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Impact of 12-weeks of Nordic Pole Walking on Arterial Stiffness in Sedentary Overweight and Obese Adults

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A thesis submitted to the Graduate Faculty of

JAMES MADISON UNIVERSITY

In

Partial Fulfillment of the Requirements

for the degree of

Master of Sciences

Department of Health Professions

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FACULTY COMMITTEE:

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Dedication

This thesis is dedicated to:

My parents

Nexhat Shehu,
Who has been my emotional anchor through my entire life,
May his memory forever be a comfort and blessing,

Luljeta Shehu
Her sacrifice to raise me as a man with cemented values and principles has given me valuable educational opportunities.

To my sister *Njomza,* her husband *Butrint,* and my nephew *Jon,* and to my younger sister *Fjolla,*
For their endless love, support, and encouragement.

And to the memory of my uncle, *Lirim Islami,*
Who has been one of my greatest supporters though my entire educational journey.

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List of Abbreviations

1RM	One Repetition Maximum
AIx	Augmentation Index
AS	Arterial Stiffness
ba-PWV	brachial-ankle Pulse Wave Velocity
BMI	Body Mass Index
CCA	Common Carotid Arteries
cf-PWV	carotid-femoral Pulse Wave Velocity
cr-PWV	carotid-radial Pulse Wave Velocity
CVD	Cardiovascular Disease
fa-PWV	femoral-ankle Pulse Wave Velocity
LSR	Low-intensity Resistance Training With a Short Inter-Set Rest Period
MAP	Mean Arterial Pressure
NW	Nordic Walking
PACES	Physical Activity Enjoyment Scale
PP	Pulse Pressure
PWV	Pulse Wave Velocity
RCT	Randomized Control Trials
SW	Standard Walking
VO_{2max}	Maximal Oxygen Uptake

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Abstract

Arterial stiffness (AS) is an independent predictor for cardiovascular disease morbidity and mortality. Regular aerobic exercise is considered to improve AS. Nordic walking provides important health benefits, however, the effect of this walking method as treatment for AS remains unclear. We conducted a randomized controlled study to examine the effect of a 12-week supervised group walking intervention (controlled pace, ~3000 steps/day, 30 minutes/day, 5 times/week), with (NW) and without (SW) Nordic poles, on AS in sedentary overweight and obese adults. Fourteen individuals were randomly assigned to NW (n=7; median age 54.0 years; body mass index (BMI)=31.3 kg/m^2) or SW (n=7; median age 39.0 years, BMI 30.5 kg/m^2). AS was measured via carotid-femoral pulse wave velocity (cf-PWV) and carotid-radial PWV (cr-PWV) using applanation tonometry at baseline and post-intervention. The following were also recorded at baseline and post: body weight, BMI, waist circumference, body composition, seated and supine blood pressure, glucose, HbA1C, lipid panel, maximal oxygen capacity, 7-day physical activity (PA), 3-day food records, and PACES (PA Enjoyement Scale). On average, median walking compliance, including supervised and self-reported walking, was 88.30% for both groups (SW=88.30% and NW=86.70%). Median supervised walking compliance was ~75% and ~70% for SW and NW, respectively. Central (cf-PWV) and peripheral (cr-PWV) AS was similar at baseline and did not change significantly in either group with the intervention. PACES scores increased significantly ($p<0.05$), meaning greater enjoyment, for NW compared to SW. Correlations according to group indicate that supervised walking correlates with changes in PACES only for NW (r=0.899 , $p<0.05$). Walking compliance was inversely associated with changes in weight and BMI for NW, and with changes in waist circumference for SW (all $p<0.05$). In the present study, 12-weeks of meeting the 150 min/week PA guidelines at a controlled pace via NW or SW did not reduce AS in previously sedentary overweight and obese adults. However, our findings indicate NW participants experienced more enjoyment in PA compared to SW.

Key Words: arterial stiffness, exercise, nordic walking, sedentary lifestyle, overweight and obesity, cardiovascular diseases

Chapter One: Introduction

Cardiovascular diseases (CVD) are the number one cause of morbidity and mortality in developed countries and most developing countries (Benjamin et al., 2019). AS is an independent predictor of CVD and can induce diseases such as hypertension, left ventricular hypertrophy, coronary ischemia, and stroke (Laurent et al., 2012). A sedentary lifestyle has been identified as a risk factor for developing CVD, and it can promote arterial health changes that lead to arterial wall stiffening (Mitchell, 2015). Lifestyle and behavioral modification play a pivotal role in preventing AS and reducing the risk of CVD (Buttar, Li, & Ravi, 2005). The role of dietary factors and exercise in AS is undeniable, with healthier dietary patterns contributing to less arterial stiffness and vice-versa. (Bowen et al., 2016; Heller et al., 2004; Naismith & Braschi, 2003; Saneei et al., 2014; Shibata et al., 2018).

Regular moderate-intensity aerobic exercise is a powerful means to improve cardiovascular health (Agarwal, 2012). Regular aerobic exercise slows the age-associated rise in AS, as middle-aged and older adults who perform habitual aerobic exercise demonstrate lower pulse wave velocity (PWV) than their sedentary peers (Gando et al., 2010). Furthermore, a meta-analysis of randomized controlled trials (RCTs) demonstrated a significant improvement in PWV and augmentation index (AIx), another measure for AS, in response to aerobic exercise interventions. Additionally, trials with longer duration of intervention showed higher improvement in AS (Ashor et al., 2014). With respect to the effect of resistance training on AS, studies have shown that resistance training provides no beneficial effect on PWV and AIx, and it may even increase AS (Miyachi, 2013).

Nordic walking (NW) is a sports discipline that engages all limbs by using handheld poles, and research reveals that it allows individuals to gain the health benefits of endurance exercise (Cebula et al., 2017). A systematic review of 16 RCTs and 11 observational studies revealed that walking with poles activates both upper and lower extremities at a sufficient intensity that in the long term allows heightened improvements in resting heart rate, blood pressure, maximal oxygen consumption, and results in increased energy expenditure compared to brisk walking (Tschentscher et al., 2013).

Recently, two studies investigated the effect of NW on AS. A pilot study investigating postmenopausal overweight and obese women concluded that combining reduced caloric intake with NW and SW reduced AS significantly in both groups. A significant improvement in AS was found in the NW group in carotid-radial PWV (cr-PWV) compared to the SW group. Furthermore, a significant reduction at six months in carotid-femoral PWV (cf-PWV) was observed in both groups (Rossi et al., 2019). Additionally, an RCT including middle-aged participants with normal glucose tolerance, impaired glucose tolerance, and Type 2 diabetes investigated whether NW would improve cardiovascular function in this population. They demonstrated that 4-months of NW is an insufficient stimulus to improve vascular function in all three groups. However, the physical activity performed by the intervention group was self-reported, compliance could not be confirmed, and the intensity of exercise (NW) was not measured (Ring et al., 2015). To our knowledge, no studies have measured the effect of NW alone on AS compared to SW, while controlling for exercise intensity and compliance via supervised group walking sessions. Our study aims to identify the effect of NW on AS in sedentary obese/overweight adults.

Research Question

Does walking with Nordic poles for 150 minutes/week (3000 steps/weekday) at a controlled pace for 12-weeks reduce AS in sedentary overweight/obese adults to a greater extent than walking without Nordic poles?

Research Hypothesis

Sedentary overweight/obese adults walking with Nordic poles for 150 minutes/week (3000 steps/weekday) for 12-weeks will have a greater reduction in AS than participants walking without Nordic poles.

Objectives

1) To study if walking for 5 days/wk (30 min – 3000 steps/day) at a controlled pace for 12-weeks would result in reduced AS in sedentary overweight/obese adults.

2) To compare if the observed changes in AS would differ between the group walking with Nordic poles and the group walking without poles.

3) To evaluate if the magnitude of change in AS would vary significantly between the central and peripheral arteries.

Literature Review

This brief literature review will highlight the role of AS as an emerging independent risk factor for the prediction of future CVD, and the importance of lifestyle and behavioral modification (i.e., regular endurance physical activity and dietary modifications) as key factors to prevent arterial aging and reduce AS. Habitual aerobic exercise training resulting in improvements in cardiorespiratory fitness is associated with reductions in AS; whereas, resistance training appears to increase AS, which can be offset by combining it with aerobic exercise.

Walking with Nordic poles is an endurance sport discipline that increases the activity of upper and lower extremities. Investigations have shown that walking with Nordic poles provides health benefits and may affect resting heart rate, blood pressure, exercise capacity, and improve the quality of life of patients with various diseases. Thus, this sport discipline can be recommended for primary and secondary care prevention (Tschentscher et al., 2013). Also, studies have demonstrated the positive effect of walking with Nordic poles on body composition, muscle strength, and lipid profile in the elderly population (Song et al., 2013).

A. Definition and Importance of Arterial Stiffness

CVD is the leading cause of mortality in the U.S. and the world, accounting for one-third of all deaths in 2019 (Benjamin et al., 2019). The pathophysiological changes, both structural and functional, that occur in the vessels of the arterial tree can cause them to lose their biomechanical properties resulting in a loss of viscoelasticity leading to stiffening of the arterial walls (Quinn et al., 2012). AS, understood as reduced arterial compliance, is an independent predictor of CVD and has become an emerging biomarker in the assessment of vascular health (Laurent et al., 2012). Central and peripheral arterial stiffening contributes to the development of

CVD and is positively associated with the occurrence of hypertension (Safar et al., 2018), coronary artery disease and stroke (Bonarjee, 2018; Liao & Farmer, 2014; Sutton-Tyrrell et al., 2005), heart failure (Pandey et al., 2017), and atrial fibrillation (Fumagalli et al., 2017; Mitchell et al., 2007).

B. Pathophysiology and Mechanisms of Arterial Stiffness

The contractions of the heart cause blood to flow through the arterial system, providing oxygen and nutrients to the various tissues and organs. Under healthy physiological conditions, the left ventricle ejection of blood transmits the pulse waves down to the aorta. The transmitted pulse waves are partially reflected back to the heart, and the remaining waves are transmitted to the microcirculation. During diastole, the reflected wave arrives at the heart which allows perfusion of the coronary arteries to occur (Pappano et al., 2013). When the aorta is stiffer and with reduced elasticity, the reflected wave will arrive quicker during diastole or sometimes even during late systole, which reduces the coronary vessels' time to fill with blood (Garnier & Briet, 2016). The pulse waves traveling faster through a stiffened aorta increases the afterload, which provides greater resistance for the left ventricle to pump blood and contributes to hypertension and left ventricular hypertrophy (Mitchell, 2014). Furthermore, decreases of the perfusion pressure of coronary arteries may reduce the coronary blood flow, developing ischemic heart diseases such as myocardial infarction (Bonarjee, 2018).

In addition to the heart, other end organs are affected by the hemodynamic alterations and increased PWV related to AS. In the case of stroke the increased velocity of the transmitted pulse waves from stiffened large vessels to the cerebrovascular microcirculation increases the cerebral vascular resistance to the brain which damages the cerebral microvasculature and causes impaired cognitive functions (Chen et al., 2017). As mentioned previously, elevated blood pressure is associated with an increase of PWV, which may impact kidney health by reducing the glomerular filtration rate (Garnier & Briet, 2016). An inverse relationship between reduced glomerular filtration rate and elevated PWV has been observed in individuals with chronic kidney disease (Lioufas et al., 2019). Thus, AS may contribute to the eventual damage of end organs such as the heart, brain, and kidneys (Mitchell, 2015).

The development of AS is not uniform, occurring more often in larger elastic arteries (aorta, carotid) than in peripheral arteries (brachial, radial, tibial) (Adji et al., 2011). The proximal aorta has greater potential to stiffen because, as mentioned above, it is subject to greater stress from left ventricular ejection compared to medium and small arteries (Zhang et al., 2013). Structural remodeling of arterial layers and functional changes play a key role in AS development. Structural alterations involved in AS progression include: increased collagen, decreased elastin (Semba et al., 2009), increased calcium deposition, accumulation of advanced glycation end-products, and accumulation of non-specific proteins (Demer & Tintut, 2014; Fleenor et al., 2010). Oxidative stress plays an important role in multiple diseases, and current studies have found a correlation between arterial dysfunction and oxidative stress (Ismaeel et al., 2018; Patel et al., 2011). Furthermore, greater oxidative stress, which is a result of pro-oxidative superoxide production and reduced superoxide dismutation from antioxidative mechanisms, promotes aortic stiffness (Fleenor et al, 2012).

C. Risk Factors for Arterial Stiffness

Prevention is important to avoid a variety of severe diseases, so understanding risk factors is beneficial. There are some important factors that influence the etiology of developing AS. First, aging is associated with AS, and studies reveal that AS starts to increase in a linear acceleration after 50 years of age (Redheuil et al., 2010), which can lead to the development of

CVD such as hypertension, left ventricular hypertrophy, and impaired coronary perfusion (Cooper, L. L. et al., 2016). Ethnicity is also a risk factor for the development of AS. Studies indicate that AS values are constantly higher in African-Americans compared to Caucasians (Din-Dzietham et al., 2004).

Obesity, particularly visceral obesity, is another important risk factor for AS (Coutinho et al., 2013). Pal and Radavelli-Bagatini (2013) investigated the association between AS and obesity in overweight/obese women, and their results showed a higher significance in (AIx) in the overweight/obese group compared to the lean group (Pal & Radavelli-Bagatini, 2013). Additionally, a longitudinal study of aortic stiffness in the Whitehall II cohort concluded that general and central adiposity, mean body mass index (BMI)=26.5 kg/m^2, in later midlife (mean age 65.5 years) are strong independent predictors of aortic stiffening. This study estimated a 12% increase in the risk of developing CVD in overweight older adults (Brunner et al., 2015). A 2010 study by Dengo and colleagues demonstrated the importance of weight loss and AS reduction in middle-aged and older overweight and obese adults. They conducted a RCT for 12 weeks with thirty-three participants divided into a weight loss by diet alone (n=25; age: 61.2±0.8 years; BMI: 30.0±0.6 kg/m2) and a control group (n=11; age: 66.1±1.9 years; BMI: 31.8±1.4 kg/m2). The results showed significant reductions in the β-Stiffness index (−1.24±0.22 versus 0.52±0.37 U) and cf-PWV (−187±29 versus 15±42 cm/s) in the weight loss group (average weight loss −7.1±0.7 kg) versus as compared to the control group (average weight loss −0.7±0.4 kg) (Dengo et al., 2010). Furthermore, a prospective study showed that sedentary participants compared with those who engage in a higher level of moderate-to-vigorous physical activity demonstrated increased AS (Ahmadi-Abhari et al., 2017). Additional details about the role of exercise and AS will be discussed below.

Other risk factors that contribute to greater AS are diabetes (Cai et al., 2012; Petersen et al., 2016; Sindler et al., 2013), dyslipidemia (Blumenthal et al., 2010), and inflammation (Cai et al., 2012). The association between smoking and CVD has long been established (Holbrook et al., 1984). The vascular endothelial dysfunction from smoking and its effect on AS is shown in various studies (Jatoi et al., 2007; Mahmud & Feely, 2003; Rehill et al., 2006). According to these authors, there is a significant positive linear relationship between smoking status and PWV. Interestingly, in ex-smokers, the duration of smoking cessation has a significant linear relationship with the improvement of PWV (Jatoi et al., 2007).

D. Non-pharmacological Interventions for Arterial Destiffening (treatment)

The first-line approach for arterial destiffening strategies should include non-pharmacological treatments such as lifestyle and behavioral modifications (Güngör, 2014). The role of dietary factors in accelerating or slowing the progression of CVD is very crucial. Studies have revealed that increasing the intake of some nutrients may result in beneficial effects for attenuating AS, including polyphenol compounds (Pereira et al., 2014), omega-3-fatty acids (Bowen et al., 2016), and vitamins C and E (Heller et al., 2004; Saneei et al., 2014), and that decreasing sodium intake is also beneficial for arterial health (Saneei et al., 2014). The importance of exercise in the prevention and/or management of CVD has also been well documented. Consequently, there has been increasing interest in evaluating the effects of regular exercise on AS (Cooper, J. N. et al., 2012; Mazzeo & Tanaka, 2001). Given that our research focus is on the effect of Nordic pole walking on AS, the following sections will briefly discuss the findings related to aerobic (endurance) exercise, eccentric (strength) exercise, and concurrent training or cross-training, and their effect on AS.

D.1. Aerobic (endurance) exercise training.

Prior research shows that habitual aerobic exercise is an effective lifestyle strategy for preventing and reversing arterial stiffening in healthy adults (Seals et al., 2008; Shibata et al., 2018). Tanaka et al. (2000) designed a cross-sectional and interventional study separated into two protocols. In the first protocol, the researchers compared the arterial compliance of individuals (151 healthy men, aged 18 to 77 years) with different activity levels according to age groups. Firstly, subjects were either sedentary, recreationally active (light to moderate exercise ≥ 3 times per week), or endurance exercise-trained (vigorous aerobic-endurance exercise ≥5 times per week and active in local road running races). They grouped the subjects into consecutive 20-year age ranges starting from the young group (aged 18 to 37 years), the middle-aged group (aged 38-57), and the older group (aged 58-77 years). For all activity levels, arterial compliance was significantly lower in middle-aged and older men compared with young men. Also, central arterial compliance of endurance-trained middle-aged and older adults was 20-30% higher than their recreationally active and sedentary peers in the same age group ($P<0.01$). In the second protocol, 20 middle-aged and older (53±2 years) participants performed exercise training for an average 13.5 ± 1.0 weeks, 5.3 ± 0.2 days/week, and 42 ±1 min/day at 73 ± 1% of maximal heart rate. They concluded that a brief period of regular aerobic exercise (13 to 14 weeks) can destiffen arteries in previously sedentary middle-aged and older individuals. Lastly, according to this investigation, regular aerobic-endurance exercise may be one of the methods by which habitual exercise lowers the risk for CVD (Tanaka, H. et al., 2000).

Furthermore, it has been shown that participants who engage in regular endurance exercise have lower AS than those doing only resistance training and those who are sedentary individuals (DeVan & Seals, 2012). A cross-sectional study by Holland et al. (2016) investigated the association between habitual high levels of vigorous physical activity on large and small arteries. This study was conducted in 83 healthy men and women between the ages of 18 and 78 years, who have maintained a daily routine of intense swimming for at least the past 5 years throughout their life span. Subjects were involved in regular, vigorous exercise ≥5 times/wk or less active/sedentary individuals (participate in light to moderate exercise ≥3 times/wk or none at all). Study demonstrated that there is an association between vigorous-intensity physical activity compared to light-intensity physical activity. The habitual vigorous physical activity increased the arterial compliance of large arteries in older individuals compared to less active older individuals. On the contrary, sedentary older participants experienced reduced large arterial compliance compared to younger active and inactive subjects (Holland et al., 2016).

D.1.a. Aerobic exercise and mechanisms of arterial destiffening.

Animal and human studies revealed that aerobic exercise reduces AS through different mechanisms. One of the mechanisms was demonstrated in mice that ran voluntarily on wheels over a period of 10 to 14 weeks. The effect of regular aerobic exercise for this time period may reduce AS via modification in arterial structural elements, including a shift in collagen subtypes and alterations in collagen cross-linking (Fleenor et al., 2010).

Another mechanism contributing to the improvement of the elastic properties of arteries with aerobic exercise, as observed in an 8-week training program with human subjects, is the reduction in vasoconstrictor tone exerted by the vascular smooth muscle cells. Systemic arterial compliance determined non-invasively using applanation tonometry and doppler aortic velocimetry increased from 0.57±0.11 to 0.77±0.14 arbitrary compliance units (Parnell et al., 2002).

Another potential mechanism in which aerobic exercise can decrease AS is by impacting overall oxidative stress. Overweight (BMI 24.4-27.5 kg/m^2) sedentary individuals with a median age of 54 years (48-66 years), participated in an aerobic exercise study which involved two sessions per week (8 weeks) of supervised exercise on a cycle ergometer (55 min per session at 60%-75% of peak oxygen consumption). The results showed their cf-PWV was reduced by 9.9% compared to baseline. Also, this study demonstrated the role of oxidative stress and exercise training as a natural anti-oxidative strategy. The researchers analyzed urinary 8-isoPGF$_{2\alpha}$ levels as an integrated biomarker of systemic oxidative stress. After 8 weeks of the training program, the excretion rate of the biomarker decreased compared to the basal measurement. This reinforced the idea that physical activity exerts one of its favorable effects on endothelial function through a reduction of oxidative stress which contributes to decreased AS (Lessiani et al., 2015).

D.1.b. Aerobic exercise, limb engagement, and arterial destiffening.

Regarding the engagement of different limbs with exercise and its effect on AS, it seems that the mode of exercise determines the pattern of change in stiffness along the arterial tree. Naka et al. (2003) investigated the effect of a single bout of exercise (60 min maximum treadmill exercise) in arterial distensibility in 50 healthy young adults (31 ± 6 years old). They measured upper and lower limb PWV immediately after the exercise session and observed that AS in the lower limbs decreased approximately 23% below baseline 10 minutes after maximal treadmill exercise while in upper limb decreased ~ 6% (Naka et al., 2003). Furthermore, Sugawara et al. (2003) demonstrated that after low-intensity single-leg exercise the PWV from femoral to the ankle arteries significantly decreased in the exercised leg of 18 young adults, but not in the resting leg (Sugawara et al., 2003). A randomized cross-over study of 15 healthy individuals (9 males and 6 females) between the ages of 18 and 45 compared the effects of maximal aerobic arm versus leg exercise on local AS. Participants had a mean height 170.6±6.9 cm, weight of 67.3±13.8 kg, and BMI 22.9 ±3.4 kg/m^2. Each participant visited the laboratory twice and completed both maximal arm and maximal leg ergometer VO_{2peak} test in a randomized, cross-over design. Their findings show that peripheral cr-PVW decreased by approximately 13% following arm exercise, while leg exercise had no significant effect on it. On the other hand, both maximal lower and upper limb cycling showed a significant effect on the PWV from the femoral to the superior dorsalis pedis arteries with a 13.3% (lower limb) and 10.4% (upper limb) reduction respectively. According to the study, upper limb exercise may provide more beneficial changes in AS – which affects both the recruited and non-recruited limbs – compared with lower limb exercise which only affects the exercised limbs (Ranadive et al., 2012).

D.1.c. Aerobic exercise intensity, acute versus chronic, and arterial stiffness/destiffening.

High-intensity interval training has become increasingly popular in recent years; but investigators have shown detrimental effects of a single 30-second bout of high-intensity cycling on common carotid arteries (CCA) dimensions, stiffness, and wave intensity. The CCA β-stiffness increased significantly immediately post-exercise (Babcock et al., 2015). Similarly, other investigators have reported that AS increases during an acute single bout of aerobic exercise (Ashor et al., 2014). However, following the exercise bout, AS appears to fall below the baseline levels. In contrast, after healthy young adults engaged in a single bout of stretching exercise, their cf-PWV values remained the same while femoral-ankle PWV (fa-PWV) and brachial-ankle PWV (ba-PWV) were reduced at 15 and 30 minutes after acute stretching ($P<0.05$). However, both fa-PWV and ba-PWV values returned to baseline within 60 min post-exercise. Chronic and repetitive muscle stretching may result in high arterial compliance (Yamato et al., 2016).

Furthermore, a systematic review by Mutter et al. (2017) indicated that the effect of acute aerobic exercise on AS in healthy human subjects is dependent on the anatomical segment being assessed, and on the timing of measurement post-exercise. For this review, a total of 43 studies were identified which included 1089 healthy adults (811 men and 253 women, aged 21-61 years old). All studies included in this review used a form of cycling, running, or leg extensor exercise as their primary aerobic physical stressor. The intensity and duration of exercise varied among studies, ranging from 30 seconds of high-intensity exercise to 10 minutes of low intensity walking to a 2 hour marathon-pace run. Findings were separated into time intervals post-exercise, those measured in the first 5 minutes and those measured more than 5 minutes post-exercise. It was noted that immediately post-exercise (0-5 min) central and upper body arterial segments demonstrated an increase in AS whereas lower limb segments demonstrated an immediate decrease in AS. However, as time post-exercise progressed (>5 min), measures of stiffness decreased to at or below the resting values. Additionally, the magnitude and timeline for these changes varied among the different studies (Mutter et al., 2017). Interestingly, a cross-sectional study evaluated central hemodynamics and AS 15 and 30 minutes following acute maximal aerobic exercise in obese and normal-weight individuals. The results indicated that obese individuals exhibited increased central AS compared to normal-weight individuals following exercise (Bunsawat et al., 2017).

It appears that the effect of regular exercise on AS is due to chronic adaptation of the cardiovascular system rather than a single bout of exercise (Mutter et al., 2017). Tanaka et al. (2018) examined the association between habitual physical activity and AS in 3,893 participants (median average age: 74 years) in community-dwelling older adults. Reduced AS was shown in individuals who performed regular moderate and high intensity physical activity compared with no physical activity (Tanaka, Hirofumi et al., 2018). A 12-week supervised moderate intensity exercise intervention demonstrated that carotid AS decreased at different time periods, first at 8 weeks then at 12 weeks more significantly. Their findings suggested that sedentary participants who want to engage in high-intensity training should undergo first moderate-intensity training for a period of 8 to 12 weeks to decrease the detrimental effects of acute high-intensity training on their carotid arteries (Liu et al., 2018). Furthermore, the effect of 12 weeks of supervised high-intensity intermittent exercise on men (aged=24.9 ± 4.3 years) at the frequency of 30 min/day, three times a week showed that cf-PWV was significantly reduced (p=0.013) compared to the control group (Heydari et al., 2013).

Contrastingly, a study by Aizawa and Petrella (2008) examined the effect of 20 weeks of aerobic exercise in older (68.2 ± 5.4 years) participants with hypertension. Participants performed a graded exercise treadmill test to volitional fatigue, and they were prescribed standard exercise aerobic training with an intensity set a heart rate representing 70% of VO_{2max} (30 minutes or more per day, 3 or more days/week). Subjects performed aerobic exercise on a cycle ergometer or treadmill, 50% of exercise in the laboratory, and 50% at their home. After a 20-weeks of aerobic training for an average of 4.3 ± 1.2 day/wk, 44.2 ± 13.6 min/day, and at 91.1 ± 6.1% of target heart rate, neither arterial distensibility nor β stiffness index changed significantly (Aizawa & Petrella, 2008).

D.2. Resistance exercise training.

The aforementioned studies in the previous section demonstrated the importance of regular aerobic exercise in preventing and reversing AS in adults. Resistance training, another common form of exercise modality, plays a pivotal role in health promotion and has gained a widespread application in exercise prescription. The impact of resistance training on the attenuation of osteoporosis and sarcopenia and related risks, including falling and functional disability has been well documented (Hong & Kim, 2018). However, there is little information regarding the influence of resistance training on CVD. Also, information concerning the impact of resistance training on AS is limited. In contrast to the favorable effect of regular aerobic exercise on AS, studies have found resistance training to increase AS in healthy men. A meta-analysis of 8 RCTs with an average sample size of 9-15 participants (n=193 total), both male and female (age range=19 to 54 years), with high (>70% 1 repetition maximum [1RM]) and moderate (40-70 % 1RM) training intensity assessed the association between resistances training and changes in AS. In the subgroup of high resistance training (n=87), AS increased significantly by 11.6% ($p<0.001$), but the subgroup of moderate-intensity resistance training (n=106) revealed no association between AS and resistance training, similarly to control group (Miyachi, 2013).

Previously, Miyachi et al. (2004) showed a reduction in carotid arterial compliance from strenuous resistance training in young men. Twenty-eight healthy men (20-38 years of age) were randomly assigned to the intervention group, three supervised resistance sessions per week over a period of four months or the control group. Carotid arterial compliance decreased by approximately 19% ($p<0.05$) and β-stiffness index increased by 21% ($p<0.01$) in the resistance training group after the 4-month intervention period. Arterial compliance did not change in the control group. Interestingly, the arterial compliance and stiffness values returned completely to baseline levels after a 4-month detraining period (Miyachi et al., 2004). Regarding limb engagement, Okamoto et al. (2009) randomly assigned thirty young healthy subjects into three groups: the upper limb, the lower limb, and sedentary groups. The upper and lower limb groups performed resistance training at 80% of 1RM twice weekly for 10 weeks. The training was conducted in five sets (upper limb: chest press, arm curls, seated rows, shoulder press, and lat-pull downs; lower limb: leg press, squats, seated calf raise, leg extensions, and leg curls) of eight to ten repetitions with an inter-set rest period of 2-minutes. The results showed that ba-PWV increased significantly in the upper limb group. There were no significant changes in AS measurements in the lower limb and sedentary groups (Okamoto et al., 2009).

On the contrary, low-intensity resistance training with a short inter-set rest period (LSR) demonstrated a reduction in AS and improved vascular endothelial function. This study was conducted in 26 young healthy individuals (aged 18.5 ± 0.5 years), both males (n=19) and females (n=7). They performed LSR twice a week at 50% of 1RM for 10 weeks. The training was conducted in five sets of ten repetitions with an inter-set rest period of 30 seconds. ba-PWV after training decreased (from 1093 ± 148 to 1020 ± 128 cm/s, $p<0.05$); no significant changes were observed in the control group (Okamoto et al., 2011).

Additionally, it is crucial to consider the association between resistance training, aging and AS. A RCT in eleven healthy sedentary middle-aged and older men (mean age 64 years) revealed that short-term resistance training (three sets of isokinetic knee flexion and exertion, two days a week over a period of 12 weeks) may increase nitric oxide production without stiffening central arteries (Maeda et al., 2009). Another resistance training intervention with sedentary middle-aged and older adults, both male and female, demonstrated that moderate intensity strength training two to three times per week over a period of 13 weeks did not reduce central arterial compliance (Cortez-Cooper et al., 2008). According to these studies, moderate resistance training in older adults can bring health benefits to this group of individuals without affecting AS.

A systematic review of RCTs of acute and chronic effect of resitance training in AS was conducted by Garcia-Mateo and collegues (2020). All participants included in the RCT had been randomized into a sedentary control group and a resistance training group. All studies performed either single-session intervention (acute effects), or sessions with a minimum of four weeks with a frequency of training of two days per week (chronic effects). All subjects who participated in the studies were healthy, normotensive, and had a BMI in the normal range. In total, 16 RCTs were included in the analysis (10 investigated the chronic effects of resistance training and 6 investigated the acute effects). Investigators revealed that in general, chronic resistance interventions (4-12 weeks, 2-3 days/week, 1-12 exercises, with 2-6 sets of 8-25 repetitions) at lower-intensitites (<50% of 1RM) and moderate-intensities (50-69% 1RM) did not alter AS. On the other hand, in terms of acute effects, lower-intensities provided greater changes compared to higher-intensities (>70% 1RM). Additionally, training based on weight machines and elastic bands did not change AS. Furthemore, with the regards to acute effects, the use of free weights for upper body muscle training showed decreases in AS at lower intensities, while the same training demontrated small and large increases in AS at vigourus intensities (García-Mateo et al., 2020).

D.3. Concurrent training or cross-training.

Previous studies demonstrated that endurance training increases arterial compliance whereas resistance training often increases AS. Rowing is considered a sport which incorporates a combination of both endurance and strength training. A cross-sectional study compared the central and peripheral arterial compliance of 15 healthy habitual rowers (aged 50 ± 9 years) and 15 sedentary controls (aged 52 ± 8 years). The rowers had been training approximately 65% of their training sessions on high-intensity workouts (with 87 ± 8% of sessions performed on water) for 5.4 ±1.2 days/wk for 5.7± 4.0 years, performing a combination of endurance and strength training. The cross-sectional results showed that central arterial compliance was higher $p<0.001$) and the carotid β-stiffness index was lower ($p<0.001$) in rowers than in the sedentary group. However, peripheral (femoral) arterial compliance and β-stiffness index were not different between rowers and the sedentary group (Cook et al., 2006).

A 12-week exercise intervention combining aerobic and resistance training protocol (60 min/day, 3 times/week) for 40 obese adolescent girls (15 ± 1 years old) resulted in significant reductions in ba-PWV (-1.23 ± 0.49 m/s, $p < 0.05$) (Son et al., 2017).

Montero, Vinet, and Roberts (2015) completed a meta-analysis of RCTs which included young and older individuals (overall $n=752$) to quantify the effect of combined aerobic and resistance training on AS. They showed that aerobically trained groups compared with control groups showed a decrease in PWV ($p<0.0001$), but no decrease of PWV was observed with combined training groups compared with control groups ($p<0.12$). This meta-analysis indicated that combined aerobic and resistance training has less impact on AS compared to aerobic training alone (Montero et al., 2015). Additionally, Loimaala et al. (2009) conducted a study to assess the effects of 24 months of combined endurance and muscle strength training on cardiovascular risk factors and arterial PWV. They included forty-eight men (age 52.3 ± 5.6 years) with new-onset of diabetes mellitus without clinical signs of vascular complications. Participants performed aerobic training consisted of jogging or walking twice a week at a heart rate corresponding to 65% to 75% of VO_{2max}. Resistance training was performed separated twice per week in 3 to 4 sets with 10 to 12 repetitions. Both exercise activities were supervised. The investigators concluded that the cardiovascular risk profile was improved and significantly better hemoglobin A1c for 15 months. Also, slight separation of trends in PWV was observed, suggesting a positive effect of exercise, however, true regression did not occur and large-artery elasticity was not improved (Loimaala et al., 2009).

E. Nordic Walking and Health Benefits

Over the last few decades, a myraid of research has been completed to reveal the beneficial role of physical activity in health and disease. Data from numerous studies revealed that being physically inactive has major negative health consequences and plays a role in the development of many chronic diseases such as CVD, diabetes, obesity, neurological disorders (dementia, Alzheimer's, and Parkinson's disease), and osteoporosis. Importantly, physical inactivity decreases the quality of life and accelerates mortality risk (Booth et al., 2017). Even though the role of physical activity in health is well known, sedentary lifestyle prevalence is increasing (Lavie et al., 2019).

NW was first developed in Scandinavia as a modified version of standard walking in which the use of a specific pair of poles engages the upper body muscles thus contributing to greater energy expenditure and quicker improvement of overall physical activity compared to standard walking (Francesco Mocera et al., 2018). Studies have shown a greater positive role of walking with Nordic poles compared to SW on a variety of health conditions such as lower back pain (Hartvigsen et al., 2010), type 2 diabetes (Sentinelli et al., 2015), chronic obstructive pulmonary disease (Breyer et al., 2010), Parkinson's disease (Monteiro et al., 2017), depression (Lee & Park, 2015), fibromyalgia (Mannerkorpi et al., 2010), and chronic heart failure (Keast et al., 2013).

Furthermore, a study conducted in elderly women demonstrated a significant effect of NW on upper body strength, weight, and lipid panel results compared to a control group. Sixty-seven women were assigned to three different groups: the NW group, the SW group, and the control group. They performed walking sessions 3-4 times a week, 30-50 minutes each time, for 12 weeks. The results showed significant improvements in body density, muscle strength, and lipid panel results in both active groups (the NW and the SW) compared to the control group. However, more significant changes were shown in upper extremity muscle strength in the NW group (from 22.9 kg to 27.4 kg), compared to the normal walking group (from 23.5 kg to 26.1 kg). Also, both groups compared to the control group showed significant differences in decrease in body weight, increase in muscle strength, and lowered total cholesterol, with more significant changes in the NW group (Song et al., 2013).

NW (45 min/session, 3 times/week, 4 weeks total) demonstrated significant increases in oxygen consumption, heart rate, and energy expenditure in sedentary, obese middle-aged (59 ± 5 years and BMI =33.14 ± 3.66 kg/m2) women compared to those in the SW group (Figard-Fabre et al., 2010). Furthermore, a RCT was conducted to determine whether NW improves cardiovascular function in middle-aged individuals (n=201, males and females, age 45-69 years). Subjects in the intervention group were instructed to use NW as a form of physical activity for 5h/week over 4 months, and those in the control group were instructed to keep their normal physical activity habits. In addition, all participants were instructed to not change their eating habits. Self-reports were used to keep track of walking compliance for both groups. The walking compliance for both groups was between 4.0 ±1.4h/week (NW) to 4.9±1.7h/week (control group). The results revealed that the arterial structure and function were unaltered in the intervention group after the training program (Ring et al., 2015).

Another 12-week pilot RCT was conducted to examine the effect of an intensive lifestyle intervention (diet and exercise) on weight loss in overweight and obese postmenopausal women. Thirty-two participants were randomized into two groups, diet and supervised NW, and diet and supervised SW. Twenty-two (68.7%) of the individuals completed the training program (NW or SW program) of 60-90 minutes per session, 3 times/week over a period of six months. The results revealed that for this population, NW and SW supervised programs, combined with moderate caloric restriction, are both effective in decreasing AS. Nonetheless, the reductions in cr-PWV ($p<0.001$) were greater for the NW program compared to SW (Rossi et al., 2019).

However, there is a need to clarify whether supervised NW and SW programs when combined with dietary restrictions lead to greater improvements of arterial compliance, or if this improvement in arterial compliance occurs even without caloric restriction. To our knowledge, there are no studies that measure the impact of NW alone, compared to SW, on AS without adding dietary restrictions or other lifestyle modifications in sedentary overweight and obese individuals. Our research group conducted a RCT to identify if NW at a controlled pace for 30 minutes/weekday (about 3000 steps/weekday Monday - Friday) for 12 weeks will reduce AS in overweight/obese sedentary adults to a greater extent than walking without Nordic poles. We hypothesize that previously sedentary individuals that undertake NW for 150 min per week during the 12 weeks will have greater reductions in AS compared to those walking without the poles (SW).

Chapter Two: Methods

Study Design and Participant Characteristics

This study is a randomized controlled trial that compares the effects of NW and SW on the AS of sedentary overweight/obese adults for 12-weeks. The study protocol was approved by the Institutional Review Board at James Madison University (Protocol ID: 19-1020, appendix A). Informed consent to participate in the study was granted by all participants before undergoing any testing.

To be eligible to participate in this study, individuals 21-65 years of age must have a history of sedentary behavior, have been weight stable (± 5 kg) for 6 months prior to the study with a baseline body mass index (BMI) between 25 and 40 kg/m^2. Sedentary behavior was defined as not meeting the U.S. Physical Activity Guidelines' recommendations for weekly exercise over the previous 6 months. Initially, participants had to be free of overt disease to be accepted into the study but given the population characteristics (i.e., sedentary, overweight/obese) and difficulties in recruitment we did allow some individuals with chronic disease into the study as long as they had been stably taking their medications for several months (see Table 1). Furthermore, subjects were instructed to inform researchers of any changes in their medication during the study period.

Table1.
Distribution of medication use by participants with chronic diseases in the NW and the SW group.

Group	**Medication**	**# Subjects**
SW	Levothyroxine	1
	Imuran	1
NW	Levothyroxine	1
	Levoxyl	1
	Amlodipine	1
	Metformin	1
	Depression / Anxiety	1

Note. This table demonstrates the distributions of medications used by subjects in the NW group and the SW group.

Figure 1 below illustrates the consort diagram of the study. After baseline testing, subjects were randomly distributed into the NW (n=11, 2 males, 9 females) or SW (n=12, 2 males, 10 females) group. Participants were asked to not change their nutritional habits or engage in any physical activity outside of the exercise intervention.

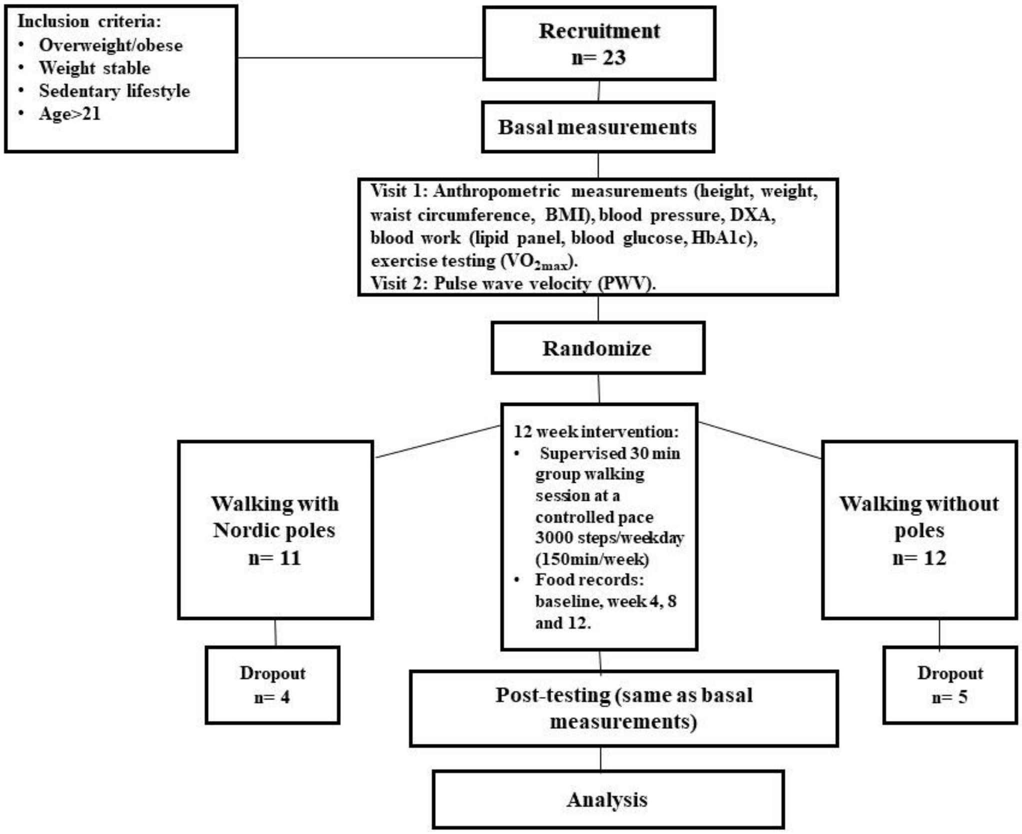

Figure 1. Study design

Exercise Intervention

Subjects in the NW and SW groups completed supervised group walking sessions 5 times a week for 12 weeks on the established walking trail in Purcell Park in Harrisonburg, VA. The group walking sessions were led by a graduate student and were designed to have a controlled pace of 100 steps/min using a digital metronome (Metronome, ONYX Apps) that guaranteed the completion of 3000 steps in 30 minutes. The walking loop was flat with slight hills with a mixed surface of granite, grass, and concrete. At the end of each week, participants had completed the recommendation of 150 minutes of moderate-intensity activity outlineded in the US Physical

Activity Guidelines. For each group, two daily sessions were offered, morning and evening, to promote compliance with the exercise intervention. Attendance logs were kept to estimate compliance. Supervised walking compliance includes all sessions completed with the group. In the case that participants could not attend a group session, they were encouraged to walk on their own using a digital metronome application in their smartphones to keep their pace and self-report their completion of the session. Participants were asked, when possible, to provide evidence of the completed session (i.e., screenshoot of a fitness app) to the graduate student who led their group with the time and pace data they walked. Important to note that the NW group kept the poles for the duration of the intervention, so in the case that they walked on their own they were always using the poles. Total walking compliance percent encompasses supervised walking and self-report walking.

Measurements

Baseline and post-measurements were completed in the Human Assessment Laboratory at JMU. Subjects reported to the laboratory under fasting conditions to complete two visits. Visit one included anthropometric assessments, seated blood pressure measurements, biomarker testing via finger-pricks, and a VO_{2max} test. Visit two included a supine blood pressure and PWV (AS).

Anthropometrics. Weight, height, and BMI were measured using a digital scale (Detecto MV1 MedVue Medical Weight Analyzer) with the participant wearing light clothing and no shoes. Waist circumference at the umbilical level was measured using a Gulick tape measure. Body composition was evaluated using dual energy x-ray absorptiometry (DXA) (Norland @ Swissray, Illuminatus DXA, Fort Atkinson, WI).

Blood pressure. Resting seated blood pressure was measured using an automated monitor (Dinamap Carescape V100, GE Medical Systems Ltd.) Three measurements (right arm) were taken every two minutes in a seated position after a 10-minute rest. If the systolic and diastolic pressures were within 6 mmHg, then the average blood pressure was calculated, if not, one or two additional blood pressure measurements were obtained. Supine blood pressures were measured on the right arm after a 15 minute rest (NIHem USB, Cardiovascular Engineering). Similar to the seated blood pressure measurements, three supine blood pressures were measured and if they were not within 5 mmHg, a fourth and possibly fifth blood pressure measurement was obtained.

Biomarkers. Fasting capillary blood samples, obtained via finger pricks, were collected for the determination of glucose and lipid panel (CardioChek PA Analyzer, PTS Diagnostics), as well as glycosylated hemoglobin (Siemens DCA Vantage Analyzer).

VO_{2max} test. Cardiorespiratory fitness was assessed via a volitional maximal graded treadmill exercise test. An oxygen plateau in response to an increase in workload, or an RER of ≥ 1.1, or a maximal HR value within 10 beats of expected max served as the criteria to determine VO_{2max}. To determine peak oxygen uptake (VO_2 peak), participants performed a ramped maximal walking protocol to volitional fatigue on a treadmill while oxygen consumption was measured (Cosmed Quark $K4b^2$). A maximal walking test was chosen to evaluate the participants' fitness levels because of the sedentary nature of this population. Participants were fitted with a heart rate monitor and face mask. Participants warmed up for three minutes at a speed between two and three miles per hour. The test was conducted at three miles per hour. Every three minutes, the grade increased by 2.5%. At the end of each stage, rating of perceived exertion was recorded. Recovery data were collected for an additional three minutes.

Physical activity. The Physical Activity Readiness Questionnaire for Everyone (2019 PAR-Q+) (Warburton et al., 2018) was used for eligibility screening. Physical activity was assessed using GT3X ActiGraph accelerometers at baseline and week 12. The participants wore the accelerometers on the upper and lateral part of their right hips for the period of one week at the pre and post-intervention. The Physical Activity Enjoyment Scale (PACES) (Kendzierski & DeCarlo, 1991) was used to assess self-reported physical activity, perception of exercise, and enjoyment of exercise at the baseline and week 12.

Nutritional assessment. Dietary intake was assessed via 3-day food records at baseline, week 4, week 8, and week 12. Participants recorded their food intake on two consecutive weekdays and one weekend day. Food records were analyzed using NDS-R software (NDS-R 2016 Nutrition Data System for Research, University of Minnesota).

PWV measurements for AS. Central and peripheral AS was estimated using the NIHem USB device (Cardiovascular Engineering Inc, Norwood MA) to complete the following steps: 1) Acquisition of rested supine blood pressure (as explained above); 2) tonometry acquisition of arterial pulse waves; 3) arterial tree distance measurements; and 4) data analysis to calculate PWV. Arterial pulse waves (carotid, brachial, radial, and femoral arteries) were obtained via applanation tonometry using non-invasive sensors placed over the skin while the participant was in the supine position, after a 15 min rest. Distance from the suprasternal notch to the tonometry point on the carotid, brachial and radial arteries was obtained using a tape measure. The distance from the suprasternal notch to the tonometry point on the femoral artery was obtained using a body caliper. The formula of [*velocity = distance/time]* was used to calculate the cf-PWV and the cr-PWV, where *distance* represents the pulse wave travel distance within the arterial tree and *time* is understood as the average transit time from foot-to-foot of the pulse waves of interest.

Statistical analyses

SPSS 26.0 Software for Windows (IBM SPSS Inc., Chicago, IL, USA) was used for data analysis. All data were tested for normality by group and individual variables using Shapiro-Wilk tests, histograms, skewness, and kurtosis data. Given that the majority of the variables were not normally distributed and the small sample size, nonparametric statistics were used for data analysis. Mann-Whitney U tests were used to compare differences in median ranks of variables of interest at baseline and post testing between the intervention groups. The nonparametric Levene's test was used to verify the assumption of homogeneity of variance for the Mann-Whitney U test. Spearman's rank correlations coefficient, r, was computed to assess the relationship among variables of interest. All data are expressed as median with interquartile range. The significance level was set a prior at the $p<0.05$.

Chapter Three: Results

A total of 23 subjects were enrolled in this study, and 14 completed the walking intervention. Seven participants dropped out mostly because of scheduling conflicts with the walking sessions or personal reasons, one completed baseline testing but did not begin the intervention,and one was asked to interrupt participation after baseline testing due to a medical concern. The data were analyzed only for participants who completed the 12-week intervention (i.e., excluding drop outs). Seven individuals from the NW (1 male, 6 female, median age 54 years, median BMI 31.30 kg/m^2) completed post-testing, as well as seven subjects from SW (2 male, 5 female, median age 39 years, median BMI 30.50 kg/m^2).

Descriptive characteristics at baseline and after the intervention are shown in table 2. There were no significant differences in body weight, BMI, body fat %, fat mass, lean mass, waist circumferences, or blood lipids at baseline or after compeletion of the intervention, either between or within groups. Also, fasting blood glucose and HbA1c % were similar in the two groups at baseline and after the intervention. Median seated blood pressure (systolic and diastolic), seated pulse pressure (PP), and mean arterial pressure (MAP) were similar (all $p>0.05$) in both groups and did not change significantly with the intervention. Furthermore, median VO_{2max} did not show significant differences in the two groups before and after the intervention. Median total compliance, including supervised and self-report exercise, for SW and NW 88.30% % and 86.70%, respectively. However, the median supervised compliance for the SW group (75%) was higher than that of the NW group (70%) ($p>0.05$). Additionally, the PACES scores show that the post median score for the NW group increased significantly ($p<0.05$) but this was not the case for the SW group. Participants performed exercise intervention supervised by graduate students. If they could not performed exercise intervention in group they were instructed to exercise by themselfe, and self-report the session. The majority of exercise intervention was supervised 75% and 70%, respectively. The average walking distance for a period of 12 weeks, was 1.46 miles (3086.5 steps) for an exercise session for both the SW group and the NW group (see Table 2).

Table 2.
Subject characteristics before and after the standard and Nordic pole walking intervention

Variable	**Standard walking**		**Nordic walking**	
	Baseline Median (IQR)	**Post Median (IQR)**	**Baseline Median (IQR)**	**Post Median (IQR)**
Sex (M/F)	7 (2/5)	7 (2/5)	7 (1/6)	7 (1/6)
Age (years)	39.00 (19)		54.00 (13)	
Body weight (kg)	91.89 (17.23)	93.07 (19.05)	86.27 (18.51)	88.45 (15.34)
Body mass index (kg/m^2)	30.50 (8.8)	30.80 (10.1)	31.30 (14.8)	30.40 (12.7)
Body fat (%)	52.60 (12.9)	52.95 (13.83)	49 (7.6)	49.20 (6.8)
Fat mass (kg)	45.36 (20.08)	41.95 (22.31)	41.64 (20.11)	41.95 (15.67)
Lean mass (kg)	46.07 (15.93)	45.07 (17.31)	45.79 (12.65)	44.11 (14.71)
Waist circumference (cm)	102.60 (15.00)	101.75 (17.25)	98.70 (21.70)	102.23 (20.10)
Seated SBP (mmHg)	130 (31)	124 (21)	117 (12)	114 (31)
Seated DBP (mmHg)	74 (23)	74 (17)	70 (14)	74 (17)
Seated Pulse Pressure (mmHg)	48 (15)	42 (9)	47 (22)	51 (16)
Seated MAP (mmHg)	92 (27)	91 (21)	86 (13)	83 (22)
Total cholesterol (mg/dL)	167 (21)	153 (29)	178 (83)	188 (94)
LDL cholesterol(mg/dL)	100 (26)	90 (46)	103 (38)	108 (50)
HDL cholesterol (mg/dL)	46 (4)	46 (11)	54 (14)	57 (26)
Triglycerides (mg/dL)	107 (62)	95 (26)	70 (67)	78 (90)
Ratio cholesterol/triglycerides	3.70 (0.4)	3.1 (1.0)	3.3 (1.7)	2.9 (1.2)
Fasting glucose (mg/dL)	91 (15)	85 (16)	93 (82)	81 (72)
HbA1c %	5.4 (0.6)	5.4 (0.6)	5.6 (0.7)	5.7 (0.8)
VO_{2max} (ml/kg/min)	27.05 (9.52)	25.67 (13.28)	23.78 (6.69)	24.48 (6.38)
Total compliance %	… …	88.30 (15.0)	… …	86.70 (11.7)
Supervised compliance %	… …	75 (26.7)	… …	70 (30)
PACES	60 (8)	64 (5)	61 (31)	72.50 (12)*

SBP: systolic blood pressure, DBP: diastolic blood pressure, MAP: mean arterial pressure, Total compliance: self-report + supervised, IQR: Interquartile range.
*$p<0.05$.

Table 3 displays descriptive characteristics of indices of AS (cf-PWV, cr-PWV, PP) and supine blood pressure of between and within groups at baseline and after the intervention. There are no significant differences (*p*>0.05) in central (cf-PWV) and peripheral (cr-PWV) AS in both groups before and after the intervention (see Figure 2). Also, there are no significant differences (*p*>0.05) in supine blood pressure, supine MAP, and PP in either group at baseline or after the intervention.

Table 3.
Indices of arterial stiffness and supine blood pressure before and after the SW and NW intervention

Variable	**Standard walking**		**Nordic walking**	
	Baseline Median (IQR)	**Post Median (IQR)**	**Baseline Median (IQR)**	**Post Median (IQR)**
Supine SBP (mmHg)	118 (24)	118 (11)	118 (27)	116 (18)
Supine DBP (mmHg)	77 (6)	76 (14)	78 (16)	72 (11)
Supine MAP (mmHg)	90 (12)	88 (14)	97 (15)	87 (14)
Supine PP (mmHg)	39 (20)	41 (10)	44 (24)	41 (10)
cf-PWV (cm/s)	685.3 (236.3)	652.1 (220.9)	818.2 (178.9)	828.3 (180.6)
cr-PWV (cm/s)	939.4 (354.1)	924.2 (283.1)	987.1 (304.8)	912.4 (264.6)

SBP: systolic blood pressure, DBP: diastolic blood pressure, MAP: mean arterial pressure, PP: pulse pressure, cf-PWV: carotid-femoral pulse wave velocity, cr-PWV: carotid-radial pulse wave velocity, IQR: Interquartile range.
* $p<0.05$.

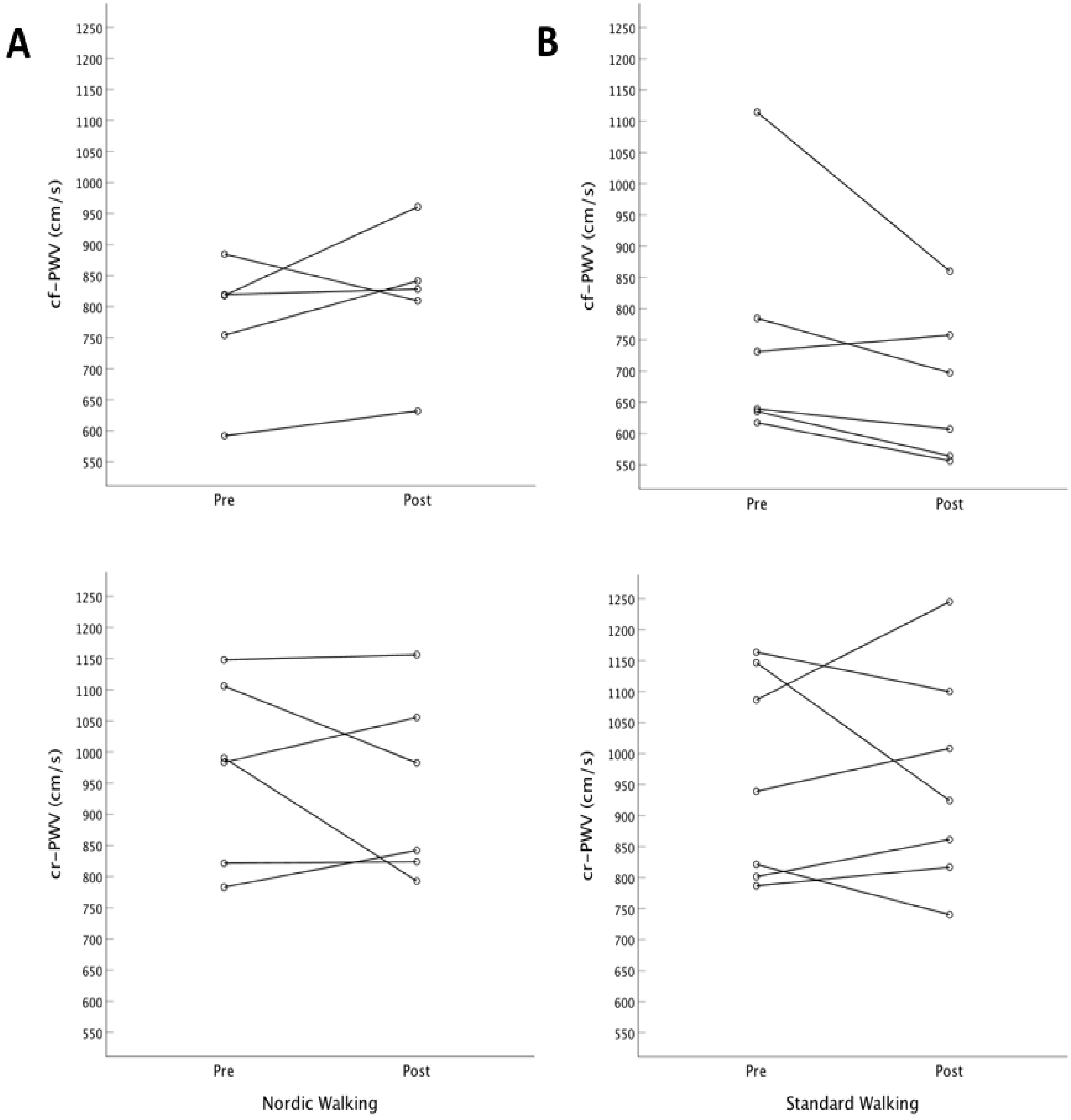

Figure 2. The central (cf-PWV) and peripheral (cr-PWV) arterial stiffness measurements and post-walking intervention.

Physical activity and dietary intake before and after the intervention are displayed in Table 4. There were no significant changes in dietary intake (*p*>0.05) after the intervention in either group, indicating that study participants followed the instructions to not alter their dietary habits during the intervention.

Table 4.
Physical activity and dietary intake before and after the standard and Nordic pole walking intervention

Variable	**Standard walking**		**Nordic walking**	
	Baseline Median (IQR)	**Post Median (IQR)**	**Baseline Median (IQR)**	**Post Median (IQR)**
Steps counts (avg per day)	5048.9 (1360.2)	4019.28 (2113.8)	6487.21 (4078.9)	5952.2 (1834.0)
Sedentary time (min)	629.07 (50.61)	648.15 (129.14)	548.50 (149.57)	601.07 (113.03)
Energy, kcal	1716 (877)	1506 (774)	1754.50 (1220)	1583 (700)
Fat, %	34.61 (8.98)	36.58 (12.08)	35.36 (9.66)	35.58 (12.08)
Carbohydrates, %	47.38 (10.71)	45.55 (19.02)	46.09 (9.64)	42.08 (21.43)
Protein, %	17.56 (7.31)	16.79 (5.37)	15.24 (8.65)	18.63 (6.26)
Sodium (mg)	2755 (1598)	2806 (1371)	2985 (2424)	2555.50 (1134)

IQR: Interquartile range
* *p*<0.05

Spearman correlations between changes in indices of AS and changes in total cholesterol, triglycerides, sodium, walking compliance, and PACES are presented in Table 5. There were significant positive correlations between cf-PWV versus total cholesterol (r=0.65, *p*<0.05) and triglycerides (r=0.62, *p*<0.05). These findings indicate that when total cholesterol and triglycerides increase, cf-PWV increases also. Additionally, correlations by group are present between between changes in walking compliance and changes in weight, BMI, waist circumference (see Figure 3), as well as a correlation between changes in supervised exercise and changes in PACES and sedentary time (see Figure 4).

Table 5.
Correlations between change in indices of arterial stiffness with the intervention and other variables

Variable	**cf-PWV**	**cr-PWV**
Total Cholesterol	0.656*	0.201
Triglycerides	0.627*	0.390
Sodium	-0.745 **	-0.247
PACES	0.742*	-0.368
Walking compliance	0.211	-0.426

cf-PWV: carotid-femoral pulse wave velocity, cr-PWV: carotid-radial pulse wave velocity.
*p<0.05.
**p<0.01.

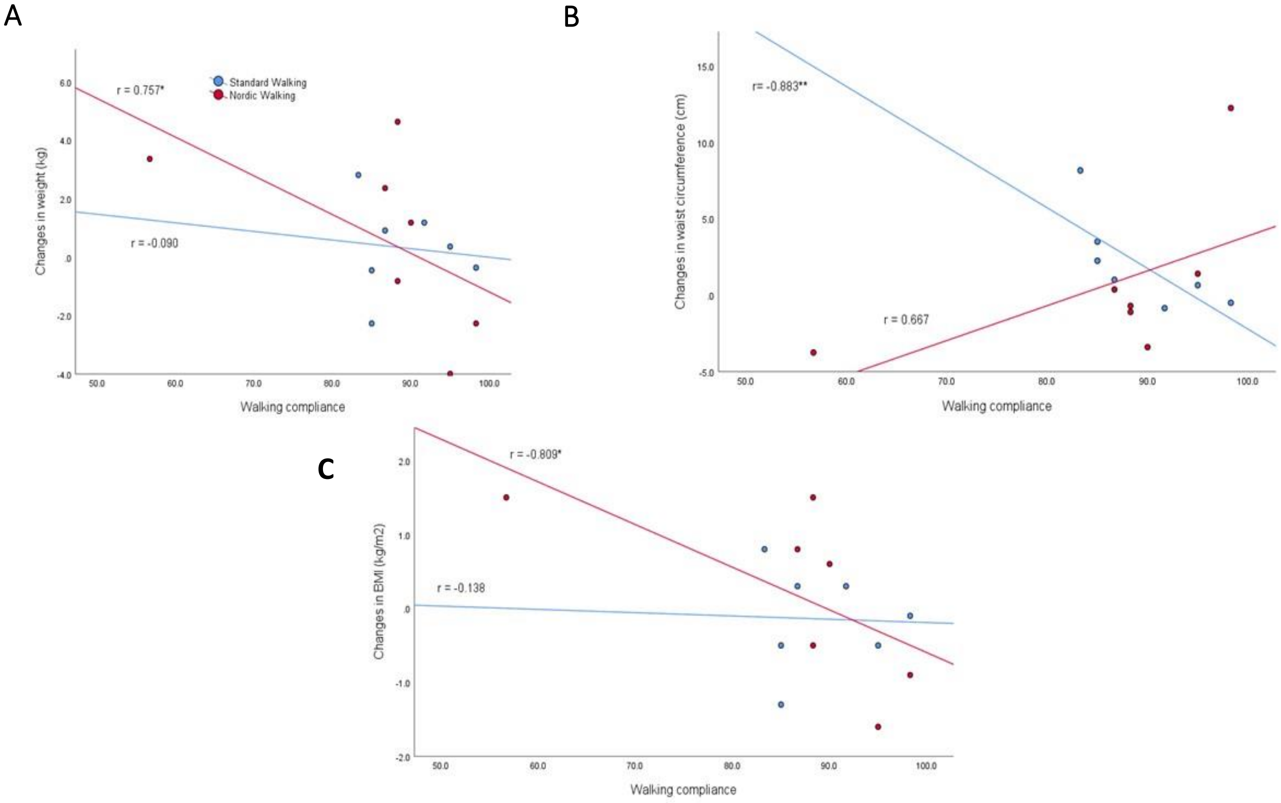

Figure 3. Relationships between percent walking compliance and changes in weight (A), waist circumference (B), and BMI (C).

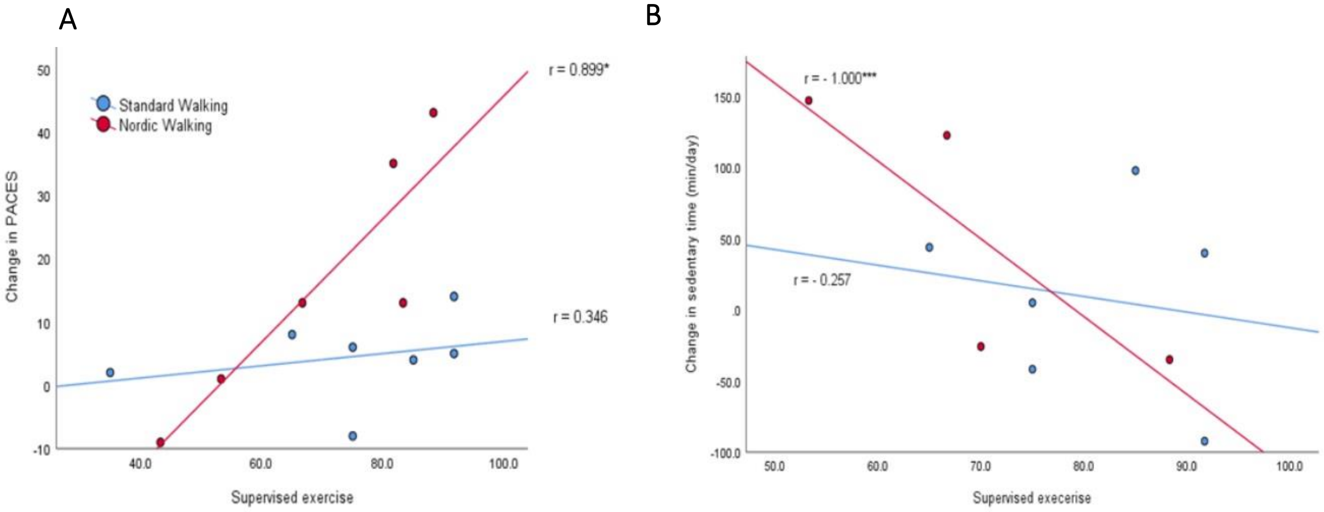

Figure 4. Relationships between perecent supervised exercise and changes in PACES (A) and sedentary time (B).

Chapter Four: Discussion

The main purpose of this study was to identify the effect of NW and SW on AS in sedentary overweight and obese individuals. We tested the hypothesis that walking with Nordic poles during 12 weeks (150 minutes/week at a controlled pace) would reduce AS to a greater extent than SW for the same amount of time via supervised group walking sessions in this population. Although average median of total walking compliance for both groups was 88.30% and supervised walking (i.e., only with the group) was ≥75% both central (cf-PWV) and peripheral AS (cr-PWV) were not significantly different between and within groups. We acknowledge that the small sample size could be a factor in these findings and that further research is necessary. Furthermore, other parameters such as weight, waist circumference, body compartments, BMI, lipid panel, glucose, and HbA1c, resting blood pressure (seated and supine), and VO_{2max} did not differ after 12-weeks of walking between the two groups.

Our results regarding the reduction of central and peripheral AS are consistent with the previous study by Ring et al. (2015) where arterial structure and function were unaltered after training with Nordic poles 5h/week for a period of four months in middle-aged participants across three groups: participants with normal glucose intolerance, impaired glucose intolerance, and type 2 diabetes. However, in contrast with our study, subjects showed reduced body weight in the normal glucose intolerance group, and an improvement in aerobic physical capacity in the impaired glucose intolerance group and the type 2 diabetes group after four months of the NW intervention compared with a sedentary. It is noteworthy to mention that physical activity was not supervised in this study (Ring et al., 2015).

On the contrary, a six-month pilot study by Rossi et al. (2019) including NW and SW elicited a decrease in AS in overweight/obese postmenopausal women. However, their study added moderate caloric restriction to the intervention. Their findings revealed that moderate caloric restriction combined with both walking programs (NW and SW) resulted in reductions of cf-PWV (central stiffness). Interestingly, the reductions in cr-PWV (peripheral stiffness) were only significant for the NW group (Rossi et al., 2019). To our knowledge, our study is the first one comparing the effect of walking with Nordic poles and SW on central and peripheral AS in this population without dietary intervention and under supervision for a period of 12 weeks. Numerous studies have shown an association between food intake and AS. In our study, participants were instructed to not change their dietary intake and eating habits. Pre/post-intervention analysis of the food records indicated that there were no significant changes in both groups regarding caloric intake, fat %, carbohydrate %, protein %, and sodium intake in both groups.

Furthermore, a 6-month study of middle-aged and older adults (66±7 years) suggested that a long-supervised NW combined with diet can result in improved health parameters at a greater and faster rate compared with SW. After 6 months of weekly supervised aerobic exercise consisting of 60-90-min exercise sessions of either NW or SW, three times per week, BMI and waist circumference were decreased in the NW and SW group, but only the NW group reduced total body fat, android fat, and leg fat. Also, peak power output increased in both groups, but VO_{2max} improved ($p<0.05$) only in the NW groups (8%) (Rossi et al., 2019). In our study, VO_{2max} did not improve in either group after the intervention program.

As mentioned before, a previous study revealed significant changes in body composition and metabolic markers in participants who were involved in physical activity with NW compared with SW but with a diet as a component of the intervention. Min-Sun Song et al. (2012) showed significant differences in body weight, BMI, skeletal muscle mass, and percent of body fat in 67 women who performed NW and standard walking three times per week, 60 minutes each time for 12 weeks. Also, there were significant differences in triglycerides and HDL cholesterol in the NW group compared to the normal walking and the control group (Song et al., 2013).

Another study included twenty women separated into two groups: the NW active group and the control group. The active NW group performed exercise intervention three sessions per week, 60-90 minutes each for a period of 12 weeks. The control non-active group with the same clinical features were advised to maintain an active lifestyle and a constant practice of physical activity. Both groups were proposed dietary guidelines, recommending the adoption of normocaloric a Mediterranean diet based on balance distribution. In women with type 2 diabetes after 12 weeks of the exercise program, the non-active control group only showed a significant decrease in weight of 1 kg ($p<0.04$) at the end of the 12 weeks (Sentinelli et al., 2015). However, in our study, we did not observe significant changes in these variables for either group. We did observe significant inverse correlations (i.e., greater improvements) between walking compliance and changes in weight and BMI for the NW group, and walking compliance and changes in body fat percent in the standard walking group.

The increase in central AS results in progressive age-associated elevations in systolic blood pressure and pulse pressure (Mitchell, 2014). Previous studies showed that regular physical activity is associated with lower blood pressure, reduced cardiovascular risk, and cardiac remodeling (Hegde & Solomon, 2015). Several studies consistently demonstrated the beneficial effects of exercise on hypertension with a reduction in both systolic and diastolic blood pressure. However, the anti-hypertensive response of exercise is variable; it is dependent on exercise regimens, environmental factors, and genetic factors (Diaz & Shimbo, 2013). A study by Pescatello et al. (2008) demonstrated that 20-25 % of participants with hypertension were non-responders showing no effect on blood pressure with exercise (Pescatello et al., 2008). This corresponds with our study when both seated and supine blood pressure (systolic and diastolic) as well as pulse pressure did not change significantly in either group with exercise.

Finally, enjoyment is an important construct in physical activity participation and maintenance. Studies show that expected enjoyment from physical activity can increase exercise intention and predict physical activity adoption and maintenance (Dunton & Vaughan, 2008; Ruby et al., 2011). A major findings of our study is the significant median increase of the PACEs score for NW. Plus the significant positive correlation between change in PACEs score and supervised group walking for all subjects, which when analyzed by group only remained significant for the NW group.

One limitation of this study is its small sample size. While the sample size was similar to some other studies, a larger sample size should be used in future investigations to better answer the research question regarding the effect of NW on AS. Also, it is important to address the number of participants who withdrew from the study during our 12-week intervention program. In total 9 participants dropped out of our study. The reason behind these participants' withdrawals was the commitment to the 12-week exercise intervention, except one whom we decided to remove after observing health issues during baseline measurement. Furthermore, the participants' ages and medications used for chronic diseases could have affected on the outcomes in both groups (Table 1), especially for NW which had a considerable higher distribution of medications.

A major strength of our study is the fact that all participants who were enrolled in the study performed great median walking compliance in the NW and SW, 86.70%, and 88.30%, respectively. Also, the majority of exercise intervention was supervised with 75 % in the SW group and 70 % in the NW group, respectively. Four graduate students supervised the intervention program, monitored the walking pace via a metronome app, and kept attendance logs.

Chapter Five: Conclusions and Future Directions

The findings from the present study including sedentary overweight and obese adults, performing exercise intervention for a period of 12 weeks, 5 times/week, at 3000 steps/exercise demonstrated no significant changes in central and peripheral AS in both groups during this intervention time. However, a significant difference was observed in enjoyment scale in the NW group compared to the SW group. Also, the findings of the present study observed some correlations in changes between cf-PWV and changes in total cholesterol and triglycerides. Additionally, the findings did not demonstrate significant changes in caloric or macronutrient intake in either group during the intervention which indicates that dietary habits were likely not a confounding variable. Moreover, an inverse correlation was found between walking compliance and changes in weight and BMI in the NW group, and changes in waist circumference in the SW group. Furthermore, a positive correlation was found between supervised exercise and changes in PACES in the NW group, as well as an inverse correlation with sedentary time in the same group. Other parameters did not differ after 12 weeks of exercise intervention between and within the two groups. Further studies with a larger sample size and a longer duration of exercise intervention are needed to assess the effect of walking with Nordic poles in AS and other variables compared to SW in this population.

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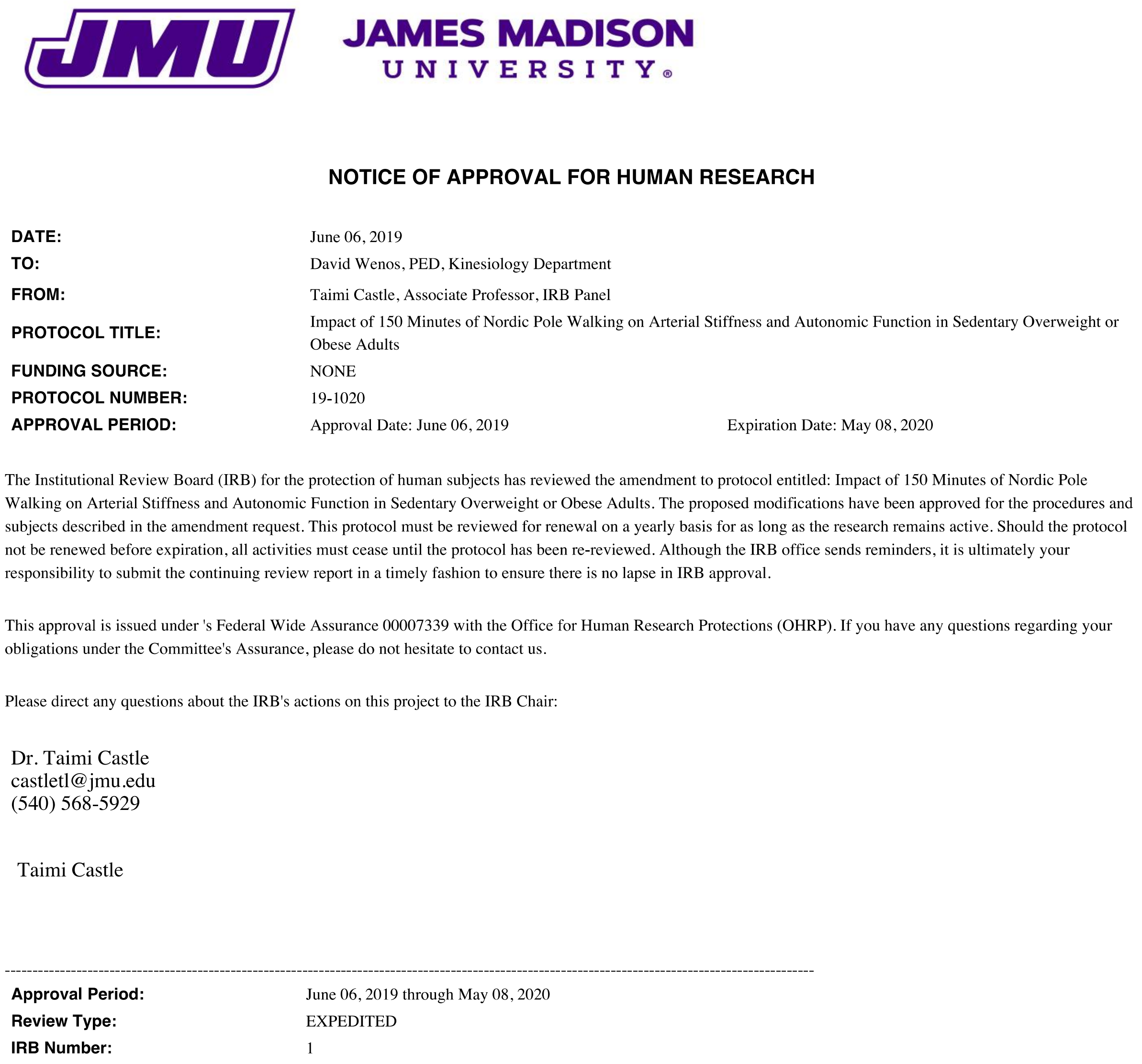
Appendices

Appendix A – The Institutional Review Board Approval



JMU JAMES MADISON UNIVERSITY®

NOTICE OF APPROVAL FOR HUMAN RESEARCH

DATE: June 06, 2019
TO: David Wenos, PED, Kinesiology Department
FROM: Taimi Castle, Associate Professor, IRB Panel
PROTOCOL TITLE: Impact of 150 Minutes of Nordic Pole Walking on Arterial Stiffness and Autonomic Function in Sedentary Overweight or Obese Adults
FUNDING SOURCE: NONE
PROTOCOL NUMBER: 19-1020
APPROVAL PERIOD: Approval Date: June 06, 2019 Expiration Date: May 08, 2020

The Institutional Review Board (IRB) for the protection of human subjects has reviewed the amendment to protocol entitled: Impact of 150 Minutes of Nordic Pole Walking on Arterial Stiffness and Autonomic Function in Sedentary Overweight or Obese Adults. The proposed modifications have been approved for the procedures and subjects described in the amendment request. This protocol must be reviewed for renewal on a yearly basis for as long as the research remains active. Should the protocol not be renewed before expiration, all activities must cease until the protocol has been re-reviewed. Although the IRB office sends reminders, it is ultimately your responsibility to submit the continuing review report in a timely fashion to ensure there is no lapse in IRB approval.

This approval is issued under 's Federal Wide Assurance 00007339 with the Office for Human Research Protections (OHRP). If you have any questions regarding your obligations under the Committee's Assurance, please do not hesitate to contact us.

Please direct any questions about the IRB's actions on this project to the IRB Chair:

Dr. Taimi Castle
castletl@jmu.edu
(540) 568-5929

Taimi Castle

Approval Period: June 06, 2019 through May 08, 2020
Review Type: EXPEDITED
IRB Number: 1

Appendix B – Means and Ranges for all Variables

Table 2a.

Subject characteristics before and after the SW and NW intervention

Variable	**Standard walking**		**Nordic walking**	
	Baseline Mean (Range)	**Post Mean (Range)**	**Baseline Mean (Range)**	**Post Mean (Range)**
Sex (M/F)	7 (2/5)	7 (2/5)	7 (1+6)	7 (1+6)
Age (years)	40.86 (30)		50.86 (27)	
Body weight (kg)	93.05 (29.58)	93.37 (32.03)	92.41 (65.32)	93.04 (67.50)
Body mass index (kg/m^2)	31.90 (13)	31.75 (12.2)	33.71 (17.8)	33.91 (19.7)
Body fat (%)	49.60 (20.4)	50.20 (20.80)	47.86 (20.6)	47.23 (18.93)
Fat mass (kg)	48.96 (24.25)	49.70 (24.35)	46.65 (45.36)	46.70 (45.50)
Lean mass (kg)	46.74 (26.87)	46.23 (26.07)	48.05 (29.33)	48.06 (30.50)
Waist circumference (cm)	101.97 (20.50)	104 (22.25)	104.04 (39.50)	104.76 (35.75)
Seated SBP (mmHg)	123.43 (41)	120.14 (42)	119.14 (43)	124.29 (36)
Seated DBP (mmHg)	73.86 (29)	75.86 (33)	70.71 (27)	72.14 (22)
Seated Pulse Pressure (mmHg)	49.57 (18)	44.29 (17)	48.43 (28)	52.14 (23)
Seated MAP (mmHg)	90.57 (31)	90.71 (33)	86.86 (28)	89.57 (23)
Total cholesterol (mg/dL)	169 (24)	158.86 (60)	181.43 (130)	190 (110)
LDL cholesterol(mg/dL)	99.43 (32)	101 (88)	106.29 (113)	120.86 (155)
HDL cholesterol (mg/dL)	45.43 (17)	48.29 (13)	56.29 (59)	63.29 (59)
Triglycerides (mg/dL)	118.57 (114)	97.29 (90)	93.14 (87)	104 (99)
Ratio Cholesterol/triglycerides	3.74 (1.9)	3.31 (1.6)	3.34 (2.0)	3.08 (1.5)
Fasting glucose (mg/dL)	91.57 (27)	90.86 (36)	106.86 (103)	102.14 (96)
HbA1c %	5.50 (1.4)	5.51 (1.5)	6.15 (3.3)	6.11 (3.4)
VO_{2max} (ml/kg/min)	27.68 (19.84)	27.58 (16)	26.12 (21.54)	26.23 (19.20)
Total compliance %	…	89.26 (15)	…	86.18 (41.6)
Supervised compliance %	…	74.05 (56.7)	…	69.51 (45)
PACES	57.57 (33)	62 (28)	55 (38)	62 (19)

SBP: systolic blood pressure, DBP: diastolic blood pressure, MAP: mean arterial pressure, Total compliance: self-report + supervised.

*$p<0.05$.

Table 3a.

Indices of arterial stiffness and supine blood pressure before and after the SW and NW intervention

Variable	**Standard walking**		**Nordic walking**	
	Baseline Mean (Range)	**Post Mean (Range)**	**Baseline Mean (Range)**	**Post Mean (Range)**
Supine SBP (mmHg)	117 (55)	119.14 (40)	112.86 (45)	115 (40)
Supine DBP (mmHg)	77.86 (23)	75.14 (24)	78.43 (21)	76 (15)
Supine MAP (mmHg)	90.86 (34)	87.86 (24)	91.86 (27)	89.14 (15)
Supine PP (mmHg)	39.14 (36)	37.71 (24)	40.71 (36)	39 (25)
cf-PWV (cm/s)	753.73 (522.5)	773.66 (404.7)	673.60 (292.5)	814.48 (329)
cr-PWV (cm/s)	963.67 (380.5)	956.57 (504.6)	972.15 (365)	942.26 (363.4)

SBP: systolic blood pressure, DBP: diastolic blood pressure, MAP: mean arterial pressure, PP: cf-PWV: carotid-femoral pulse wave velocity, cr-PWV: carotid-radial pulse wave velocity.
* $p<0.05$.

Table 4a.

Physical activity and dietary intake before and after the SW and NW intervention

Variable	**Standard walking**		**Nordic walking**	
	Baseline Mean (Range)	**Post Mean (Range)**	**Baseline Mean (Range)**	**Post Mean (Range)**
Steps counts (avg per day)	4858.52 (8076)	4644.57 (4802)	7082.85 (5331)	6169.64 (2395.1)
Sedentary time (min)	630.59 (228.7)	639.11 (190.4)	546.92 (198.42)	598.82 (145.14)
Energy, kcal	1801 (1833)	1714.43 (1339)	1844.50 (1833)	1687.50 (1178)
Fat, %	37.33 (19.6)	35.50 (28.41)	37.76 (16.07)	35.50 (28.41)
Carbohydrates, %	45.36 (30.45)	46.95 (45.82)	43.54 (26.51)	43.45 (45.82)
Protein, %	15.88 (11.65)	16.89 (15.17)	14.61 (10.43)	17.61 (8.93)
Sodium (mg)	2719.43 (3083)	3311.14 (3627)	3116.17 (3083)	2794.67 (1988)

* $p<0.05$.