeks (intervention 42.1% vs control 10.5%; p= 0.028) and 46 weeks (intervention 36.8% vs control 5.3%; p= 0.021). The proportion of participants who reached aerobic guidelines (≥150 min of physical activity/week) was not significantly different between the two groups at 12 weeks (intervention 57.9% vs control 33.3%; p>0.05) (intervention 256 ± 261 minutes vs control 162 ± 152 minutes), 24 weeks (intervention 89.5% vs control 68.4%; p>0.05) (intervention 392 minutes ± 231 minutes vs control 358 minutes ± 424 minutes) and 46 weeks (intervention 73.7% vs control 57.9%; p>0.05) (intervention 254 ± 172 minutes vs control 255 minutes ± 287 minutes).

All secondary outcomes data are presented in Table 3. There was a significant reduction in waist circumference in the intervention group at 12 weeks ($p=0.001$), 24 weeks ($p=0.006$) and 46 weeks ($p=0.009$) compared to their baseline measures, while the figures for the control condition were only significant at 24 weeks ($p=0.041$) and at 46 weeks ($p=0.005$) compared to their baseline. However, between intervention and control groups, there was no significant difference at any of the time points ($p>0.05$).

There was a significant reduction in resting heart rate in the intervention group at 12 weeks ($p\leq0.001$), 24 weeks ($p\leq0.001$) and 46 weeks ($p\leq0.001$) compared to baseline measures. Similar results were observed for the control condition, with a significant reduction at 12 weeks ($p=0.023$), 24 weeks ($p\leq0.001$) and 46 weeks ($p=0.005$). Again, there was no significant difference between the two groups at measured time points ($P>0.05$). No significant change was observed for lipid profile, anthropometrics and body composition compared with baseline values in neither group.

Finally, participants in the intervention group significantly increased their exercise benefits/barriers score after 12 weeks of being exposed to the circuit program ($p=0.039$), with a greater change in the intervention group compared with the control group ($p=0.021$).

4.5 DISCUSSION

The online muscle strengthening circuit program led to a significant increase in adherence to both components of physical activity guidelines among men living with obesity 46 weeks after being offered the program. Following the program, the perceived barriers and benefits score increased more in the intervention group compared with the control group. However, only the resting heart rate and the waist circumference reduced significantly for the intervention group, and the improvements were not superior compared

with the control group. The improvements were not superior compared with the control group, and therefore no intervention effect was seen.

Many epidemiological studies suggested that meeting both components of the physical activity guidelines outweigh by far meeting each of these individually [Bennie et al. 2016, Bennie et al. 2019a, Bennie et al. 2019b, Bennie et al. 2020a, Bennie et al. 2020b, Bennie et al. 2020c, Bennie, Teychenne and Tittlbach 2020]. The proposed online muscle strengthening circuit program led to an exceptional attendance rate (95%), with almost 37% of participants still meeting both components of the physical activity guidelines after 46 weeks. This high attendance rate, which is higher than usually reported [Lin, Nguyen and Thomas 2019], could be related to the fact that the program addressed many barriers to regular exercise reported by men living with obesity, such as lack of time [Korkiakangas, Alahuhta and Laitinen 2009, Trost et al. 2002], need for transportation [Resnick and Nigg 2003], weight stigma by exercising at a private space [Himmelstein, Puhl and Quinn 2018] in addition to Covid-19 restrictions [Dwyer et al. 2020]. These findings are supported by the fact that benefits/barriers to physical activity score was significantly greater by the end of the 12-week intervention. Addressing the perception of lacking time to exercise is important because it is the most reported reason among all adults [Heesch and Mâsse 2004]. For example, Collins et al. (2022) found that among the 947 participants exercising for 6-8 months, 40% of participants reported lack of time as the reason for dropping out [Collins et al. 2022]. By removing the time to come and go from a fitness facility throughout the online muscle strengthening circuit program, it possibly contributed to a high proportion of men still meeting the two components of the physical activity guidelines after 46 weeks.

Although successful in increasing the proportion of men living with obesity to reach the two components of the physical activity guidelines, participants in the intervention group failed to improve most measured health outcomes compared to baseline and the control group. Among the measured health outcomes, only waist circumference and resting heart rate were significantly improved within 46 weeks, but in both groups. Reducing waist circumference and resting heart rate as important factors in reducing the risk of cardiometabolic diseases and premature death [Aune et al. 2017, Hartaigh et al. 2014, WHO 2011] was observed in both groups. The fact that no differences were observed between groups could be explained by the fact that the proportion of participants who reached aerobic guidelines was not significantly different between the two groups at 12 weeks (intervention 57.9% vs control 33.3%; $p>0.05$), 24 weeks (intervention 89.5% vs control 68.4%; $p>0.05$) and 46 weeks (intervention 73.7% vs control 57.9%; $p>0.05$). In a meta-analysis by Rimers et al. (2018) of 191 studies, it was reported that endurance exercises are the most effective to decrease resting heart rate and other health outcomes as opposed to resistance activities, yoga and recreational sports [Reimers, Knapp and Reimers 2018]. Future studies using the online muscle-strengthening circuit program should consider selecting outcomes associated with muscle-strengthening activities such as muscular strength, endurance, and power.

As far as the other health outcomes measured, it was expected that body weight, body composition and other metabolic outcomes would have improved following the 12-week intervention. One of the reasons these outcomes were not seen could be that the diet was not controlled. Contrary to popular belief, it is not inevitable that increasing physical activity level leads to significant weight loss. Meta-analyses exploring the efficacy of

exercise, with and without a controlled diet, on weight outcomes for people living with obesity indicated that physical activity without controlled diet results in modest weight loss [Ballor and Poehlman 1994, Garrow and Summerbell 1995, Miller, Koceja and Hamilton 1997]. Similarly, systematic reviews have shown that regular exercises could improve metabolic profile in patients with metabolic diseases [Ashtary-Larky et al. 2021, Borror et al. 2018, Gillett et al. 2012, Ostman et al. 2017] ; but are not as effective for healthier individuals [Wang and Xu 2017]. Participants in the CIRCUIT study were middle-aged adults (average 41.7 years old), not completely inactive at baseline (31.6% meeting the aerobic component of the physical activity guidelines), with a metabolic profile within norms. Moreover, because of the mode of exercise, it is possible that the resistance training program did not led to the expected energy expenditure, as proposed by Cadieux et al. (2014) during sessions to induce significant physiological changes [Cadieux et al. 2014]. In addition, this study was conducted in the early phases of the Covid-19 pandemic crisis. There might have been many changes in participants' behaviour, including eating habits [Di Renzo et al. 2020], sleeping hours [Alomari et al. 2021], work, social and leisure time activities [Arundell et al. 2021], which were not controlled in this study and all could affect the outcomes of this study. On the other hand, It should be noted that a significant weight loss happened in participants in the control group. While this seems paradoxical despite having no prescribed activity regimen for the control group and the intervention group did not lose weight, but these observations might highlight other important factors at play for weight loss outcomes (e.g., diet, energy compensation) which were not controlled in the current study. Moreover, self-motivation of participants in the control group to loss weight

could be another potential reason why a significant weight loss happened to them [Waters et al. 2012].

4.6 LIMITATIONS

Although the current study provides insight into a program that led to an exceptional adherence to physical activity guidelines in men living with obesity, some limitations need to be acknowledged. First, the initial sample size was calculated based on the primary outcome, and therefore, the analysis for secondary outcomes was subjected to statistical errors and less power in analysis. No control was done for energy intake for both groups nor other life activities. The Fitbit used to capture the aerobic component of the physical activity guidelines using the heart rate may have presented possible errors, such as responding to changes in activity and conditions [Bent et al. 2020]. Finally, only supervised sessions were considered for the attendance rate; therefore, the attendance is unknown from the non-supervised sessions during weeks 5 to 12.

4.7 CONCLUSION

This novel online muscle-strengthening circuit program significantly increased the proportion of men living with obesity meeting both components of physical activity guidelines, with more than a third of participants still meeting both components of the physical activity guidelines 46 weeks after enrolment. While this is good news since it is hard to motivate men living with obesity to be regularly active, the health benefits normally associated with completing the physical activity guidelines were not improved. Future studies should select outcomes related to muscle-strengthening activities and could recruit men living with obesity who have more comorbidities at baseline, such as metabolic syndromes. Future studies could also focus on laboratory methods to measure oxygen

consumption/energy expenditure of the online muscle strengthening circuit program to see whether this program meets the equivalent energy expenditure of the two components of the physical activity guidelines (150 min of moderate to vigorous aerobic activities + two sessions of muscle-strengthening activities per week) in order to have a significant impact on health outcomes.

Table 1. Outcome measurement schedule

Outcome	Baseline	12 weeks	24 weeks	46 weeks
Meeting physical activity guidelines (Fitbit heart rate + exercise log)	X	X	X	X
Descriptive outcomes Age, income, education Comfort with technology (FACET questionnaire) Fitness level (VO_2 max)	X			
Health Outcomes Anthropometrics (BMI, waist circumference) Blood pressure Resting heart rate Body composition (body fat %, muscle mass) Fasting lipids profile Fasting glycemic profile	X	X	X	X
Benefits /barriers to physical activity (EBBS questionnaire)	X	X		

FACET: Functional Assessment of Currently Employed Technology Scale
EBBS: Exercise Benefits/Barriers Scale

Table 2. Baseline Characteristics of participants (N=38)

	Intervention (N=19)	Control (N=19)
Age (years)	41.4±10.1	42.0±12.7
Annual household income (≤100,000$)	4 (22.5)	5 (27.8)
Education (College or higher)	19 (100)	16 (85.3)
Body mass index (kg/m^2)	28.6±3.0	29.2±3.8
Waist circumference (cm)	111.8±10.3	112.2±10.6
Body fat (%)	35.8±5.7	34.9±6.1
Muscle mass (kg)	64.6±6.9	67.9±8.4
Resting heart rate (beats/min)	76.0±8.6	71.8±11.5
Cardio-respiratory fitness (mL/kg/min)	36.8±7.1	37.9±9.2
Systolic blood pressure (mm Hg)	128.3±12.7	130.7±10.1
Diastolic blood pressure (mm Hg)	80.4±18.8	85.5±6.2
High-density lipoprotein (mmol/L)	1.1±0.1	1.0±0.2
Triglyceride (mmol/L)	1.6±0.8	1.6±0.7
Glucose (mmol/L)	5.6±0.6	5.6±1.0
Meeting aerobic criteria of the physical activity guidelines	6 (31.6)	6 (31.6)
Meeting muscle-strengthening criteria of physical activity guidelines	0 (0)	3 (15.8)
Comfort with technology (0-50; more = better)	44.3±4.9	40.9±5.0
Benefits/barriers to exercise (43-172; more = better)	133.7±14.9	129.5±10.4

Data are presented as N (%) or average ± SD

Table 3. Measured Outcomes Before and After the Program

	Control				Intervention			
	Pre	**12-week**	**24-week**	**46-week**	**Pre**	**12-week**	**24-week**	**46-week**
BMI (kg/m^2)	29.2±3.8	27.9±3.4	27.5±3.5	27.2±3.2	28.6±3.1	28.6±3.1	28.5±3.3	29.0±4.1
Weight (kg)	105.1±15.1	100.5±13.8*	98.8±14.0*	97.4±13.2*	101.3±13.2	101.4±13.5	100.9±14.2	100.5±15.6
Waist Circumference (cm)	112.2±10.6	109.8±114	106.8±12*	104.6±12.1*	111.8±10.3	108.5±11.4*	108.1±11.8*	108.3±13.1*
Body Fat (%)	34.9±6.1	34.1±6.8	32.5±7.8	32.2±6.8	35.9±5.7	35.6±6.1	35.5±5.7	35.4±6.3
Muscle Mass (kg)	67.9±8.4	65.8±7.2	65.8±6.9	65.4±7.1	64.6±6.9	64.9±6.5	64.9±6.9	64.1±6.6
Resting Heart Rate (beat/min)	71.8±11.5	68.0±9.0*	64.8±9.1*	67.1±10.9*	76.0±8.6	68.1±10.3*	65.6±8.7*	66.0±7.4*
Systolic BP (mmHg)	130.7±10.1	127.2±126	129.4±134	129.2±13.7	128.3±12.7	127.3±12.1	131.7±12.5	131.8±15.0
Diastolic BP (mmHg)	85.5±6.2	83.6±7.3	84.4±8.3	81.8±10.1	80.4±18.8	81.8±6.3	84.3±6.6	86.1±12.3
HDL (mmol/L)	1.0±0.2	1.0±0.1	1.1±0.2	1.1±0.2	1.1±0.1	1.0±0.1	1.1±0.1	1.2±0.8
Triglyceride (mmol/L)	1.6±0.7	1.3±0.7	1.6±0.8	1.4±0.7	1.7±0.9	1.5±0.6	1.8±1.0	1.4±0.8
Glucose (mmol/L)	5.6±1.0	5.3±0.5	5.4±0.7	5.5±0.7	5.7±0.6	5.7±1.0	5.6±0.7	6.0±0.9

Data are presented as average ± SD; BP=Blood Pressure, HDL= High Density Lipoproteins
*Significant change compared with baseline

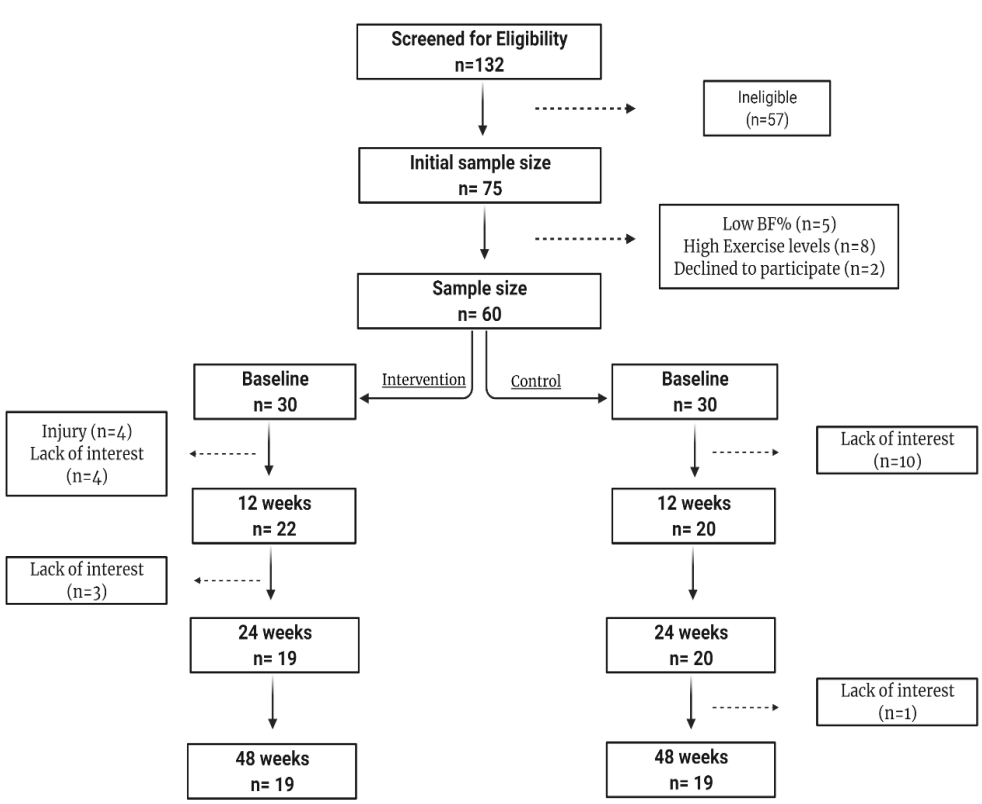

Figure 1. Participant flow chart

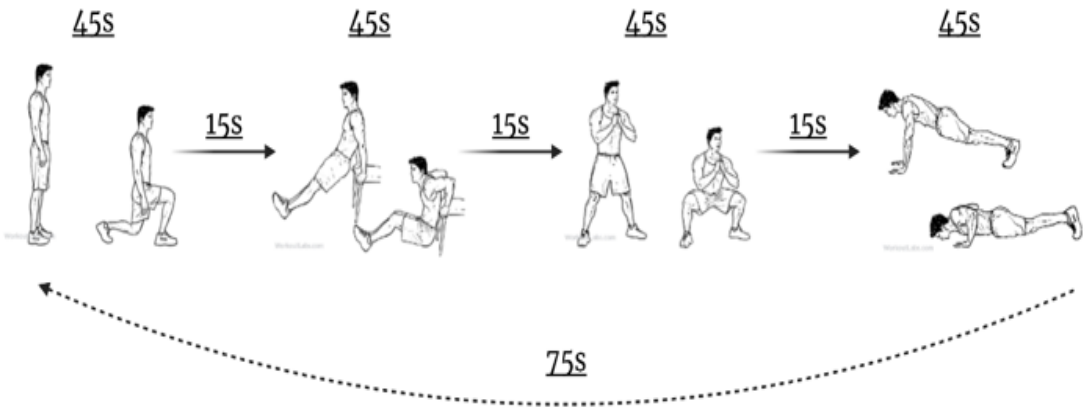

Figure 2. Online muscle-strengthening circuit program

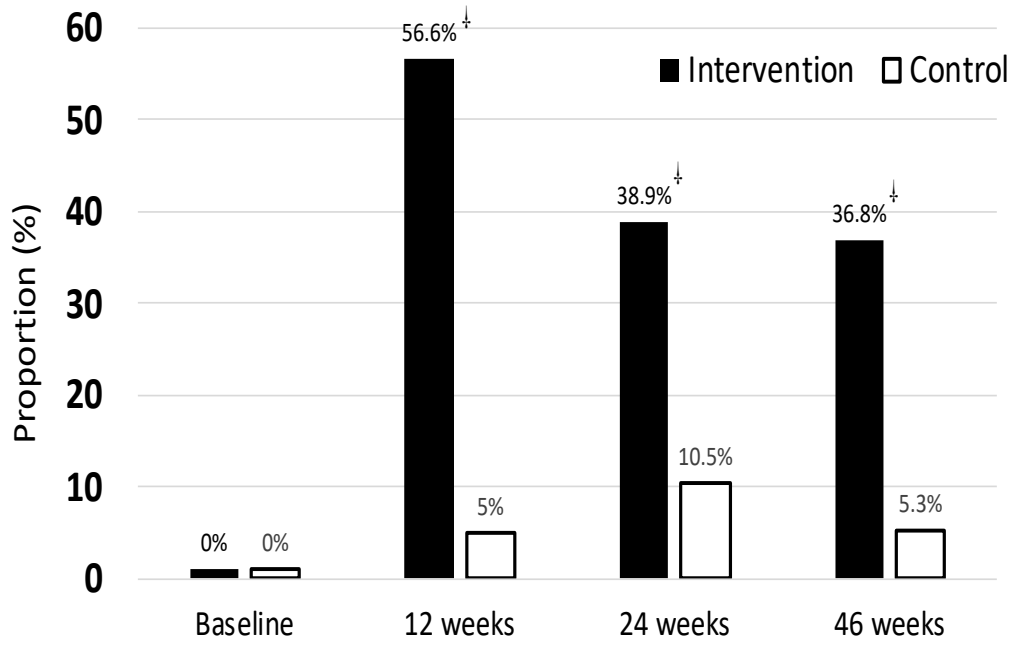

Figure 3. Chi-square results on the proportion of participants reaching both components of physical activity guidelines
⸸Significant difference between groups

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CHAPTER 5: DISCUSSION

As a reminder, the aim of this dissertation was threefold. First, to investigate the benefits of meeting muscle-strengthening activities guidelines in people living with obesity in terms of body fat percentage, mortality, and further explore whether sex moderates those outcomes. It was hypothesized that meeting the muscle-strengthening activities guideline is correlated with a lower body fat % as well as mortality and sex is a significant moderators in those correlations. We observed that meeting muscle-strengthening activity guidelines was associated with lower body fat but not mortality in people living with obesity; however, it did not affect men and women differently.

Second, we explored whether circuit strength training could reach moderate intensity and bring health benefits to individuals living with obesity. It was hypothesized that individuals living with obesity could reach moderate aerobic intensity by practicing circuit strength training and experiencing health benefits. Our main findings are that participants were able to reach moderate intensity regardless of the indicator used to quantify the intensity.

Third, using a randomized controlled trial to investigate if an online-delivered muscle strength circuit training could increase adherence to both components of the physical activity guidelines (≥150 min of moderate to vigorous aerobic exercise + ≥ two sessions of muscle-strengthening activities) by addressing barriers to engage in regular exercise in men living with obesity and improve health outcomes compared to the control group. It was hypothesized that the online delivered muscle strengthening circuit program could help men living with obesity adhering to the two components of the physical activity guidelines 46 weeks after baseline compared to the control group. Our main hypothesis was

confirmed. A 12-week online circuit program led a significant proportion of men living with obesity (36.8%) to adhere to both components of physical activity guidelines yet after 46 weeks.

Obesity is recognized as a serious and costly disease [Bray 2004]. Even though both men and women live with obesity, men are more likely to develop one of the resultant chronic conditions [White and Cash 2004] and less likely to participate in obesity management programs [Gavarkovs, Burke and Petrella 2016].

Several studies have outlined the barriers to regular participation in physical activity in adults/individuals living with obesity [Baruth et al. 2014, Benjamin and Donnelly 2013, Hickey and Mason 2017, Leone and Ward 2013, Peacock, Sloan and Cripps 2014]. Barriers include lack of time [Korkiakangas, Alahuhta and Laitinen 2009, Trost et al. 2002], costs of participating in exercise programs [Resnick and Nigg 2003], lack of transportation [Resnick and Nigg 2003], technical skills required [Kuriyan 2018], minimum fitness requirements [Gill et al. 2017], and nowadays Covid-19 pandemic restrictions [Brand, Timme and Nosrat 2020] are among the most noted barriers. Moreover, for men living with obesity, gender preferences have also been a significant barrier/enabler to participating in an exercise program [Ross et al. 2012].

Between aerobic exercises and muscle-strengthening activities, individuals living with obesity may prefer doing muscle-strengthening. This could be partially because they have more absolute muscle mass than their lean counterparts [Gill et al. 2017]. Additionally, individuals living with extra weight tend to report a lower rate of perceived exertion compared to aerobic activities at the same intensity, and may display greater self-worth compared to individuals without obesity when performing muscle-strengthening activities

[Ten Hoor et al. 2016]. However, there could be a lower energy expenditure for the same heart rate compared to aerobic activities [Bloomer 2005]

Among different muscle-strengthening exercises, circuit training is shown to significantly increase heart rate [Roberson et al. 2018], counting as an aerobic activity. Therefore, circuit training could be considered a single form of exercise that fulfills physical activity guidelines for aerobics and muscle-strengthening [Gettman and Pollock 1981, Jacobs, Nash and Rusinowski 2001, Kaikkonen et al. 2000].

In 2014, Hrubeniuk et al. (2014) realized it was possible to reach moderate intensity while performing circuit strength training [Hrubeniuk et al. 2014]. By adapting the strength training exercises with shorter breaks between exercises, Bharti et al. (2017) showed that 92.5 % of the training time could be spent at moderate intensity for people living with obesity. The four exercises used in their study were lunges, squats, lat pull down, and chest press [Bharti et al. 2017]. Later, our research team aimed to quantify aerobic intensity components while performing a circuit strength training session using oxygen consumption. We also recorded interest and enjoyment while doing circuit strength training compared to traditional guidelines involving aerobic and resistance programs. Our results showed that moderate intensity was reached no matter what cut-off was used to identify moderate intensity when performing the circuit strength training. Also, 70% of the participants in the circuit strength training group indicated a preference for the circuit strength training program if given a choice and more men than women [Keshavarz et al. et al. Submitted]. Later, we examined whether circuit strength training could be done without specialized equipment in a study involving ten men having a BMI over 30 kg/m^2. Participants performed two acute sessions of the circuit strength training program. During

the first visit, they completed exercises without equipment (lunges, push-ups, squats, tricep dips) for one-minute each, followed by one-minute of rest. The circuit repeated until 50 minutes were complete. During the second visit, the same circuit exercises were performed, but the order was altered (squats, push-ups, lunges, triceps dips). The results showed that participants reached moderate intensity for 89% of the total time with no significant difference between two visits in a different order [Keshavarz 2019].

Considering potential benefits of strength training and based on our previous work, it was determined that individuals living with obesity, both men and women, could experience different benefits when participating in regular muscle strength activities. We also thought that they could show interest, get health benefits, and reach moderate aerobic intensity by doing a brief circuit strength training. Furthermore, as adherence to physical activity guidelines among men living with obesity has been a significant challenge in the past, we thought it could be possible to use the circuit strength training delivered online at home/workplace without specialized equipment to increase long-term adherence to the physical activity guidelines among men living with obesity.

As a result, three studies were performed with specific objectives. The first was to examine the health benefits of meeting muscle-strengthening activities guidelines ($\geq$ 2 sessions/week) for individuals living with obesity and further explore whether the benefits are moderated by sex. The second was to identify the feasibility of a brief circuit strength training and test if it permits reaching moderate aerobic intensity for individuals living with obesity and document the potential health benefits for participants. Finally, the third was to test if the brief strength circuit training can be offered online to increase long-term adherence to the physical activity guidelines for men living with obesity.

5.1 Summary of findings

The objectives of the first article in chapter two [Keshavarz et al. 2022] were to study the associations between performing muscle-strengthening activities two times per week and 1- body fat % 2- mortality and if these associations were different based on sex. We found that meeting muscle-strengthening activities was associated with lower body fat %. Moreover, although more men than women living with obesity meet the muscle-strengthening activities guidelines, no interaction between sex and muscle-strengthening activities was significant for the studied outcomes. These findings indicated that regular participation in muscle-strengthening activities would similarly benefit both men and women living with obesity.

Studies have shown that muscle-strengthening activities can improve a wide range of health outcomes, including glucose metabolism [Cheng et al. 2007], body composition [Treuth et al. 1994], blood pressure [Collier et al. 2008] and other cardiovascular markers [Churilla et al. 2012, Egana, Reilly and Green 2010], and therefore, it could play a role in reducing the risk of chronic conditions (e.g. obesity, cancer, diabetes) [Castaneda et al. 2002, Galvao et al. 2006, Loprinzi, Loenneke and Abe 2015, Pu et al. 2001]. It seems that meeting versus not meeting the guidelines for muscle-strengthening exercises (≥2 sessions per/week) is the most effective factor in reducing mortality risks. For example, a prospective cohort study by Scott et al. (2016), investigated the potential dose-response relationship between the frequency of muscle-strengthening activities and the incidence of cardiovascular diseases. They used data of 8772 adults who were followed for an average of 6.7 years. It was reported that although muscle-strengthening activities were negatively related to premature all-cause mortality, only 18.6% of the study sample met guidelines for muscle-strengthening activities, and 91.6% did not engage in any muscle-strengthening

exercises. Participants who did not meet muscle-strengthening activities guidelines did not fail to meet guidelines because of insufficient exercising but due to a complete lack of participation in such activities. However, the proportion of participants who met aerobic guidelines (≥150 minutes/week) was almost twice as large as those who met muscle-strengthening (34.9% vs. 17.7%), with nearly a third of them (33.0%) still engaged in some form of aerobic activities. Therefore, it is necessary to develop strategies to help people increase participation in muscle-strengthening exercises and, more importantly, to facilitate the initiation of these activities [Dankel, Loenneke and Loprinzi 2016]. The findings of the first article in chapter two recommended that although men and women face different barriers/enablers to regular exercise and have physiological differences, doing muscle-strengthening activities (≥ 2times/week) should be equally implemented in both men and women with obesity as it can similarly benefit them.

The objectives of the second article in chapter three were to explore if individuals living with obesity show interest, reach moderate aerobic intensity, and potentially improve their health outcomes by participating in a brief circuit strength training program. The findings of the second article indicated that participants demonstrated both high levels of interest and improved their BMI throughout the program. By reaching moderate aerobic intensity, it was indicated that the circuit strength training program could contribute to the aerobic portion of the physical activity guidelines. Therefore, it could reduce the weekly time required to meet the minimum exercise recommendations. According to the literature, it is recognized that individuals living with obesity may prefer strength training over aerobic exercises considering some of their possible limitations, such as mobility issues [Fletcher et al. 2001], lower fitness levels [Schranz et al. 2014], and high rates of osteoarthritis

[Messier et al. 1994, Messier et al. 2005]. In a review by Castellani et al. (2013) on useful strategies to ensure long-term adherence to an exercise regime in individuals living with obesity, feelings of security, control, competence, and self-esteem were noted as determinative factors to help people living with overweight/obesity to keep up a regular exercise habit [Castellani et al. 2003]. Although the physiological outcomes (except BMI) in the study #2 did not improve significantly, non-significant improvements were seen in body fat % and blood lipids. Perhaps, having a larger sample size could lead to the expected health outcomes.

By proposing a novel strength training program that is brief, repetitive, and interesting to the participants, the second article recommended that it is worth investigating if implementing a circuit resistance training, using an appropriate study design, that could address barriers to regular participation in exercise, could lead to a long-term adherence in individuals living with obesity.

The objectives of the third article (Circuit study) in chapter four were to explore whether offering online supervised muscle strength circuit training to men living with obesity translates into meeting the physical activity guidelines and improving health outcomes. Based on the findings of the Circuit study, the online circuit training led to a significant increase in adherence to both components (aerobic and muscle-strengthening) of physical activity guidelines among men living with obesity after 46 weeks. The circuit program also positively changed the view of men living with obesity of the perceived benefits/barriers to engaging in a regular exercise regime by addressing barriers to participating in regular physical activity. However, similar to the results of our pilot study (Study #2 in chapter three), the Circuit study did not succeed in improving physiological outcomes. By

recruiting only men and targeting the main barriers to regular exercise, the Circuit study results were a steppingstone in recommending online-delivered circuit training as a sole strategy for men living with obesity who struggle to reach the minimum requirement for physical activity guidelines.

Although the Circuit study succeeded in engaging a significant proportion of men living with obesity in meeting the physical activity guidelines, the expected physiological outcomes, based on the literature [Boardley et al. 2007, Elliott, Sale and Cable 2002, Marques et al. 2009] were not observed. Twells et al. (2021), in a systematic review of systematic reviews and meta-analyses on non-surgical programs, investigated the results of 64 meta-analyses, including 1180 randomized controlled trials. The programs included diets, combination therapies, technology, behavioural, physical activity, and pharmacotherapy interventions. There were significant weight losses in 80% of the studies, ranging from 0.34-8.73 kg in intervention groups. Diets, either low-carbohydrate or low-fat diets, followed by six months, were the most effective non-surgical weight-loss programs. The authors reported that although physical activity and technology programs have been reported to cause weight loss, most of the studies reported non-significant values (≤ 2kg). [Twells et al. 2021]. Moreover, according to the ACSM position statement, for weight loss purposes, a minimum of 225-420 minutes/week of moderate to vigorous physical activity is needed (Swift et al., 2014). Therefore, engaging in a minimum level of recommended moderate to vigorous physical activity (150 min/week) would not be a plausible amount of exercise for weight loss.

As opposed to the Circuit study, the findings of the second article in chapter three indicated that a 12-week in-person circuit strength training (RT+ program) significantly

reduced BMI in individuals living with obesity. The differences in the studies' design (e.g., using weight machines, being in a gym environment) and participants' characteristics, such as having BMI ≥30 and age could partially explain the differences in BMI results between the two studies. Overall, the main objective of the Circuit study (study #3) focused on adherence to physical activity guidelines, and RT+ program (study #2) was a pilot study in nature. Therefore, considerations were not made to improve physiological outcomes in both articles. Perhaps, controlling lifestyle behaviours such as diet and increasing weekly physical activity levels could play a key role in improving physiological outcomes [Twells et al. 2021].

5.2 Impact of results and direction for future research

Generally speaking, after completing the three studies and articles throughout this thesis, we learned about the potentials of strength training in terms of health benefits, reaching aerobic intensity and increasing adherence to a regular physical activity regime among men living with obesity. Considering the very low participation rate in muscle-strengthening exercises among people living with obesity, steps need to be taken to introduce the potentials of strength training to the exercise professionals to be used in clinical practice. More specifically, based on the findings presented in this thesis, professionals and exercise advocates should consider strategies to engage both men and women living with obesity in muscle-strengthening exercises.

While clinical studies have demonstrated that the duration, intensity, and type of muscle-strengthening exercises could impact the outcomes, most public health research evaluates only the frequency of such activities. Developing a standardized muscle-strengthening activities assessment tool could help to establish valid global comparisons.

The fact that self-reporting tools assess muscle-strengthening exercises may be the key limitation in assessing these activities, and it might introduce bias (e.g., social desirability and over/under-reporting). Moreover, future research needs to investigate the key barriers contributing to low participation in muscle-strengthening exercise among the population subgroups who are more at risk of chronic conditions. Our findings show that a brief circuit strength training could reach aerobic intensity in people living with obesity and, therefore, reduce the weekly time required to meet the minimum exercise recommendations.

Finally, the Circuit study showed a high attendance and continuing in men living with obesity with almost a 1-year follow-up; however, in order to avoid dropouts, perhaps having a weekly session every couple of months could be helpful as the drop-out rate was increasing within the follow-up time points (12, 24 and 46 weeks). The online delivery of the Circuit study seemed to be a significant factor in addressing barriers to participating in exercise programs among men living with obesity. It could be considered an adequate delivery of an exercise program for men living with obesity. Also, to see improvement in physiological outcomes, future studies should consider outcomes related to muscle-strengthening exercises and could recruit men living with obesity who have more comorbidities at baseline, such as metabolic syndrome or higher levels of obesity. Because heart rate was the only measure of intensity during the circuit exercise program, a more accurate measure would be needed to confirm that the online-delivered circuit program is physiologically sufficient (e.g., oxygen consumption) to elicit changes in health outcomes. Moreover, having an optimal sample size based on the targeted physiological outcomes could also significantly improve those outcomes.

5.3 Conclusion

Taken together, the studies included in this dissertation show that muscle-strengthening activities lead to less body fat percentage regardless of sex, that men living with obesity can reach aerobic intensity and increase their adherence to the physical activity guidelines once exposed to a circuit muscle-strengthening training in a fitness facility setting or online. More research is needed to understand how the proposed program can lead to the typical health outcomes expected when doing regular exercise and how to implement such programs.

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