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Arterial blood pressure may decrease below pre-exercise resting levels immediately after both aerobic and dynamic resistance exercise. This response is known as post-exercise hypotension (PEH). The purpose of this study was to determine and compare the blood pressure responses to isometric and dynamic handgrip exercise through two hours following exercise in pre-hypertensive subjects. The isometric protocol consisted of 3 sets of sustained isometric handgrip with the non-dominant arm for 3 minutes at 30% MVC. The dynamic resistance handgrip exercise protocol consisted of 3 sets of 45 rhythmic contractions at 60% MVC with the non-dominant arm for 3 minutes. Neither isometric nor dynamic handgrip exercise significantly lowered post-exercise systolic and/or diastolic blood pressure compared to the control condition.

THE EFFECTS OF ISOMETRIC AND DYNAMIC RESISTANCE EXERCISE ON POST-EXERCISE BLOOD PRESSURE

by

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APPROVAL PAGE

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CHAPTER I

INTRODUCTION

Background

Arterial blood pressure may decrease below pre-exercise resting levels immediately after both aerobic (Headley et al., 1996, MacDonald et al., 1999) and dynamic resistance exercise (MacDonald et al., 1999). This response is known as post-exercise hypotension (**PEH**). There are no defined criteria for the magnitude of the pressure decrement or duration of this response (MacDonald et al., 2002). However, based on the reported hypotensive effect in studies that have examined the PEH phenomenon, it appears that the hypotensive effect on systolic blood pressure is a decrease of approximately 6 – 14 mmHg, and the hypotensive effect on diastolic blood pressure is a decrease of approximately 2 – 7mmHg (MacDonald et al., 2000, MacDonald et al., 2001, Headley et al., 1996, Rueckert et al., 1996, Birch, et al., 2002, Kaufman et al., 1987, Cleroux et al., 1992, Floras et al., 1989, Boone et al, 1993).

It has been suggested that the lowering of blood pressure typically credited to endurance *training* programs may actually be due to either the cumulative effects of PEH resulting from acute exercise or as mainly a response to the most recent exercise session (Seals et al., 1997). The contribution of PEH to the overall exercise training-induced lowering of blood pressure is not well defined. The duration of the PEH response is also unclear (MacDonald, 2002). Additionally, the mechanisms responsible for PEH have yet to be positively identified (MacDonald, 2002). PEH has been demonstrated in normotensive (Headley et al., 1996, MacDonald et al., 1999, MacDonald et al., 2000), prehypertensive (Boone et al., 1993) and hypertensive individuals (Rueckert et al., 1996, Pescatello et al. 2003). Additionally, PEH has been observed to occur in a similar fashion in both males and females (Rueckert et al., 1996). The phenomenon has been observed in as little as 5 minutes after the cessation of exercise (MacDonald et al., 1999), and has been observed to last as long as 2 hours in a laboratory setting (Headley et al., 1996). Wallace et al. (1999) observed the PEH effect for up to 12 hours after exercise in a 24-hour ambulatory setting.

Although PEH has been reported as a result of both aerobic and dynamic resistance exercise, the relationship between isometric resistance exercise and PEH is unknown. However, studies such as those conducted by Wiley et al. (1992) and Ray and Carrasco (2000) have shown that resting systolic and diastolic blood pressure can be lowered as much as 12.5 mm Hg and 14.9 mm Hg, respectively as a result of isometric handgrip training. Therefore, it is possible that isometric exercise can influence acute post-exercise blood pressure as well. It is important to investigate the acute post-exercise effects of different modes of exercise to better understand the PEH response and the potential benefits that it may have on the resting arterial blood pressure of normotensives and prehypertensive individuals.

Statement of the Problem

Arterial blood pressure has been observed to decrease significantly below resting baseline levels after aerobic exercise. In addition, comparison of mild bouts of dynamic resistance exercise and dynamic aerobic exercise have shown similar post-exercise hypotensive effects (MacDonald, 1999). However, little is known about the effects of isometric resistance exercise on post-exercise blood pressure.

Since prehypertensive individuals are at risk for hypertension, it is important to examine the post-exercise effects of resistance exercise, both dynamically and isometrically, in prehypertensive individuals in order to determine whether or not there are indeed any potential benefits associated with these modes of exercise. Factors that can influence blood pressure, such as medication, disease, and alcohol must be controlled for as well to ensure the most accurate results.

Handgrip exercise, in particular, should be investigated because of its potential to offer those who cannot or will not exercise aerobically an avenue to possibly lower resting arterial blood pressure. Handgrip exercise protocols can be simple in design, and these protocols can be performed in almost any type of setting. It is valuable to compare the effects of isometric handgrip exercise with those of dynamic handgrip exercise on post-exercise blood pressure in order to determine whether or not one contraction type is more effective than the other.

Specific Aims

1. To *determine* the blood pressure responses to isometric and dynamic handgrip exercise through two hours following exercise in pre-hypertensive subjects.
2. To *compare* the blood pressure responses to isometric and dynamic handgrip exercise through two hours following exercise in pre-hypertensive subjects.
3. To determine whether potential post-exercise hypotension (PEH) occurs locally (in the exercised arm only) or throughout the body (i.e., in both arms).

Hypotheses

1. Both isometric and dynamic handgrip exercise will significantly lower systolic and diastolic blood pressure compared to a control condition.

   Hypothosis rejected: Neither isometric nor dynamic handgrip exercise significantly lowered systolic and diastolic blood pressure compared to the control condition.
2. Isometric handgrip exercise will be just as effective as dynamic handgrip exercise in acutely lowering systolic and diastolic blood pressure.

   Hypothosis rejected: Neither isometric nor dynamic handgrip exercise was effective in acutely lowering systolic and diastolic blood pressure.
3. The PEH response will occur in both the exercising and non-exercising arms.

   Hypothosis rejected: The PEH response did not occur in either the exercising arm or the non-exercising arm.

CHAPTER II

REVIEW OF THE LITERATURE

The focus of this section is to categorize arterial blood pressure, and to review the research that concerns the acute effects of aerobic, dynamic and isometric resistance exercises on arterial blood pressure. There will be particular focus on the mode, duration, and intensity of exercise on post-exercise arterial blood pressure. The potential mechanisms of post-exercise hypotension will be briefly discussed as well.

Hypertension is defined as a systolic blood pressure above 140 mm Hg and/or a diastolic blood pressure above 90 mm Hg in the *Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure* (JNC VII) (2003). Hypertension is believed to be accountable for 840,000 deaths a year according to the Centers for Disease Control (2000). It was estimated that at least 58 million people have elevated blood pressure in the United States alone (Tipton, 1991).

The JNC VII report (2003) defined normotensive individuals as those with systolic blood pressure under 120 mm Hg and diastolic blood pressure under 80 mm Hg (Table 1). A new category, prehypertension, has been defined as systolic blood pressure between 120-139 mm Hg and/or diastolic blood pressure between 80-89 mm Hg. A large portion of the population falls into this recently defined category.

Individuals with prehypertension are at increased risk for progression to hypertension (JNC VII, 2003). Lifestyle modifications, such as regular exercise are recommended for prehypertensive individuals in order to delay or prevent the onset of hypertension (JNC VII, 2003).

Category	Systolic		Diastolic
Normal	<120	and	<80
Prehypertension	120-139	and	80-89
Stage 1 hypertension	140-159	or	90-99
Stage 2 hypertension	≥160	or	≥100

Table 1 Classification of blood pressure for individuals 18 or older. (JNC VII, 2003)

Typically, individuals with mild hypertension, as well as those at risk for hypertension, are advised to engage in regular endurance exercise in order to help lower their resting arterial blood pressure. However, there is evidence that the accumulated effects of acute exercise are primarily responsible for benefits that are typically ascribed to endurance exercise training (Seals et al., 1997). Since arterial blood pressure has been observed to decrease after acute exercise, it is possible that repeated occurrences of this phenomenon could be beneficial to cardiovascular health. Post-exercise hypotension has been observed with aerobic exercise (Headley et al., 1996, MacDonald et al., 1999) as well as both dynamic resistance exercise (MacDonald et al., 1999) and isometric exercise (O'Connor and Cook, 1998).

The Effects of Acute Endurance Exercise on Post-Exercise Blood Pressure

The decrease in arterial pressure after acute exercise, known as post-exercise hypertension (PEH), was first described by Hill in 1897 after measuring blood pressure for 90 minutes after the completion of a 400 yard dash. However, the phenomenon was not closely examined again until Fitzgerald wrote a report in 1981 detailing the effects of jogging on his own hypertension. More recent studies have shown that arterial blood pressure transiently decreases within minutes (MacDonald et al., 1999, MacDonald et al., 2000) and that the effect can last for hours (Headley et al., 1996) after acute exercise.

Systolic blood pressure rises during dynamic exercise in healthy subjects, whereas diastolic pressure normally stays at about the same level or increase slightly (Fagard & Tipton, 1994). However, both systolic and diastolic arterial blood pressures have been observed to decrease after a bout of exercise has been completed. MacDonald et al. (1999) examined the post-exercise arterial blood pressure of ten active individuals (35 years old) with baseline systolic blood pressure (SBP) of 132 mm Hg and diastolic blood pressure (DBP) of 75 mm Hg. The subjects performed 30 minutes of cycle ergometry at 50% or 75% VO_2max on separate days. Systolic blood pressure was significantly lower than baseline values at the 5-minute mark after exercise, and remained significantly lower for 15 minutes after the cessation of exercise. Diastolic blood pressure was significantly lower than baseline values at the 5-minute mark after exercise, and remained significantly lower for 45 minutes after the cessation of exercise. Interestingly, the intensity of the exercise had no effect on the magnitude or duration of the response.

Gender Effects: Gender does not appear to have an effect on PEH. The post-exercise hypotensive patterns of male and female subjects with either Stage 1 or Stage 2 hypertension were examined by Rueckert et al. (1996). Systolic blood pressure, MAP, and total peripheral resistance (TPR) were found to decrease significantly ten minutes after subjects walked on a treadmill at 70% of their heart rate reserve. Coats et al. (1989) found no difference in the PEH response of male and female subjects after voluntary maximal exercise on a cycle ergometer. Systolic blood pressure decreased as much as 7.9 mm Hg (60 min post EX), while diastolic pressure decreased 12.6 mm Hg (5 min post EX).

The influence of endurance training status and gender on post-exercise hypotension was examined by Senitko et al. (2002). The arterial blood pressure of sixteen endurance-trained and sedentary men and women was observed via an automated auscultometric device after a single 60-minute bout of exercise at 60% VO_2max. While all of the subjects exhibited a similar degree of PEH (~4-5 mm Hg), it was proposed that different groups achieved these results by different mechanisms. Sedentary men and women, as well as endurance-trained women achieved the reduction in arterial pressure through vasodilation. Although vasodilation did not occur in the endurance trained men, a decrease in cardiac output led to hypotension.

Post-exercise hypotension in females does not seem to be affected by contraceptives and menstrual cycle. Birch, et al. (2002) examined the patterns of cardiovascular recovery in 15 women (aged 20 years) across two phases of oral contraceptive use: 21 days of oral consumption and 7 days of withdrawal. There were no differences in the reduction of diastolic and systolic blood pressure following 30 minutes of cycle ergometry at 60% VO_2max. Both groups reached a peak hypotensive effect 5 minutes into the recovery period.

Race/Ethnicity Effects: Research examining the acute exercise effects on blood pressure in different races/ethnicities is limited. Although Headley et al. (1996) found that PEH does occur in black men after dynamic exercise, Pescatello et al. (2003) demonstrated that black women might not experience the effect. The latter study compared the ambulatory post-exercise blood pressure of premenopausal black and white women for one day after the subjects performed 30 minutes of cycle exercise at 60% VO_2max. It was determined that white hypertensive women experienced the PEH response (-11.0 mm Hg SBP, and -8.2 mm Hg DBP) throughout the day, whereas normotensive white women did not. However, black women, both normotensive and those with elevated baseline blood pressure, experienced an increase in SBP (6.3 mm Hg and 12.5 mm Hg, respectively) throughout the day after the exercise protocol, while DBP remained unchanged.

Baseline Blood Pressure Effects: Post-exercise hypertension occurs in both normotensive and hypertensive individuals. Hagberg et al. (1987) demonstrated PEH in older hypertensive individuals who performed cycle ergometry for 45 minutes at an intensity of 50-70% VO_2max. These individuals experienced significantly decreased mean arterial pressure (defined as cardiac output x total peripheral resistance) from 1-

3 hours after termination of exercise. However, as previously stated, that the PEH phenomenon may be influenced by racial factors (Pescatello et al. 2003).

As previously mentioned, Headley et al. (1996) observed PEH in young normotensive black men. Nineteen normotensive black men (25 years old) walked continuously on a treadmill for 40 minutes at 50-60% of their heart rate reserve (Resting HR + (0.50 to 0.60)[Predicated max HR – Resting HR]). Compared to baseline measures, SBP was significantly reduced by as much as 10 mm Hg ($p < 0.05$) from 30 minutes to 2 hours after the cessation of exercise. However, neither DBP nor mean arterial pressure (MAP) changed significantly. Dynamic exercise has been shown to elicit a post-exercise hypotensive effect on MAP in mildly hypertensive premenopausal women (Pescatello et al., 1999). These women, who performed 30 minutes of cycle exercise at 60% VO_2max, had a significant decrease in ambulatory SBP (-9.5 mm Hg), DBP (-6.7 mm Hg) and MAP (-7.7 mm Hg) compared to baseline measures for up to 7 hours after exercise. However, there was no significant change in the arterial blood pressure of normotensive subjects in the study.

The magnitude of the PEH response appears to be variable in normotensive and hypertensive individuals. The younger and older normotensives observed by Kaufman et al. (1987) demonstrated a decrease in SBP of 12 mm Hg and 10 mm Hg, respectively, while diastolic blood pressure decreased 2 mm Hg in the younger group and 5 mm Hg and older group. However, the difference between reductions in DBP between the groups was not significant. Coats et al. (1989) observed a decrease of

7.9 mm Hg in SBP in normotensive individuals (17-47 years old), with baseline arterial blood pressure of 110/62 mm Hg, one hour after the cessation of maximal cycle ergometry exercise. Diastolic pressure was significantly reduced for the entire measured hour after exercise, with the nadir (12.6 mm Hg) occurring at the 5 minute mark. Cleroux et al. (1992) examined 13 hypertensive (138/98 mm Hg) subjects and nine normotensive (105/75 mm Hg) subjects who performed cycle ergometry at 50% VO_2max for a period of 30 minutes. The hypertensive subjects experienced a decrease in SBP (11 mm Hg) and DBP (4 mm Hg) after the cessation of exercise, whereas the normotensive subjects did not experience any change in blood pressure.

Post-exercise hypotension has been observed in prehypertensives individuals as well. Boone et al. (1993) examined eight subjects with a baseline systolic blood pressure of 137 ± 1.9 mm Hg and baseline diastolic blood pressure of 85 ± 1.8 mm Hg. An average reduction in systolic blood pressure of 10 mm Hg was observed after 60 minutes of treadmill exercise at 60% VO_2max. Diastolic blood pressure did not decrease below resting levels during the post-exercise period. However, it should be noted that blood pressure was only monitored for 20 minutes after the cessation of exercise.

The post-exercise effects of cycle ergometry in eight individuals with an average baseline blood pressure of 133/79 mm Hg were examined by MacDonald et al. (1999). The subjects, who exercised at 70% VO_2max in a 10-minute bout and, on another day, exercised at the same intensity for 30 minutes, experienced a significant decrease in systolic blood pressure from 5 minutes through 60 minutes post-exercise, with the largest decrement (-14 mm Hg) occurring 15 minutes after the completion of exercise. Diastolic blood pressure was significantly lower than baseline levels 15 minutes after the completion of exercise, and remained lower until 45 minutes post-exercise. The nadir of diastolic pressure, 8 mm Hg, occurred at the 15 minute post-exercise mark. The duration of the exercise did not alter the magnitude of the post-exercise hypotensive effect. Floras et al. (1989) observed a post-exercise decrease in SBP of 13 mm Hg in nine men after they completed 45 minutes of treadmill exercise at 70% of their heart rate reserve. Diastolic blood pressure did not decrease significantly.

Wallace et al. (1999) used 24-hour ambulatory blood pressure monitoring techniques to observe the effects of 50 minutes of treadmill walking at 50% VO_2max in 31 hypertensive and 26 normotensive adults. There were significant reductions in both SBP and DBP in hypertensive individuals. The 24-hour average SBP and DBP were reduced by 6.8 mm Hg and 4.1 mm Hg, respectively, due to exercise. Hypertensives demonstrated an 11 hour reduction in SBP, as well as a 4 hour reduction in DBP after exercise. Normotensive subjects did not experience significant differences in blood pressure.

It is unclear what the role baseline blood pressure plays in post-exercise hypotension. While some studies have shown that individuals with greater baseline blood pressures tend to exhibit more of a PEH response, Kaufman et al. (1987) found that PEH is apparently not affected by either age or blood pressure classification. There is a need to determine the extent that normotensives and prehypertensives experience PEH so that it can be determined whether or not these individuals derive any sort of health benefit from the phenomenon.

Age Effects: The relationship between age and post-exercise hypotension was examined by Kaufman et al. (1987). Subjects were divided into 3 groups: younger normotensives (19-29 years old), older normotensives (35-62 years old) and hypertensives (44-57 years old) and were subjected to five 10-minute bouts of treadmill walking at 67% of age-predicted maximal heart rate. Both systolic and diastolic blood pressure decreased significantly from resting exercise values after exercise, with the nadir coming 15 minutes after the cessation of exercise. Systolic blood pressure remained significantly lower for one hour after exercise, although the diastolic pressure returned close to baseline values by the one hour mark. Neither age nor blood pressure classification had an effect on the magnitude of the PEH response.

Time Course and Response Duration: The time course and duration of the PEH response are not well defined. Some studies have shown the onset of the PEH response within a few minutes after EX (Piepoli et al., 1993, Boone et al, 1993), but most have shown it between 30 minutes and 1 hour following exercise (MacDonald et al., 1999, Fitzgerald, 1981, Franklin et al., 1993, Pescatello et al., 1991). MacDonald et al (2001) conducted a controlled study of the duration of PEH in borderline hypertensives in an ambulatory setting following 30 minutes of cycle ergometry at 70% VO_2max and found significant reductions in SBP, DBP and MAP, all of which lasted to the end of the 70 minute monitoring period.

Several studies have examined the 24-hour ambulatory blood pressure of normotensive and hypertensive individuals. Pescatello et al. (1999) observed 7 mildly hypertensive and 11 normotensive women, who performed 30 minutes of cycle exercise at 60% VO_2max. The hypertensive women had a significant decrease in SBP (-9.5 mm Hg), DBP (-6.7 mm Hg) and MABP (-7.7 mm Hg) compared to baseline measures for up to 7 hours after exercise. However, there was no significant change in the arterial blood pressure of normotensive women. Thus far, no other significant differences have been found in normotensives after 2 hours post-exercise (MacDonald, 2002).

Duration of exercise: Exercise duration does not appear to influence post-exercise hypotension a great deal. MacDonald et al. (2000a) examined the post-exercise blood pressure of 13 normotensive subjects who had an average resting blood pressure of 126/71 mm Hg. These subjects performed bouts of cycle ergometry at 70% $V0_2$ max for a duration of either 15, 30 or 45 minutes. Systolic pressure was significantly lowered 5 minutes after exercise, and stayed lower for an additional 55 minutes. Diastolic pressure was significantly lowered 30 minutes after exercise, and stayed lower for an additional 15 minutes. Both systolic and diastolic post-exercise blood pressures were similar across the time trials.

MacDonald et al. (2000a) also performed a similar trial with eight individuals with average resting blood pressure of 133/79. These subjects performed bouts of cycle ergometry at 70% $V0_2$ max for a duration of either 10 or 30 minutes. Systolic pressure was significantly lowered 5 minutes after exercise, and remained significantly lower for an additional 55 minutes. Diastolic pressure was significantly lowered 5 minutes after exercise, and again at 15 through 45 minutes after exercise. The duration of the exercise did not affect the decreases in systolic and diastolic post-exercise blood pressures.

Mass of Working Muscle: The mass of working muscle may influence the duration of the PEH response. MacDonald et al. (2000b) compared the effects of arm and leg ergometry in nine borderline hypertensive subjects. On separate days, subjects performed 30 minutes of arm ergometry at 65% armVO_2max and 30 minutes of leg ergometry at 70% leg VO_2max. Both systolic and diastolic pressures were reduced (15 and 9 mmHg, respectively) for one hour post-exercise, regardless of the muscle mass used. However, it was noted that while post-exercise blood pressure started to rebound 30 minutes after arm ergometry, it was still declining at the same point after leg ergometry.

Several factors appear to influence the PEH response. Some of these factors, such as baseline blood pressure and race, may influence the response more than others. Future investigations should further examine the effects of differing modes of exercise on the PEH response, so that the beneficial effects of the phenomenon can be maximized.

The Cumulative Effects of Acute Exercise

Responses to acute exercise and adaptations due to exercise training may be intertwined, rather than separate effects (Thompson et al., 2001). Haskell (1994) proposed that acute exercise could reduce a cardiovascular risk factor (such as blood pressure, blood lipids, and serum glucose), but also that the effect rapidly dissipates. It was also proposed that exercise training increases exercise capacity, which permits increased individual exercise session capacity and a greater overall acute affect on risk factors.

It has been suggested by Seals et al. (1997) that the hypotensive effect typically credited to endurance training programs may in actuality be due to a more acute post-exercise phenomenon resulting from recent exercise. Meredith et al. (1990) determined in an aerobic training study that a hypotensive response to dynamic exercise occurs after only three sessions of cycle ergometry at an intensity of 60% maximal work capacity. Resting supine blood pressure was measured prior to each exercise session in this study. The resting supine SBP of the 10 normotensive subjects decreased from a baseline pressure of 114 mm Hg to 106 mm Hg ($P < 0.005$) before the fourth session of cycle ergometry was started. Likewise, the resting supine DBP decreased from a baseline pressure of 74 mm Hg to 66 mm Hg ($P < 0.005$) prior to the commencement of the fourth session. Interestingly, no further reduction in blood pressure occurred beyond the fourth session of exercise.

The relative contribution of PEH to the reduction of blood pressure due to aerobic exercise training remains undefined, but may be substantial in studies where blood pressure was determined within 12 hours of the last exercise session (Thompson et al., 2001). In addition, acute blood pressure responses of isometric and dynamic resistance exercise need to be further examined, as they may play a role in the training effects that result from these exercise modalities.

Potential Mechanisms Causing PEH After Endurance Exercise

Cardiac output during PEH: No studies have attempted to directly measure cardiac output during PEH (MacDonald, 2002). However some studies that have indirectly measured cardiac output have shown that it is increased in normotensives during PEH mainly due to increased heart rate (Headley et al., 1996, Piepoli et al., 1993). Hypertensives have demonstrated a lowered cardiac output during the PEH period after endurance exercise (Hagberg et al., 1987, Rueckert et al, 1996, Headley et al., 1996, Floras & Wesche, 1992). Other studies have shown that both heart rate and stroke volume increase in normotensives during the PEH period (Floras et al., 1989, Cleroux et al., 1992), although MacDonald et al. (2000) and MacDonald et al. (1999) found that plasma volume did not change immediately after endurance exercise and during periods of PEH. It does not seem likely that changes in cardiac output play a large role in the PEH phenomenon.

Peripheral vascular resistance: Studies that have examined changes in peripheral vascular resistance have typically found decreases below pre-exercise values during PEH (MacDonald, 2002). Some studies (Isea, 1994, Cleroux, 1992) have demonstrated that post-exercise decreases in vascular resistance occur in sites other than exercising muscle, which indicates that the reduction may occur throughout the body. Hagberg et al. (1987) demonstrated that TPR increased after exercise in older hypertensives, which suggests that the mechanisms for PEH may differ in some subject populations.

The aftereffects of exercise on regional and systemic hemodynamics in normotensive and hypertensive individuals were studied by Cleroux et al. (1992). Subjects were monitored for 3 hours after performing cycle ergometry at 50% VO_2max for 30 minutes. The hypertensive individuals experienced a reduction in systolic (11 mm Hg) and diastolic (4 mm Hg) blood pressures, forearm vascular resistance (25 %) and total peripheral resistance (27%), whereas the normotensive individuals did not experience significant changes in these variables. However, Isea et al. (1994) found that normotensive individuals did experience significant decreases in TPR (6.7 mm Hg min l^{-1}) for 2 hours after cycle ergometry was performed in ever increasing increments of resistance until exhaustion. Exercising and non-exercising vascular beds were vasodilated for 2 hours (-24.1 and –23.8 mm Hg min ml^{-1} per 100 ml^{-1} of tissue, respectively). Systolic and diastolic blood pressure were decreased by 5.8 mm Hg and 8.3 mm Hg, respectively, after exercise. It appears that PEH may be related to changes in TPR after exercise, although this relationship needs to be examined further.

Vasoactive agents: The renin-angiotensin mechanism is a hormonal control system that modulates fluid volume and electrolyte balance, thereby affecting blood pressure and blood flow (McArdle et al., 1996). Exercise can lead to constriction of the renal arteries due to increased sympathetic activity. As a result, renal blood flow decreases and renin is released by the kidneys into the blood. Renin converts angiotensinogen into angiotensin I, which is then converted to angiotensin II by angiotensin converting enzyme (ACE). Angiotensin II is a potent vasoconstrictor of both the arteries and veins. Tissue-generated stimulation of the renin-angiotensin mechanism appears to be responsible for a variety of potentially negative effects such as vasoconstriction, sodium retention, myocyte and smooth muscle cell proliferation, increased release of anti-diuretic hormone, and sympathetic-adrenergic stimulation (McArdle et al., 1996). Increased levels of angiotensin II have been found during PEH after endurance exercise, so it appears that the renin-angiotensin mechanism doesn't nullify the PEH response (Wilcox et al., 1983).

The roles of other vasoactive agents on PEH are also in question. Anti-diuretic hormone, a vasoconstrictor of arterial smooth muscle, was not found to significantly affect PEH in a study by Wilcox et al. (1983). Atrial natriuretic peptide, a potent vasodilator, does not appear to affect PEH because its concentration does not appear to increase in the circulation during or after endurance exercise (MacDonald et al., 1999). Some animal models have suggested that inhibition of the vasodilator nitric oxide results in the attenuation of the normal decrease in vascular sensitivity after exercise (Patil et al., 1993, Van Ness et al., 1996). This would suggest that nitric oxide may play a role in the PEH response in animal models, but the response in humans needs further investigation. According to MacDonald (2002), no studies have examined the role of the vasodilator adenosine or vasodilative agents such as prostaglandins in the PEH response.

Sympathetic nerve activity: Sympathetic stimulation of the adrenal medulla as a result of exercise results in the release of epinephrine and norepinephrine in proportion to exercise intensity (MacDonald, 2002). Norepinephrine causes peripheral resistance to increase because it acts as a vasoconstrictor (MacDonald, 2002). Both epinephrine and norepinephrine increase cardiac output because they have the capability to increase heart rate and contractility (MacDonald, 2002). Elevated arterial pressure results from these increases in peripheral resistance and cardiac output. Although it would seem that lowering levels of norepinephrine would lead to PEH, this does not appear to be the case (MacDonald, 2002). The role of epinephrine also appears to be minimal, as the magnitude of PEH does not change with β-receptor blockade (Wilcox et al., 1987).

Changes in efferent sympathetic nerve activity may affect peripheral resistance. Muscle sympathetic nerve activity (MSNA) has been shown to decrease in normotensives during PEH (Halliwell et al., 1996), as well as borderline hypertensives (Floras et al., 1989). It is possible that prehypertensive and hypertensive individuals exhibit higher than normal MSNA during resting conditions, and that hypotension could be due in part to a transient suppression of augmented sympathetic outflow (MacDonald, 2002).

Kulics et al. (1999) examined the relationship between post-exercise hypotension and sympathetic nerve activity in spontaneously hypertensive rats. It was concluded that the reductions in arterial pressure observed immediately after dynamic exercise were associated with a decrease in sympathetic nerve activity and a decrease in total peripheral resistance. Quick et al. (2000) suggested that localized adaptations to hypotension due to shear stress, including bifurcations in the arterial and venous microvasculature, help stabilize adaptations in the larger conductance vessels in response to hypotension. These adaptations ensure that tissues receive proper blood flow during changing pressures.

Changes in afferent nerve activity may affect PEH. Unmyelinated group III afferent nerve fibers, which are thought to influence cardiovascular control by sensing changes in either tension or rate of movement, are activated during exercise. The direct stimulation of the skeletal afferents in the leg muscles of rats has been shown to elicit the PEH response (Hoffman & Thoren, 1988). However, the mechanisms behind this response are unknown (MacDonald, 2002). Cardiac muscle afferents may also play a role in PEH. Collins & DiCarlo (1993) found that PEH could be attenuated in rats with cardiac afferent blockade.

Thermodynamics: The primary mechanism for thermoregulation in humans is cutaneous vasodilation (MacDonald, 2002). It is possible that PEH may be caused by a redistribution of blood to the periphery due to exercise-induced body temperature increases (MacDonald, 2002). Franklin et al. (1993) found that PEH occurred only when normotensives rested in a warm environment after endurance exercise, as opposed to a cool or neutral environment, after exercise. However, the PEH phenomenon has been demonstrated to last for 2 or more hours after exercise in an ambulatory environment (Headley, et al., 1996). This would theoretically be more than enough time for body heat to return to normal. Therefore, the role of thermoregulation on PEH would appear to be minimal.

Opiods: The opioid system may be a system that affects blood pressure, possibly through the manipulation of sympathetic activity by β-endorphins (Boone et al., 1992). Eight normotensive subjects performed 2 trials of cycle ergometry at 60% VO_2max. The injection of naloxone, an opioid receptor antagonist, was been shown by Boone et al. (1992) to reverse the post-exercise hypotensive response for up to 27 minutes. However, Hara & Floras (1992) found that naloxone did not significantly affect the PEH response.

Other substances released in the brain may have an effect on post-exercise blood pressure in animal models, but their role in the PEH response in humans is open to debate. Serotonin has shown to have a significant effect on PEH in animal models (Yao, et al., 1982), but does not appear to play a role in the PEH response of humans (MacDonald et al, 1999). Boone & Corry (1996) observed that PEH in rats may be regulated in part by proenkephalin synthesis and release in the brainstem, but this model has not been studied in humans.

Post exercise recovery: Recovery posture may have an effect on PEH, but it does not appear to affect it greatly. Raine, et al. (2001) compared effects of upright or supine recovery posture on the hypotensive effects of upright cycling exercise and determined that MAP was lower during supine recovery, but not to an extent great enough to achieve statistical significance. The change in MAP during seated recovery was attributed to a decrease in arterial pulse pressure, whereas the change during supine recovery was ascribed to a change in diastolic blood pressure. The reduction in arterial pulse pressure during the seated recovery was accompanied by a decline in stroke volume, which was not seen in the supine position. The decline in stroke volume limited cardiac output, which in turn affected MAP.

It is possible that several mechanisms contribute to post-exercise hypotension. Changes in TPR after exercise may occur due to changes in sympathetic nerve activity, as well as changes in afferent nerve activity. These acute changes may lead to PEH. If multiple mechanisms do indeed contribute to PEH, the relationships between these mechanisms needs to be elucidated.

Acute Effects of Resistive Exercise on Blood Pressure

Resistive exercises traditionally have not been recommended to hypertensive individuals because of the risk of increased arterial blood pressure during the course of exercise. MacDougall et al. (1985) demonstrated that weight-lifting exercises such as the double-leg press can lead to temporary increases in systolic blood pressures during exercise, ranging from 320 mm Hg to 480 mm Hg in healthy weight lifters. The potential for even higher pressures in hypertensive subjects has raised concern. As a result, the ACSM recommended in their 1993 Position Stand, *Physical Activity, Physical Fitness and Hypertension*, that resistance training not be used as the only mode of exercise to lower blood pressure, but as part of a well-rounded fitness program that includes regular endurance exercise.

Training status: The effects of isometric training status on the arterial blood pressure and vascular conductance responses during both rhythmic and sustained forearm isometric exercise in trained normotensive rock climbers and sedentary individuals was examined by Ferguson & Brown (1997). It was concluded that there was a clear attenuation of the systolic blood pressure response during sustained isometric handgrip exercise to fatigue in the trained individuals. These findings are similar to those of White et al. (1995), who observed an attenuation of the pressor response as a result of voluntary acute isometric exercise. The attenuation of the systolic blood pressure response in the sustained handgrip exercise in the Ferguson and Brown study was not observed in rhythmic isometric handgrip exercise. Since the maximal voluntary contraction force was not significantly different between the trained and untrained groups, this was ruled this out as a factor affecting the attenuation of the blood pressure response.

Carrington, et al. (1999) examined muscle training status and its effects on the pressor response. It was determined that there were no significant differences in systolic blood pressure, diastolic blood pressure or heart rate responses between an anaerobically trained sprint group, an aerobically trained group, or an untrained group as a result of voluntary or electrically induced isometric contraction of the triceps surae. Although these findings appear to contrast those of Ferguson & Brown (1997), it is most likely because the subjects examined in this study were not isometrically trained.

Sympathetic nerve activity: Seals (1991) examined the acute effects of isometric handgrip in trained endurance athletes and found no relationship between endurance training status and MSNA. Likewise, Saito et al. (1993) found that endurance training status had no effect on MSNA during both isometric and dynamic handgrip exercises. However, Somers et al. (1992) observed that isometric handgrip training appears to attenuate MSNA. It appears that the mode of exercise training may have an effect on muscle sympathetic nerve activity (MSNA), although the relationship is unclear.

The acute effects of submaximal and maximal isometric exercise on pain perception and blood pressure in men and women were examined by Koltyn et al. (2000). The women in this study had significant increases ($P < 0.05$) in systolic blood pressure immediately after submaximal handgrip exercises, whereas the men did not. The results of this study also indicated that isometric exercise lowers pain thresholds, although this appears to be more consistent in women. Future research is needed to determine whether or not mechanisms involved with the amelioration of pain have a relationship with the mechanisms that regulate sympathetic influence on the vascular system.

Acute Post-Exercise Hypotensive Effects of Dynamic Resistance Exercise on Systolic Blood Pressure

Although dynamic resistance and isometric exercise can result in increased arterial blood pressure during exercise, limited data suggest that both of these forms of exercise lead to post-exercise reductions in arterial blood pressure. The effects of dynamic resistance exercise and cycle ergometry on recovery blood pressure were examined by Brown et al. (1994). Seven normotensive individuals performed resistance exercise consisting of three sets of five exercises (arm curl, hamstring curl, squat, "lat pull downs", and bench press) using 40% of their one-repetition maximum (1RM) for 20-25 repetitions on two occasions, and using 70% 1RM for 8-10 repetitions on two other occasions. The same subjects also performed cycle ergometry for 25 minutes at 70% of their heart rate reserve on two occasions. The three different exercise protocols all lead to very similar post-exercise hemodynamic results. Systolic blood pressure was an average of 5 mm Hg lower from 5 to 60 minutes after the completion of exercise, although this decrease in pressure was not statistically significant. Diastolic blood pressure was 20 mm Hg lower 2 minutes after exercise and continued to be significantly lower from 2 to 10 minutes after exercise. Additionally DBP was an average of 3 mm Hg lower throughout the 60 minutes that were monitored after exercise, although this average value was not significantly lower than baseline. It is possible that resting blood pressure of these subjects (107/68 mm Hg) was already so low that it was difficult to maintain a significant post-exercise hypotensive effect for prolonged period of time.

The post-exercise effects of weight lifting exercises were examined by Hill et al. (1989). Six subjects with mean arterial pressure of 119/86 mm Hg performed 3 sets of free weight exercises (arm curl, bench press, bent arm row, and squat) at 70 of their 1RM, and completed as many repetitions as possible. Blood pressure decreased significantly immediately after the exercise protocol to 99/62 mm Hg, but rebounded within a minute to 116/74 mm Hg). This pressure, while not significantly lower than baseline levels, remained for the entire 60-minute recovery period. It should be stated that the low sample size of this study limits the relevance of these results.

Baroreceptor control: Baroreceptor mediated control of blood pressure during exercise is believed to withdraw due to a “resetting” of the receptors to a higher operating set-point (Guyton, 1980). Blood pressure increases more in resistive exercise than in endurance exercise (MacDougall, et al., 1985). According to MacDonald (2002), if baroreceptors were the primary mechanisms responsible for PEH, then one would expect to see a greater reduction in post-exercise arterial pressure after resistance exercise. However, Brown et al. (1994) and MacDonald et al. (1999) did not observe any difference in the post-exercise blood pressure of individuals who had performed resistance and endurance exercises on separate occasions. Despite these findings, baroreceptors do appear to influence PEH in animal models. Chandler and DiCarlo (1997) found that PEH was not evident in rats with sinoaortic baroreceptor denervation, while it was evident in intact rats.

The hypotensive effects of resistance exercise and submaximal dynamic exercise were compared by MacDonald et al. (1999). Thirteen individuals aged 24 years, with an average resting blood pressure of 130/87 mm Hg, performed 15 minutes of unilateral leg press exercise at 65% of 1RM and one week later performed 15 minutes of cycle ergometry at 65% VO_2 max. Systolic blood pressure was 20 mmHg lower from 10 to 60 minutes post-exercise following both exercise modalities. Diastolic blood pressure was not significantly reduced, however. There was no difference in post-exercise blood pressure due to mode of exercise throughout the 60-minute post-exercise period..

Although data on the acute post-exercise hypotensive effects of resistance exercise on systolic blood pressure is scarce, it is promising. A better understanding of the post-exercise hypotension phenomenon after resistance or isometric exercise may help us to better understand the process of blood pressure regulation. The mechanisms that influence the PEH response may also influence the mechanisms of hypertension. The ideal mode, duration, and frequency of exercise should also be determined in order to maximize the potential benefits of post-exercise hypotension. Therefore, future research needs to examine the possible relationships between acute post-exercise hypotension resulting from resistance exercise and the possible amelioration of hypertension.

The Effects of Dynamic Resistive Exercise Training on Blood Pressure and Hypertension in Humans

It is well documented that regular endurance exercise can lead to lowered resting arterial blood pressure (Meredith et al., 1990). As previously mentioned, isometric and dynamic resistance exercise have not been recommended as the as the sole source of exercise in prehypertensive and hypertensive individuals. However, the few studies that have examined the effects of isometric and dynamic resistive training on resting blood pressure have produced results that contrast the notion that these types of exercise are not beneficial and perhaps even hazardous to human health.

Although some studies have shown that dynamic resistive training does not alter resting blood pressure of healthy individuals, other studies have demonstrated that dynamic resistance training can lower the resting blood pressure of hypertensives to some extent. The effects of intense dynamic resistance training on resting blood pressure were examined by Hurley et al. (1988). Untrained men aged 40-55 underwent a 16 week program which required them to perform 14 different dynamic resistance exercises on Nautilus™ machines between 3 to 4 times per week. Subjects performed between 8-12 repetitions maximum (RM) for upper body exercises and 15-20 RM for lower body exercises. Supine resting diastolic pressure was significantly lowered (84 ± 7 before training vs. 79 ± 6 mm Hg after training, $P<0.05$) as a result of the training, whereas standing diastolic pressure was not. Resting systolic pressure was not significantly altered as a result of the training. This study provided evidence that intense dynamic resistance exercise can cause resting blood pressure to be altered without changes in VO_2max or body weight.

Hagberg et al. (1984) examined the effects of dynamic resistance training on the resting blood pressures of 5 hypertensive adolescents who were aerobically trained. The endurance training consisted of running at 60-75% VO_2max at a frequency of three times per week for 20 weeks. After the completion of the endurance training, subjects underwent 20 weeks of dynamic resistance weight training. As a result of the endurance training, the subjects had a reduction of 13 mm Hg in resting systolic pressure and a reduction of 3 mm Hg in resting diastolic pressure. Interestingly, the weight training led to a further reduction of 4 mm Hg in both resting systolic and diastolic pressures, however this was not significantly lower than it was after the endurance training. The subjects were re-assessed 12 months after cessation of the weight training. The subjects did not engage in endurance or dynamic resistance training during this period. Resting systolic pressure increased significantly, to a level that was the same as the baseline value. Resting diastolic pressure also increased, but not significantly and to a level that was somewhat lower than the baseline value.

Resting systolic pressure was shown to decrease after a 19-week resistance training program consisting of leg presses and knee extensions conducted by Tatro et al. (1992). The exercises were performed at loads that lead to a failure to lift the weight by the third set of 6-12 repetitions. Baseline systolic blood pressure decreased significantly (6 mm Hg) due to the training. It was proposed that the sensitivity of the carotid-cardiac baroreflex subtly increased, potentially due to a resetting of the carotid baroreflex. However, the observed changes in carotid-cardiac baroreflex function did not alter systolic blood pressure responses to artificially induced LBNP. A recent study has demonstrated that resistance training can lower resting systolic and diastolic blood pressure to a certain extent. Byrne & Wilmore (2000) conducted a 20-week graded resistance training program in which subjects exercised between 6-12 repetitions to fatigue. Although the training led to reductions in both systolic and diastolic pressure (3 mm Hg and 2 mm Hg, respectively), these changes were not statistically significant.

The Acute Effects of Isometric Exercise on Arterial Blood Pressure

Isometric exercise elicits a "pressor" response, in which both systolic and diastolic blood pressure increase in a manner disproportional to the amount of work being done. In contrast, systolic pressure increases fairly linearly with oxygen consumption during dynamic exercise, while diastolic pressure typically changes very little. Fardy (1981) demonstrated that the size of the muscle mass is related to the extent of the pressor response. However, there was apparently no additive effect on the cardiovascular system when two muscle groups contract at the same relative percent of the maximal voluntary contraction.

Bezucha et al. (1982) examined the differences of hemodynamic responses of humans to isometric and dynamic exercise and found that the observed elevation in MAP during isometric exercise occurs as a result of increased cardiac output caused by increased heart rate. TPR increased only slightly during isometric exercise, suggesting that TPR does not contribute to increased blood pressure as profoundly as does increased heart rate. In addition, stroke volume was found to decrease significantly during exercise. Bezucha and colleagues concluded that the exaggerated heart rate response found in isometric exercise is due to a perception of effort and added cortical input to the cardiovascular control centers, rather than the response of the medulla to input from peripheral receptors.

A direct comparison between the acute hypotensive effects of isometric and dynamic resistance exercise on systolic blood pressure was conducted by O'Connor & Cook (1998). Both isometric and dynamic resistance exercises were performed at an intensity equivalent to 10% of 1 RM. The isometric exercise consisted of 8 sets of 3 minute-long contractions. The dynamic resistance exercise was performed at a rate of 20 contractions per minute. Systolic blood pressure decreased significantly (13.7 mm Hg) after the isometric exercise. The reduction in SBP began 3 minutes after the completion of exercise, and lasted for the rest of the 20 minute post-exercise measuring period. Diastolic blood pressure did not decrease significantly as a result of either exercise. It is possible that changes in diastolic pressure might have occurred after exercise, but measurements were not taken after the 20 minute post-exercise mark.

The prevailing concerns about the acute increases in arterial blood pressure during isometric exercise have likely stymied research of this exercise modality. Although the prevailing sentiment is that isometric and dynamic resistance exercise have not been shown to be beneficial to cardiovascular health, studies by Wiley et al. (1992) and Ray & Carrasco (2000) indicate otherwise. Since there have been few studies focusing on the acute effects of isometric and dynamic resistive exercise on blood pressure in humans, more research needs to be conducted in order to shed more light on the potential cardiovascular benefits of these types of exercise.

The Effects of Isometric Exercise Training on Resting Blood Pressure and Hypertension in Humans

Innovative studies have been conducted involving isometric training, which have demonstrated that resting blood pressure can be lowered with this simple mode of regular activity. Buck & Donner (1985) conducted an intriguing assessment of the prevalence of hypertension in the workplace by categorizing jobs based on the amount of isometric activity. The incidence of hypertension was lowest in jobs that required moderate or heavy isometric activity. This trend was apparent even after statistical adjustment for age, social class, obesity, and level of alcohol consumption. It was concluded that isometric activity was beneficial in lessening hypertension.

Isometric exercise training may have a positive impact on resting arterial blood pressure. Ferguson & Brown (1997) observed an attenuation of the systolic blood pressure response in isometrically trained rock climbers after acute sustained handgrip exercise, but not in the rhythmic isometric handgrip exercise. It should be noted that the isometrically trained subjects were not compared with dynamic resistance-trained individuals. While Tatro et al. (1992) demonstrated that dynamic resistance training can significantly lower resting systolic blood pressure (-6 mm Hg, $P < 0.05$), there is little evidence of significant effects on resting blood pressure in other studies (Cononie et al., 1991, Hurley, 1984, 1988).

However, there is evidence that isometric exercise training can significantly lower resting blood pressure. The training protocol of Wiley et al. (1992) consisted of sustained handgrip contractions set at moderate intensities with breaks between sets. This design was used in order to avoid the dangers of the pressor response associated with high levels of isometric exercise. The authors performed two separate studies. Subjects in the first protocol (*n* = 8) performed four 2-minute isometric handgrip contractions with the dominant arm at 30% of the maximal voluntary contraction (MVC), with 2 minutes rest between sets. This protocol was performed three times per week for eight weeks. Resting blood pressure was measured in the non-dominant arm on the days in which training occurred. Subjects in the control group (n = 7) did not train in any way during the eight weeks. Candidates who did not have initial resting diastolic pressures between 80-90 mm Hg were excluded from this study.

The second protocol consisted of four contractions at 50% MVC for 45 seconds, with one minute rest between sets. Subjects (n = 10) were required to alternate the exercising arm in this protocol, which was performed five days per week for five weeks. Baseline resting blood pressures for these subjects were 127 mm Hg systolic and 86 mm Hg diastolic. The effects of detraining were assessed in this study by examining the resting blood pressures of subjects 5 weeks after the cessation of the training. Although resting blood pressure was measured once per week for 5 weeks, it was unclear whether or not it was measured with the same arm on a consistent basis. It also should be noted that there was no control group in the second study and there was no inclusion criteria for resting arterial blood pressure.

The subjects performing the first protocol experienced a significant decline in resting systolic pressure (-12.5 mm Hg) and diastolic pressure (-14.9 mm Hg). The subjects performing the second protocol also experienced significant declines in resting pressure, although not as pronounced as the subjects in the first protocol. The resting systolic and diastolic pressures, which had decreased 9.5 and 8.9 mm Hg, respectively, returned gradually to pre-training levels after 5 weeks of detraining.

Wiley and colleagues suggested that the repeated exposure to the increased systolic and diastolic blood pressures caused by the pressor response to isometric exercise might serve as a stimulus for baroreceptor resetting. Sympathetic neural influences might also be altered by changes in muscle afferent information, which could in turn affect total peripheral resistance (TPR). Also, it was proposed that endocrine and endocrine-like substances could be influenced by the pressor response or muscle stimuli so that TPR is affected.

The effects of isometric handgrip training on resting arterial pressure and sympathetic nerve activity in normotensive individuals were recently examined by Ray and Carrasco (2000). The training protocol used in this study was similar to the models used in the Wiley et al. (1992) study. Subjects in the exercise group (n = 9) performed 4 sets of isometric handgrip exercise at 30% MVC with the dominant arm for a duration of 3 minutes per set. The exercises were performed 4 times per week for 5 weeks. Each set was separated by a 5-minute rest period. Control group subjects (n = 8) did not train in any way. A group of sham-trained subjects (n = 7) held the handgrip dynamometer, but they did not generate any force during the exercise bouts. Resting systolic and diastolic blood pressure was measured before the commencement of training and then again at the end of the training 5 weeks later. It was unclear whether or not resting blood pressure was monitored with the same arm on a consistent basis. Resting and exercise MSNA was measured in the control and exercise training groups via sensors inserted into the peroneal nerve. Exercise MSNA was recorded in both groups during isometric handgrip exercise of 30% MVC.

Compared to the control and sham-trained subjects, the trained subjects experienced significantly lower diastolic (-5 mm Hg) and MAP (-4 mm Hg). However, there was no significant change in systolic pressure in the trained group (-3 mm Hg). However, mean baseline blood pressure was in the normotensive range (116 mm Hg systolic, 67 mm Hg diastolic), unlike the Wiley et al. (1992) study.

Wiley et al. (1992) suggested that TPR may change due to altered sympathetic nerve activity as a result of the training. Although the training protocols differ, this line of thought is compatible with the findings of Somers et al. (1992), who demonstrated that forearm endurance training results in an attenuation of the muscle sympathetic nerve activity during isometric exercise. However, neither resting nor exercise sympathetic nerve activity changed significantly with training in the Ray & Carrasco (2000) study. Since the subjects used in this study were mostly normotensive, Ray & Carrasco suggested that it may be possible for hypertensives to achieve greater reductions in arterial blood pressure as well as attenuated MSNA.

The effects of isometric handgrip training on older hypertensives was examined by Taylor et al. (2003). The average baseline blood pressure of these individuals was 156/82 mm Hg. The 10-week training protocol of four 2-minute isometric handgrip contractions at 30% MVC performed 3 days per week resulted in a significant decrease in systolic blood pressure (-19 mm Hg). Diastolic blood pressure was also reduced as a result of the training, but not to a significant degree. The investigators in this study proposed that the attenuation of resting blood pressure due to the training may have resulted in part from an increase in blood flow due to decreased peripheral resistance. It was also suggested that the training led to decreased sympathetic and enhanced parasympathetic modulation of blood pressure.

It is apparent that future research needs to be done to verify and draw further conclusions based on the findings of the previously mentioned studies of isometric and dynamic resistance exercise so that the prevailing views of these types of exercise can be effectively challenged. The methodologies of future studies should include protocols that can elicit empirically measurable, comparable and readily repeatable results.

This study may potentially shed more light on the post-exercise effects of dynamic and isometric exercise. It is important to determine whether or not there are indeed any potential cardiovascular benefits associated with these modes of exercise. If it is determined that there is potential for lowering cardiovascular risk factors through either isometric or dynamic resistance exercise, these modes of exercise could then be recommended to those who cannot or will not exercise aerobically.

CHAPTER III

OUTLINE OF PROCEDURES

The methodology of this study is discussed in detail in this section. The screening and assessment of the 18 subjects occurred before the experimental trials began. The experimental protocols in this study consisted of an isometric handgrip exercise trial, a dynamic resistance exercise trial, and a control trial (Table 2). Procedures for data analysis are also described.

Subjects

This study of the effects of isometric handgrip exercise and dynamic resistance handgrip exercise on post-exercise arterial blood pressure consisted of 18 subjects (mean ± SEM: age, 45 ± 11.4 yr; body mass index, 24.9 ± 3.8 $kg \cdot m^{-2}$). This sample size was selected because it was similar, if not larger than most other studies that have examined the PEH phenomenon (MacDonald et al., 1999, Headley et al., 1996, MacDonald et al., 2001). Participants in this study were sedentary. Participants did not use tobacco products or medications known to affect blood pressure. Other factors that excluded potential participants included the following: diabetes mellitus, pregnancy (suspected or confirmed), target organ damage, cardiovascular disease, and any condition that would impair a person's ability to perform handgrip exercises.

A screening session was conducted to assess the blood pressure of potential candidates. Potential candidates were given a health-history questionnaire (see Appendix A), which focused on cardiovascular health and exercise frequency. In addition, it contained general health questions. All blood pressure measurements were taken according to JNC VII Guidelines (2003), which require subjects to rest in a quiet environment for at least 10 minutes prior to the measurement with a sphygmomanometer. The blood pressure of subjects participating in this study was required to fall into at least one of two categories during the screening session: systolic blood pressure was required to be in the 120-159 mm Hg range and/or diastolic blood pressure was required to be in the 80-99 mm Hg range. These blood pressures encompass the "Pre-hypertensive" and "Stage 1 hypertensive" categories as established by JNC VII (2003).

Assessment of Subjects

Blood Pressure Measurement: Resting arterial blood pressure was assessed in each candidate at the same approximate time of day that the exercise protocol occurred. Subjects rested in a quiet environment for at least 10 minutes prior to the measurement. Blood pressure measurements were taken with an AND model UA-751 automated sphygmomanometer (Long Island, NY) according to JNC VII Guidelines (2003).

The initial blood pressure measurements of the automated cuff were followed by readings with a manual mercury sphygmomanometer to verify the accuracy of the automated cuff readings. Automated systolic and diastolic measures were within ± 4 mm Hg of the manual measures. The automated cuffs were reliable throughout the study. Subjects were seated in a chair with their backs supported with their arms bared and supported at heart level during the measurement. The forearm rested on a table at an angle of approximately 135º during the blood pressure assessment.

There were 2 automated sphygmomanometer readings taken per arm, each separated by 2 minutes. The results of these readings were averaged. Additional readings were performed if the first 2 readings differed by more than 5 mm Hg. Subjects were required not to ingest any caffeine for a period of 3 hours and to refrain from ingesting any food for one hour prior to measurement of blood pressure.

Isometric Grip Strength Assessment: Isometric grip force in this study was measured by a model J-20 Jamar hydraulic dynamometer (Chicago, IL). The exercising forearm was rested on a table at an angle of approximately 135º for all activities involving the use of the dynamometer. The maximal voluntary contraction (MVC) of the non-dominant hand of each subject was measured with the dynamometer prior to the commencement of the experimental protocol. The MVC was obtained by having subjects exert maximal force on the dynamometer for 5 seconds. Subjects performed a second MVC in the same manner after 2 minutes of rest.

Testing facilities

To minimize commuting distance, two separate laboratories were used for this experiment. However, each given subject completed screening and all trials in the same laboratory. Both locations provided controlled environments in which external stimuli (e.g., noise, interruptions) were kept to absolute minimums. Having a controlled environment was considered to be of paramount importance so that the arterial blood pressure of subjects during and after the experimental protocols was not affected by disruptive external stimuli.

Experimental Protocol

There were two exercise protocols used in this study: isometric handgrip exercise and dynamic resistance handgrip exercise. In addition, there was also a control protocol. The test administrator closely monitored the force of the contractions in both exercise protocols. The order of the protocols was randomized for all subjects, and each protocol was separated by at least 4 days. The experimental protocol is outlined in Table 2.

Isometric resistance protocol: The isometric handgrip exercise protocol was similar to that of Ray and Carrasco (2000). This protocol consisted of 3 sets of sustained isometric handgrip with the non-dominant arm for 3 minutes at 30% MVC. There were 3 minutes rest between sets.

Dynamic resistance protocol: The dynamic resistance handgrip exercise protocol consisted of 3 sets of 45 rhythmic contractions at 60% MVC with the non-dominant arm for 3 minutes. There were 3 minutes of rest between sets for this protocol as well. Each contraction was held for 2 seconds, followed by a 2 second rest. Although the timing and required grip forces differed, he total work performed in each of the 2 trials was the same. Timing was made audible by a metronome.

<u>*Control protocol*</u>: The control protocol consisted of loosely holding the handgrip dynamometer for 3 sets of 3 minutes each. There were 3 minutes in between each set in which the subjects did not hold the dynamometer.

Arterial blood pressure was assessed immediately before the commencement of each protocol, immediately after, and at the following intervals after the protocol: 1.5, 5, 10, 15, 20, 30, 40, 50, 60, 75, and 90 minutes. Additionally, BP was assessed immediately after, and then again 1.5 minutes after the first 2 sets. Pre and post BP was measured simultaneously in the exercised and non-exercised arms.

<table>
<tr><td colspan="3">Telephone Screening</td></tr>
<tr><td colspan="3">In-Person Screening
▪ Blood pressure assessment
▪ Health history questionnaire</td></tr>
<tr><td colspan="3">Experimental Protocol (randomized order):</td></tr>
<tr><td>Isometric
3 sets of sustained isometric handgrip with the non-dominant arm for 3 minutes at 30% MVC. 3 minutes rest between sets.</td><td>Dynamic
3 sets of 45 rhythmic contractions at 60% MVC with the non-dominant arm for 3 minutes. 3 minutes of rest between sets. Each contraction was held for 2 seconds, followed by a 2 second rest.</td><td>Control
The handgrip dynamometer was held loosely for 3 sets of 3 minutes each. There were 3 minutes in between each set in which the subjects did not hold the dynamometer.</td></tr>
</table>

Table 2–Experimental Design

Data Analysis

Differences between the arterial pressures of the isometric handgrip exercise trial, the dynamic resistance group and the control trial during the course of the exercise training was determined using a repeated measures analysis of variance (ANOVA) with a between-within design in SPSS® statistical data analysis software. The data used for this analysis was collected from a pre-test, an immediate-post-test, and at specified post-test intervals at the conclusion of the respective protocols. Statistical significance was set at $P < 0.05$.

Due to the large quantity of data points collected in this study, the analysis of data focused on groups of post-exercise time-points. After observation of all post-exercise time-points (Fig. 1-2), consecutive data points that were in close proximity to one another were grouped and averaged. Since the lowest blood pressures occurred from 20-90 minutes post-exercise, only this period was compared to the pre-exercise blood pressure values in the statistical analyses.

CHAPTER IV

RESULTS

There were trends for decreasing blood pressure as a result of the exercise trials, but these decreases were not statistically significant when compared to the control trial. The trends in decreased blood pressure occurred in both the exercising and non-exercising arms. These trends persisted through 90 minutes of post-exercise.

Subjects were aged 45 years (±11.3) and were predominately white. Demographic data for each subject as well as the resting systolic, diastolic and mean arterial blood pressures averaged from the pre-exercise measures of the 3 trials are presented in Table 3.

Age (Yr)	45.3 ±11.39
BMI (kg/m^2)	24.9 ±3.74
Sex (%)	
Female	28 (n=5)
Male	72 (n=13)
Ethnicity (%)	
Asian	5.5 (n=1)
African American	5.5 (n=1)
White	89 (n=16)
SBP (mmHg)	125.2 ±5.91
DBP (mmHg)	79.6 ±4.92
MAP (mmHg)	94.6 ±4.95

Table 3–Subject demographic data and body mass index.

Subjects (N = 18) participating in the study were required to meet inclusion requirements for minimum resting systolic and diastolic arterial blood pressure (≥120 mmHg systolic and/or ≥80 mmHg diastolic) during the screening session. Although all of the subjects met these criteria during the screening session, a few demonstrated resting blood pressures below these minimum levels before the commencement of one or more experimental trials. The data in this study are presented in several ways. All data points from all subjects were analyzed, regardless of whether or not individual subjects demonstrated resting blood pressure rates lower than the inclusion requirements indicated. However, the entire data set was used primarily to obtain a profile of how blood pressure levels changed after the completion of the exercise protocols. In addition, the raw data was filtered via the SPSS® statistical data analysis software in order to exclude those subjects who did not meet minimal inclusion requirements for blood pressure (systolic blood pressure ≥120 mmHg and/or diastolic blood pressure ≥80 mmHg) during the actual trials. If subjects did not meet the original inclusion requirements for any given trial, additional analyses were conducted without their data. The data was also grouped into time periods that reflected the typical changes in blood pressure after the protocol sessions. These grouped time periods were compared to the pre-trial resting arterial blood pressures.

When analyzing the entire subject pool, systolic blood pressure in the exercising arm declined (Fig. 1) after the isometric and dynamic exercises, but not to a level that reached statistical significance when compared to the control trial. The largest observable decrease in systolic pressure following the isometric exercise, -3.9

mmHg, was noted at the 30 minutes post-exercise mark (Table 4). The greatest observable decrease in systolic pressure as a result of the dynamic exercise was -6.2 mmHg at the 30 minutes post-exercise mark. Diastolic blood pressure in the exercising arm (Fig. 1) appeared to be lower to some extent after the dynamic handgrip exercise, but this was not statistically significant. The nadir was –2.1 mm Hg at the 15 min post-exercise mark.

	SBP (mmHg)	Timepoint (min)	DBP (mmHg)	Timepoint (min)
Iso EX	-3.6	75	-1.3	90
Iso NON	-3.9	30	-0.4	2.5
Dyn EX	-6.2	30	-2.1	15
Dyn NON	-5.4	30	-1.0	2.5
Ctl EX	-2.7	50	-1.8	30
Ctl NON	-2.8	15	-2.1	30

Table 4–Largest mean decreases in blood pressure after each protocol. Iso=isometric handgrip exercise, Dyn=dynamic handgrip exercise, Ctl=control, EX=exercising arm, NON=non-exercising arm

Blood pressure in the non-exercising arm was measured simultaneously with that of the exercising arm. There was a trend for decreased systolic pressure (Fig. 2) after both the isometric and dynamic exercise trial, but not to a level that reached significance when compared to the control trial. The nadir of the post-exercise systolic blood pressure reduction as a result of the isometric exercise was –3.9 mm Hg at the 30-minute mark (Table 4). The lowest post-exercise blood pressure noted as a result of the dynamic exercise was –5.4 mm Hg at the 30-minute mark.

Due to within-trial variations of blood pressure across time, the data was also grouped together and analyzed to look for the possibility of significant decreases in post-exercise pressure as a result of either the dynamic or isometric trials. The pre-trial resting blood pressures in each arm were compared to the grouped resting periods of 20-90 minutes post-exercise. This timeframe was chosen because it appeared that the largest observable decreases in systolic pressure in the exercising arm occurred during this period. Visual analysis of this time period revealed systolic measures consistently below resting level following both exercise trials (Fig 1-2). There was a trend for decreased systolic blood pressure in both the exercising (Fig. 3) and non-exercising (Fig. 4) arms, but this change was not quite enough to be statistically significant ($p>0.05$). The was also a slight trend for decreased diastolic pressure in both arms as well but, again, not enough for statistical significance (Fig. 3-4).

Mean arterial blood pressure (Fig. 5) in the exercising arm decreased after dynamic exercise, but not significantly. At some points, post-exercise diastolic and mean arterial pressure were increased after isometric handgrip exercise, but not to a significant degree. Mean arterial blood pressure (Fig. 5) in the non-exercising arm was slightly lower after the dynamic trial, but not to a level that reached significance when compared to the control trial.

The data was also filtered in the SPSS® statistical data analysis software so that only those subjects who met the inclusion requirements for either systolic (≥120 mmHg) or diastolic (≥80 mmHg) blood pressure across all trials were compared to each other. This filtering was arm-specific, and any instance of the inclusion requirements not being met during any given trial would result in that subject's data to not be included in the analysis for all trials for any given measure. For example, if a subject reported to a protocol session and demonstrated lower systolic blood pressure in the non-exercising arm than was called for in the inclusion requirements, the subject's data was excluded from the data pool during the analysis of systolic blood pressure in the non-exercising arm for all trials. Even with this filtering in place, systolic blood pressure was not shown to decrease significantly after the exercise trials in either the exercising (N = 15, Fig. 6) or non-exercising (N = 13, Fig. 7) arms. Likewise, diastolic pressure did not decrease significantly in either the exercising (N = 7, Fig. 6) or non-exercising (N = 8, Fig. 7) arms.

Finally, it is possible that subjects with higher resting blood pressures would demonstrate a greater change in post-exercise arterial blood pressure as a result of the dynamic and isometric trials. However, Pearson's correlation analyses indicated no relationships between higher initial blood pressure and magnitude of lowered blood pressure in these particular subjects. The strongest correlation was r = -0.25 (include p value) in diastolic blood pressure in the exercising arm after isometric exercise.

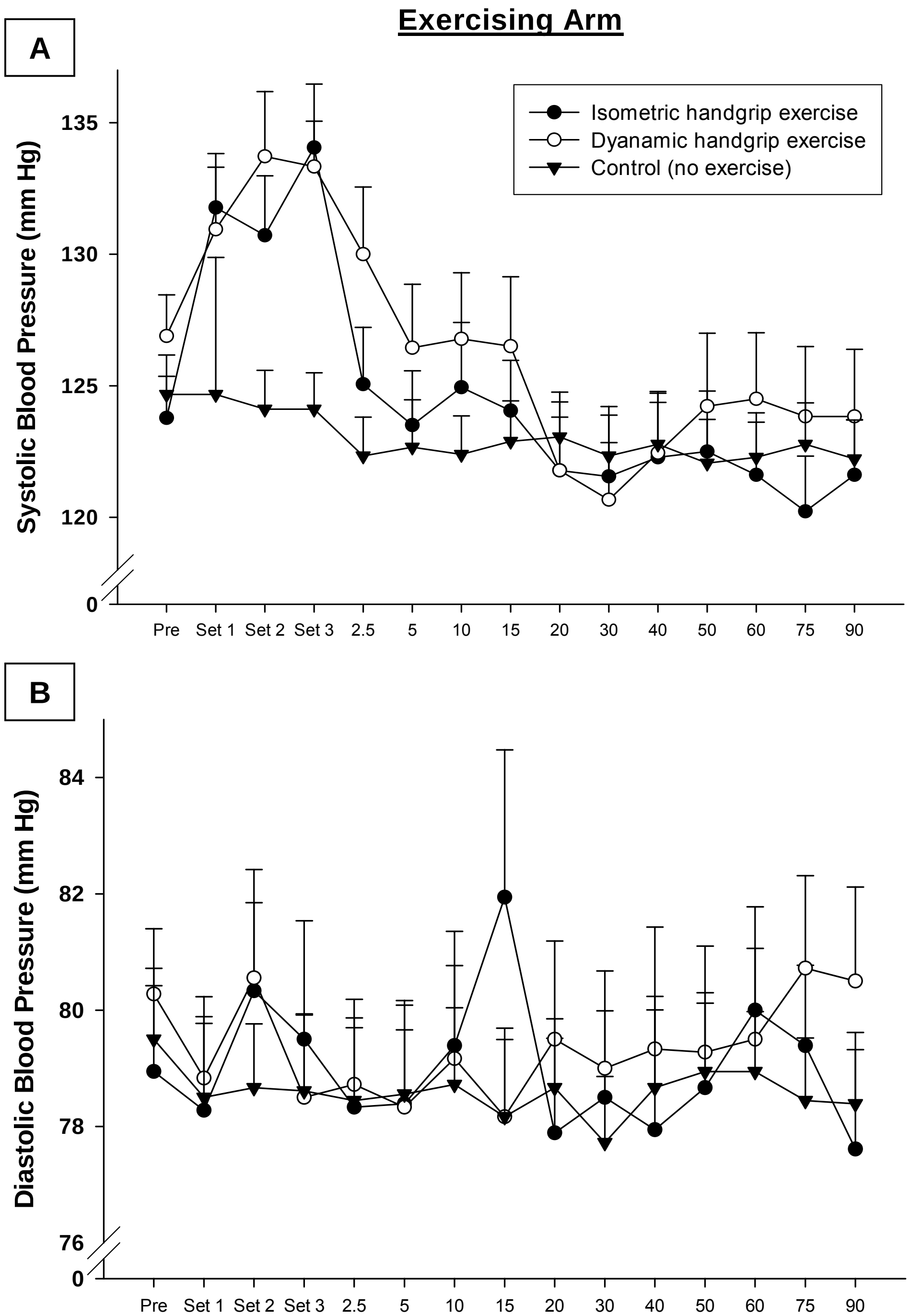

Figure 1–Systolic (A) and diastolic (B) blood pressures of the exercising arm of subjects (N = 18) after the isometric handgrip and dynamic handgrip exercise trials, as well as the control session. Blood pressure responses are shown as means (±SE) from the pre-exercise measurements. Post-exercise blood pressure did not significantly decline (p>0.05) in either exercise trial.

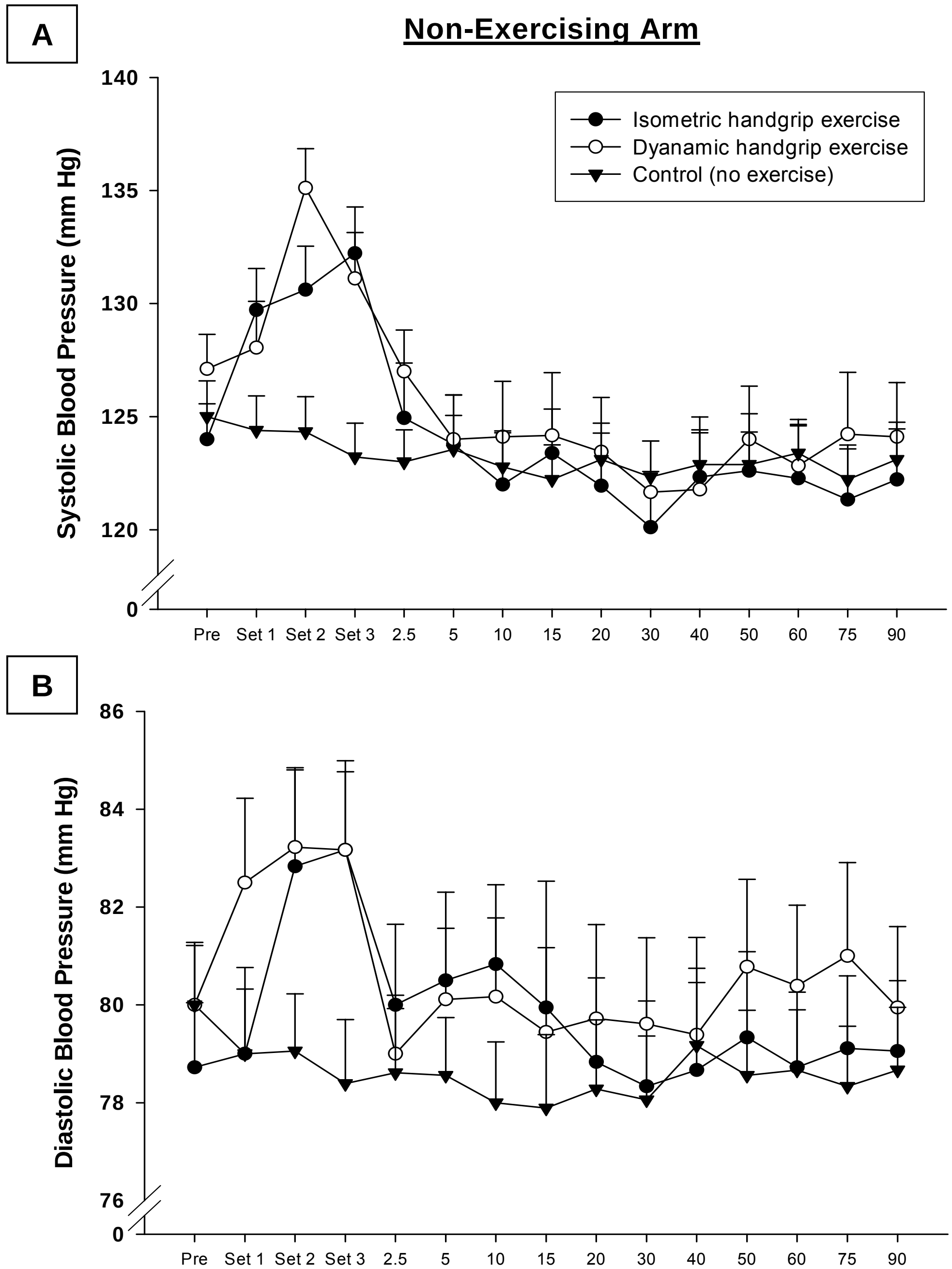

Figure 2– Systolic (A) and diastolic (B) blood pressures of the non-exercising arm of subjects (N = 18) after the isometric handgrip and dynamic handgrip exercise trials, as well as the control session. Blood pressure responses are shown as means (±SE) from the pre-exercise measurements. Post-exercise blood pressure did not significantly decline ($p>0.05$) in either exercise trial.

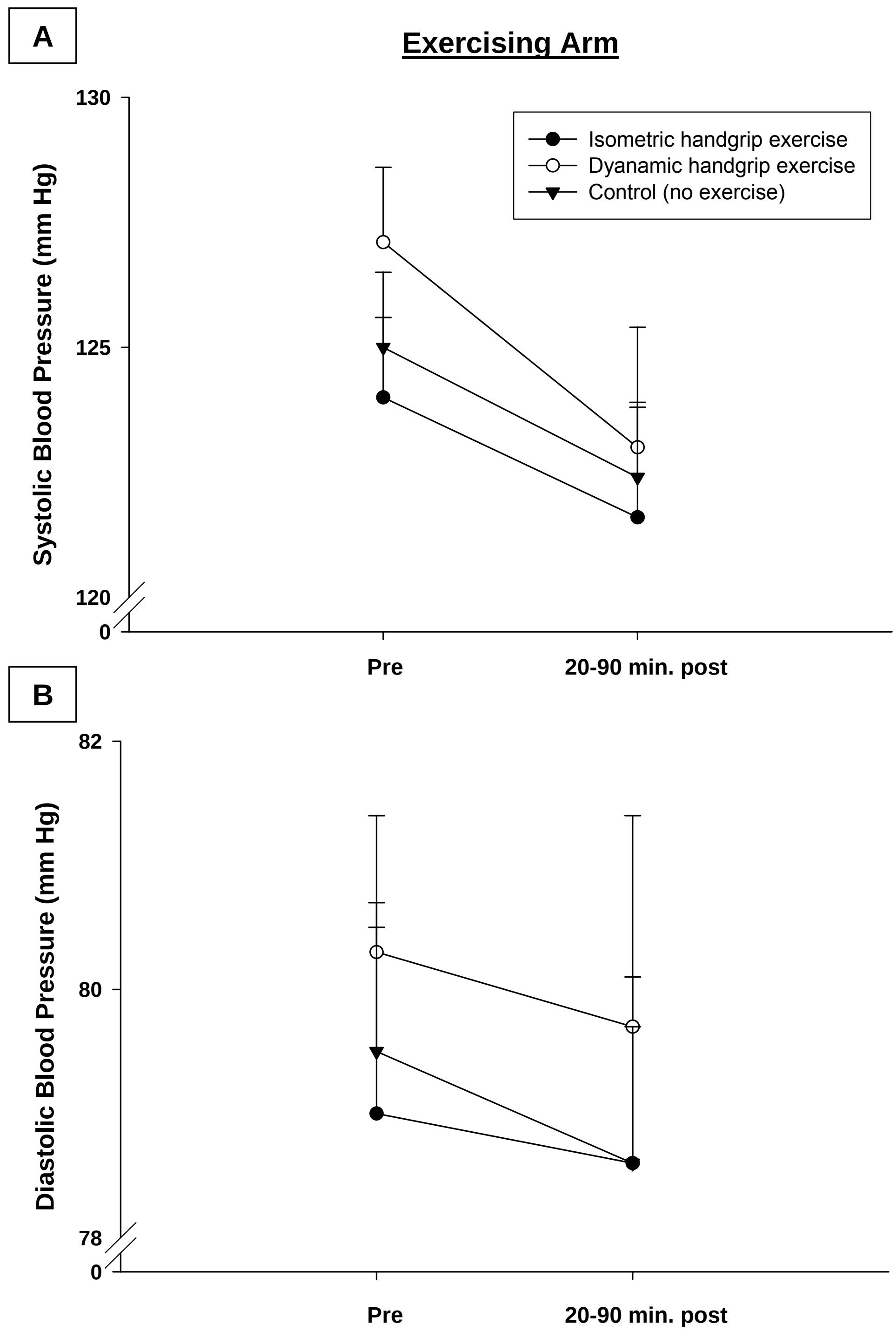

Figure 3–Pre and post (20-90 minutes) systolic (A) and diastolic (B) blood pressures of the exercising arm of subjects (N = 18) after the isometric handgrip and dynamic handgrip exercise trials, as well as the control session. Blood pressure responses are shown as means (±SE) from the pre-exercise measurements. Post-exercise blood pressure did not significantly decline ($p>0.05$) in either exercise trial compared to the control trial.

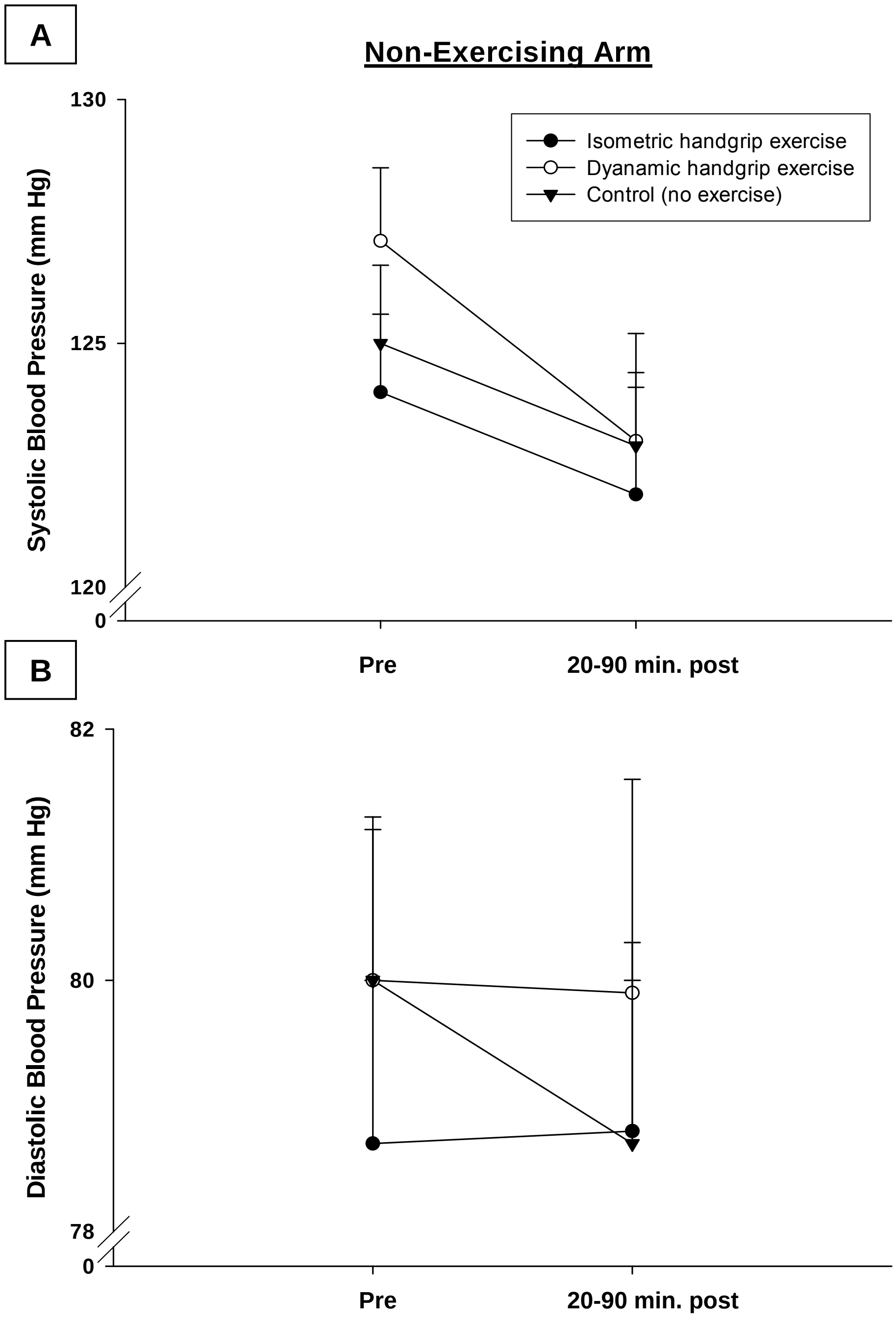

Figure 4–Pre and post (20-90 minutes) systolic (A) and diastolic (B) blood pressures of the non-exercising arm of subjects (N = 18) after the isometric handgrip and dynamic handgrip exercise trials, as well as the control session. Blood pressure responses are shown as means (±SE) from the pre-exercise measurements. Post-exercise blood pressure did not significantly decline ($p>0.05$) in either exercise trial.

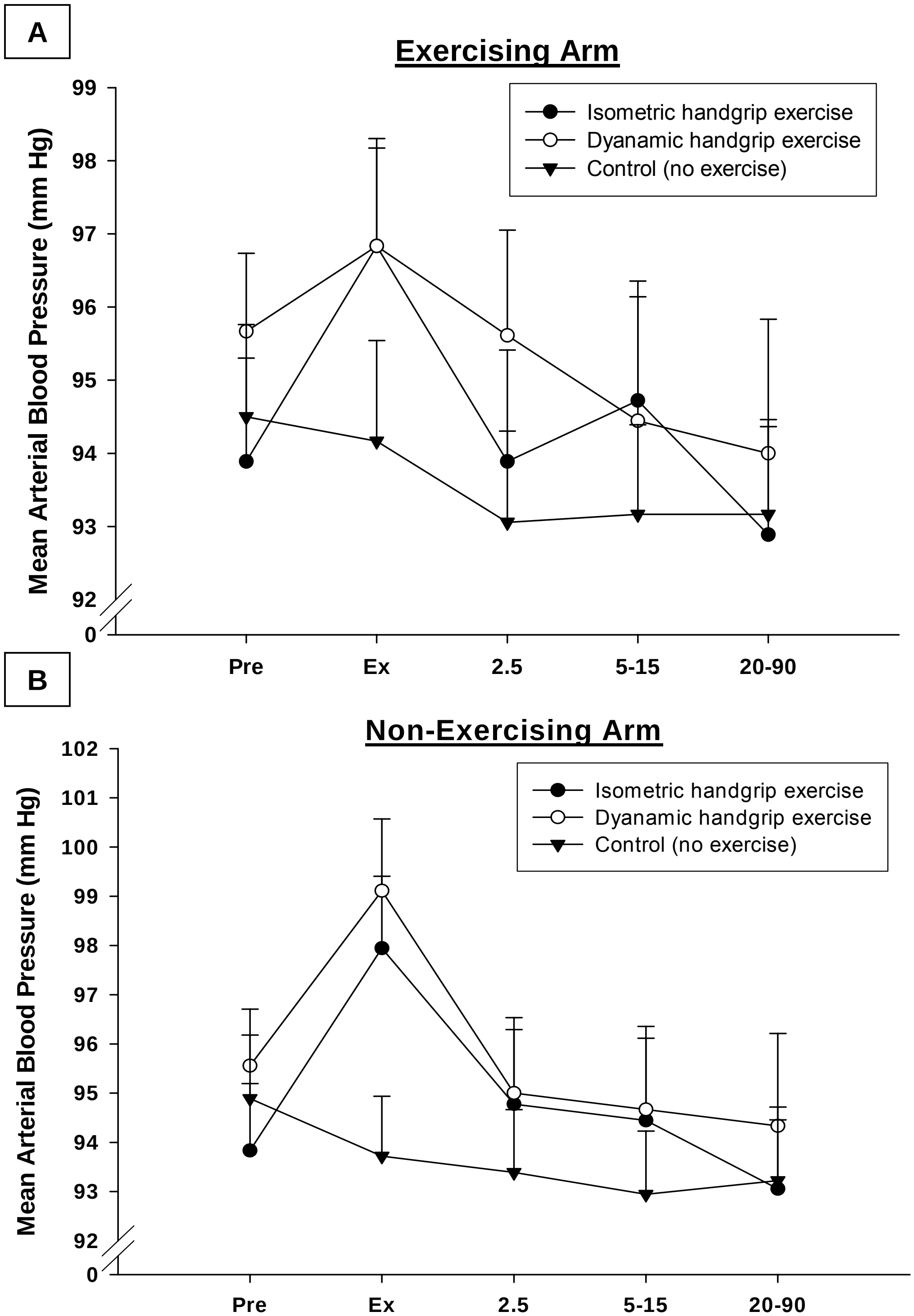

Figure 5–Grouped mean arterial blood pressures of both the exercising (A) and non-exercising (B) arms of subjects (N = 18) after the isometric handgrip and dynamic handgrip exercise trials, as well as the control session. Blood pressure responses are shown as means (±SE) from the pre-exercise measurements. Post-exercise blood pressure did not significantly decline ($p>0.05$) in either exercise trial.

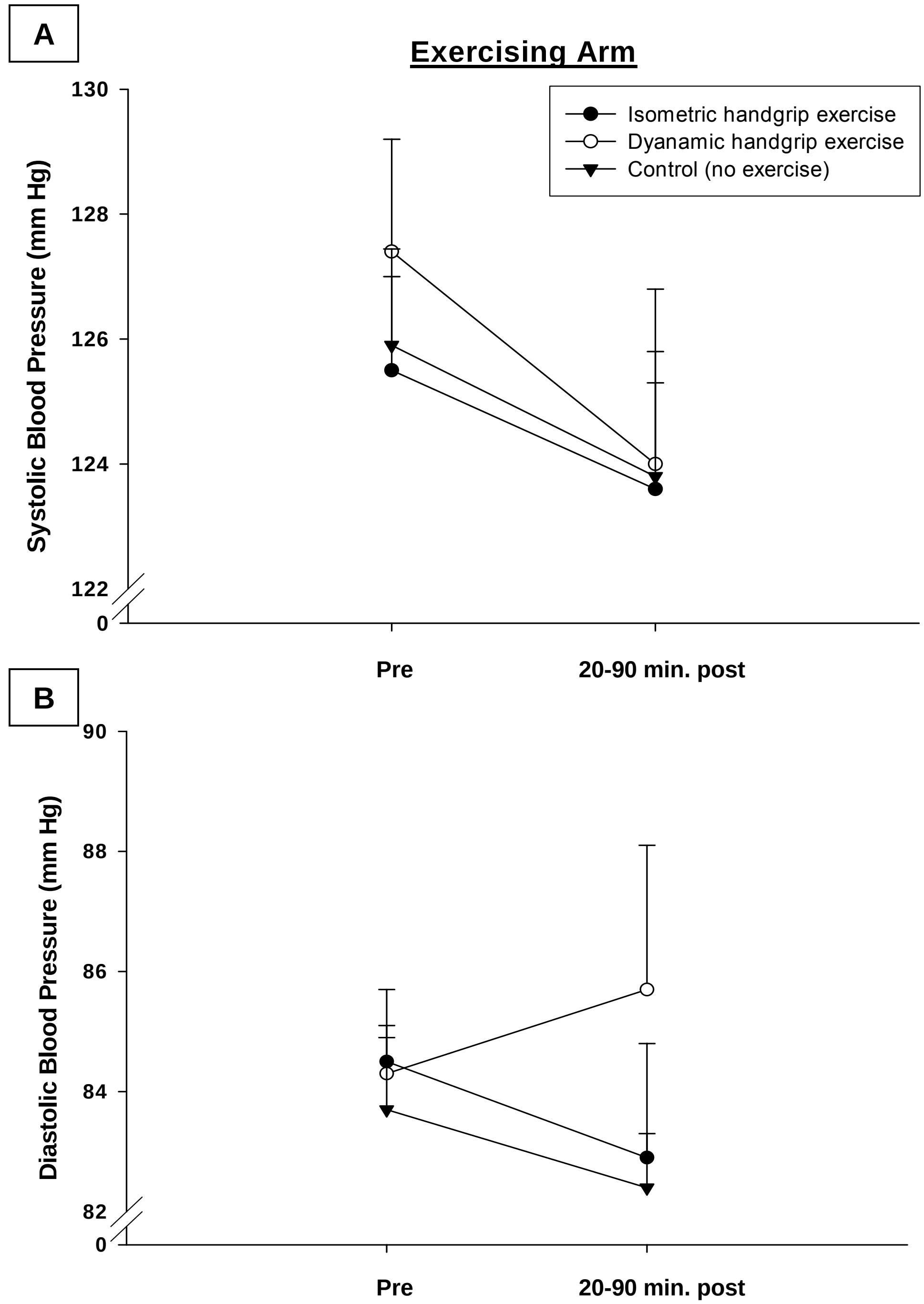

Figure 6–Filtered pre and post (A) systolic (N = 15) and (B) diastolic (N = 7) blood pressures of the exercising arm of subjects after the isometric handgrip and dynamic handgrip exercise trials, as well as the control session. Blood pressure responses are shown as means (±SE) from the pre-exercise measurements. Post-exercise blood pressure did not significantly decline ($p>0.05$) in either exercise trial.

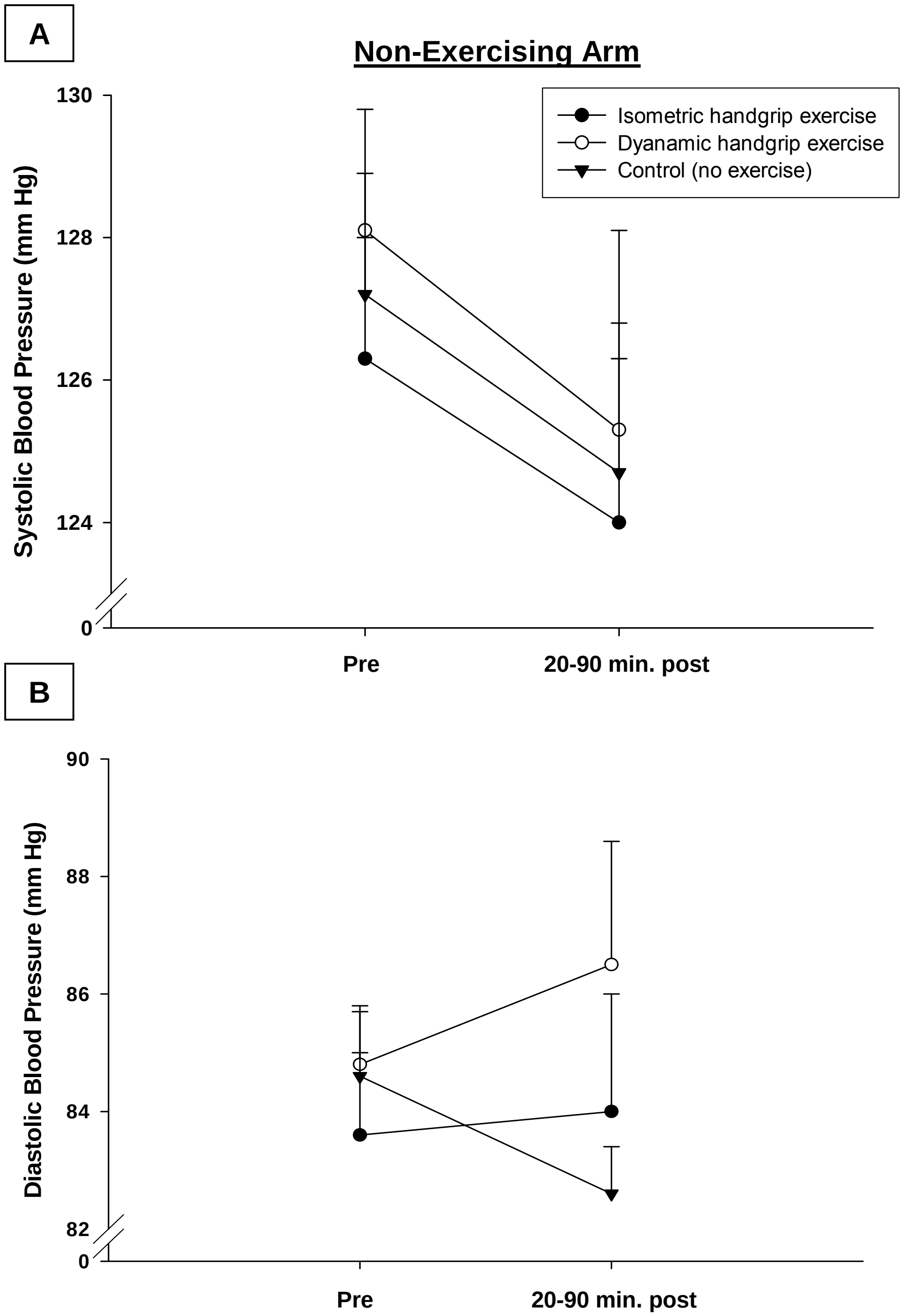

Figure 7–Filtered pre and post (A) systolic (N = 13) and (B) diastolic (N = 8) blood pressures of the exercising arm of subjects after the isometric handgrip and dynamic handgrip exercise trials, as well as the control session. Blood pressure responses are shown as means (±SE) from the pre-exercise measurements. Post-exercise blood pressure did not significantly decline ($p>0.05$) in either exercise trial.

CHAPTER V

DISCUSSION

The focus of this study was to determine the effects of both isometric and dynamic handgrip exercise on post-exercise blood pressure. The exercise trials did not result in significant reductions in post-exercise blood pressure. However, the results revealed a slight, but not a significant trend for decreased systolic blood pressure after the dynamic exercise in both the exercising and non-exercising arms. A modest trend of decreased systolic blood pressure was observed in both arms after the isometric exercise as well. However, since there was also trend for decreasing systolic blood pressure noted in the control trial, it is possible that there was a relaxation effect on systolic blood pressure as subjects sat throughout the post-trial monitoring periods.

The trends in diastolic blood pressure were less impressive. Diastolic blood pressure in the exercising arm did not appear to be any lower than baseline levels after both the dynamic handgrip and isometric handgrip exercises (Fig. 1). Mean arterial blood pressure (which is influenced more by diastolic pressure) was somewhat lower after the dynamic trial in both arms, but again, not to a level that was statistically significant (Fig. 5).

Since neither isometric nor dynamic handgrip exercise significantly lowered systolic and diastolic blood pressure compared to the control condition, Hypothesis 1 (pp. 7-8), that both isometric and dynamic handgrip exercise would elicit lower systolic and diastolic blood pressures when compared to a control condition, was rejected. The failure of blood pressure to decrease following exercise also lead to the rejection of Hypothesis 2, that the blood pressure-lowering effect of isometric and dynamic handgrip exercise would be similar. This finding also lead to the rejection of Hypothesis 3, that the blood pressure-lowering effect of handgrip exercise would occur in both the working and noon-working arm.

The exercise protocols in this study were modeled after isometric handgrip *training* studies (Table 5), such as those conducted by Wiley et al. (1992) and Ray and Carrasco (2000). In the Wiley et al. (1992) study, the subjects performing the first protocol experienced a significant reduction in resting systolic pressure (-12.5 mm Hg) and diastolic pressure (-14.9 mm Hg). The subjects performing the second protocol also experienced significant decreases in resting pressure, although not as pronounced as the subjects in the first protocol. The resting systolic and diastolic pressures, which had decreased 9.5 and 8.9 mm Hg, respectively, returned gradually to pre-training levels after 5 weeks of detraining. The isometric handgrip study conducted by Ray and Carrasco (2000) showed that the trained subjects experienced significantly lower diastolic (-5 mm Hg) and MAP (-4 mm Hg) compared to the control and sham-trained subjects. However, there was no significant change in systolic pressure in the trained group (-3 mm Hg).

The handgrip exercise training studies of Wiley et al. (1992) and Ray and Carrasco (2000) both showed significant reductions in resting blood pressure due to the isometric handgrip exercise training. However, these studies did not report post-exercise blood pressure after each training session. Interestingly, Wiley et al. (1992) did not see any reductions in systolic blood pressure until the second week of training. This indicates that 3 individual training sessions occurred in the first of their two studies before any sort of decrease in resting systolic blood pressure was noted. The subjects in this training study did not experience statistically significant reductions in resting systolic pressure until week 4 of the training.

Resistive Exercise Training Studies						
Author	**Baseline SBP/DBP (mm Hg)**	**Mode / Intensity**	**Frequency**	**Duration**	**Results**	**Control subjects**
Tatro et al., 1992	122 / ?	Leg presses and knee extensions: 3 sets to failure.	2x per week for 19 weeks	4-5 sets to failure	SBP: -6* mmHg	No
Byrne & Wilmore, 2000	119 / 72	Resistance circuit training: 6-12 reps to failure	4x per week for 20 weeks	6-12 reps to failure	SBP: -3 mmHg DBP: -2 mmHg	Yes
Wiley et al., 1992	134 / 87	4 isometric handgrip sets, 30% MVC	3x per week for 8 weeks	2 min. per set	SBP: -12.5* mmHg DBP: -14.9* mmHg	Yes
Wiley et al., 1992	127 / 86	4 isometric handgrip sets, 50% MVC	3x per week for 5 weeks	45 sec. per set	SBP: -9.5* mmHg DBP: -8.9* mmHg	No
Ray & Carrasco 2000	116 / 77	4 isometric handgrip sets, 30% MVC	4x per week for 5 weeks	3 min. per set	SBP: -3 mmHg DBP: -5* mmHg	Yes

* = Significant change
EX = Exercise
LCE = Leg cycle ergometry
MVC = Maximal voluntary contraction
RM = One repetition maximum

Table 5–Comparison of Resistive exercise training studies.

Studies that have examined the acute effects of exercise on post-exercise blood pressure (Table 6) have compared modes of exercise that are not necessarily similar. For example, MacDonald et al. (1999) compared leg press exercise with aerobic leg cycle ergometry. On the other hand, O'Connor& Cooke (1998) compared 8 different weight lifting exercises performed both statically and dynamically. The work performed in their study was with larger muscle groups, but of low intensity (10% RM). The present study sought to compare two modes of handgrip exercise performed with a moderate intensity of effort. Although the intensity varied in this study, the total work performed was the same. Unlike the present study, the aforementioned studies of MacDonald et al. (1999) and O'Connor & Cooke (1998) did not include a control trial. The examination of post-exercise blood pressure should include a control trial to compare to exercise trials so that extraneous factors that could influence post-exercise blood pressure, such as a relaxation effect over time, can be identified and taken into account.

Acute Resistive and Static Exercise Studies						
Author	**Baseline SBP/DBP (mm Hg)**	**Mode / Intensity**	**Frequency**	**Duration**	**Results**	**Control trials**
Brown et al., 1994	108 / 68	1 set of resistance EX at 40% RM; 8-12 reps.	2 sessions	1 set to failure	SBP: -5 mmHg (10 min post) DBP: -23* mmHg (2 min post)	Yes
Brown et al., 1994	108 / 68	1 set of resistance EX at 70% RM; 8-12 reps.	2 sessions	1 set to failure	SBP: -5 mmHg (10 min post) DBP: -20* mmHg (2 min post)	Yes
MacDonald et al., 1999	130 / 87	Leg press: 65% RM	1 session	15 min	SBP: Significant drop from 10-60 min. post EX	No
MacDonald et al., 1999	130 / 87	LCE: 65% VO_2 max	1 session	15 min	SBP: Significant drop from 10-60 min. post EX	No
O'Connor & Cook, 1998	122 / 70	8 weight lifting exercises performed statically at 10% RM each	1 session	8 consecutive 3 min bouts for both modes, with 1 min rest interval	SBP: Significant drop from 3-20 min. post EX	No
O'Connor & Cook, 1998	122 / 70	8 weight lifting exercises performed dynamically at 10% RM each	1 session	8 consecutive 3 min bouts for both modes, with 1 min rest interval	SBP: Significant drop at 20 min. post EX	No
Present study	125 / 80	3 isometric handgrip sets, 30% MVC	1 session	3 min. per set	SBP: -4mmHg (30 min post) DBP: -1 mmHg (90 min post)	Yes
Present study	125 / 80	3 dynamic handgrip sets, 60% MVC	1 session	3 min. per set	SBP: -6 mmHg (30 min post) DBP: -2 mmHg (15 min post)	Yes

* = Significant change
EX = Exercise

LCE = Leg cycle ergometry

MVC = Maximal voluntary contraction

RM = One repetition maximum

Table 6–Comparison of acute resistive and static exercise studies.

In the present study, several subjects had dramatic reductions in post-exercise blood pressure after just one isometric and/or dynamic exercise sessions as compared to the control session. For example, subject 6 demonstrated a –15 mmHg decrease in systolic blood pressure in the exercising arm compared to the pre-exercise value after the dynamic resistance protocol. This decrease in blood pressure was determined by comparing the pre-exercise value to the averaged time period of 20-90 minutes post-exercise. By comparison, the same subject only experienced a –1 mmHg decrease in systolic pressure in the control session. Subject 14 demonstrated a –10 mmHg decrease in diastolic blood pressure in the exercising arm compared to the pre-exercise value in the isometric protocol. In the control session, this subject only demonstrated a –3 mm Hg decrease in diastolic blood pressure. However, as a group, the overall handgrip exercise effect was not statistically significant.

Prior post-exercise hypotension studies, such as Boone et al. (1993) and MacDonald et al. (1999) have focused on the effects of dynamic aerobic exercise in large muscle groups on blood pressure. Boone et al. (1993) observed an average decrease in systolic blood pressure of 10 mm Hg after 60 minutes of treadmill exercise at 60% VO_2max. Diastolic blood pressure did not decrease below resting levels during the post-exercise period, which was only monitored for 20 minutes after the cessation of exercise. In the MacDonald et al. (1999) study, subjects exercised at 70% VO_2max for 30 minutes and experienced a significant decrease in systolic blood pressure from 5 minutes through 60 minutes post-exercise, with the largest decrement (-14 mm Hg) occurring 15 minutes after the completion of exercise. Diastolic blood pressure was significantly lower than baseline levels 15 minutes after the completion of exercise, and remained lower until 45 minutes post-exercise. Pescatello et al. (1999) compared the post-exercise blood pressure in mildly hypertensive and normotensive women, who performed 30 minutes of cycle exercise at 60% VO_2max. The hypertensive women had a significant decrease in SBP (-9.5 mm Hg), DBP (-6.7 mm Hg) and MABP (-7.7 mm Hg) compared to baseline measures. Interestingly, there was no significant change in the arterial blood pressure of normotensive women.

Wiley et al. (1992) suggested that a potential mechanism for decreased blood pressure due to isometric handgrip training was that repeated exposure to the increased systolic and diastolic blood pressures caused by the pressor response to isometric exercise might serve as a stimulus for baroreceptor resetting. It was also suggested that sympathetic neural influences might also be altered by changes in muscle afferent information, which could in turn affect total peripheral resistance (TPR). This line of thought is compatible with the findings of Somers et al. (1992), who demonstrated that forearm endurance training results in an attenuation of the muscle sympathetic nerve activity during isometric exercise. Also, Wiley et al. (1992) proposed that endocrine and endocrine-like substances could be influenced by the pressor response or muscle stimuli so that TPR is affected. Taylor et al. (2003) proposed that the attenuation of resting blood pressure due to the isometric handgrip training of older hypertensives may have resulted in part from an increase in blood flow due to decreased peripheral resistance. The training was thought to result in decreased sympathetic and enhanced parasympathetic modulation of blood pressure.

Although no potential mechanisms of blood pressure regulation were directly examined in the present study, there were factors uncovered that deserve mention. It is noteworthy that 2 of the subjects in this study who did not experience any sort of post-exercise hypotension noted that they had a history of high levels of cholesterol. Neither of these subjects was on medication for cholesterol at the time of the study. Both claimed that they controlled their lipoprotein levels through dietary modifications. It is possible that increased levels of lipoproteins in the peripheral vascular system could have had an impact on TPR due to arteriosclerosis. Although there is no direct evidence correlating high lipoprotein levels with lessened ability to achieve a post-exercise hypotensive effect, this possibility should be explored in further research.

It was suggested by Thompson et al. (2001) that responses to acute exercise and adaptations due to exercise training might be intertwined, rather than separate effects. Seals et al. (1997) posited that the hypotensive effect typically credited to endurance training programs may in actuality be due to a more acute post-exercise phenomenon resulting from recent exercise. Although some trends for decreased post-exercise blood pressure were observed, the present study did not reveal an acute post-exercise hypotensive effect with handgrip exercise. The results of this study support the findings of Wiley et al. (1992), in which it was determined that training adaptations likely took place before a significant decrease in blood pressure was observed. It is reasonable to assume that some individuals might experience cumulative benefits from repeated handgrip exercise. However, based on the results from the present study, a decrease in blood pressure found after isometric handgrip training is likely more that just an acute response resulting from the last exercise session completed.

Future research into the post exercise hypotension phenomenon is needed to determine the optimal mode, duration, and frequency of handgrip exercise needed to achieve significant beneficial effects on arterial blood pressure. Since there does not appear to be a clear hypotensive effect after one bout of dynamic or isometric handgrip exercise, future training studies should be designed to compare these modes of exercise with a control trial or sham-training.

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APPENDIX A

Subject Questionnaire

All of the information below is necessary to 1) insure your safety as a participant in this study, 2) to determine if you meet the qualification guidelines of this study, and/or 3) for the reporting of the demographics of this study. Please answer all questions accurately. If you are unsure as to how to answer any question, please notify the investigator. All information on this form will be kept confidential.

Name ____

Age __________ Birth date _______________________

Emergency contact: Name ____

Phone #_________________

Please check the appropriate responses:

Questions 1 and 2 are for demographic purposes only. No answer will exclude you from participation in this study.

1. What is your gender?

   _____Female _____Male

2. What is your race?

   _____African American _____Caucasian _____Asian
   _____Hispanic _____Other (please list)_____________________

3. Do you use tobacco products?

   _____Yes _____No

4. If you answered "no" to Question #3, have you ever used tobacco products on a regular basis in the past?

   _____Yes _____No

5. If you answered "yes" to Question #4, how long ago did you quit?

   ____

6. Have you ever been told that you have high blood pressure?

   _____Yes _____No

7. Have you ever been told by a doctor that you should not exercise or that you should only exercise under medical supervision?

_____Yes _____No

8. Have you ever had problems with chest discomfort or dizziness?

_____Yes _____No

9. Have you ever had a stroke or heart attack?

_____Yes _____No

10. Are you diabetic?

_____Yes _____No

11. Are you, or do you suspect that you may be, pregnant?

_____Yes _____No

12. Do you have any bleeding disorders?

_____Yes _____No

13. How many days per week do you exercise vigorously enough to sweat?

14. In what type(s) of exercise do you participate?

15. What is the average amount of time you spend participating in each activity?

16. Have you exercised continuously for at least one hour at least once during the past month?

_____Yes _____No

17. Do your answers to Questions 12-15 represent your exercise habits for at least the past six months?

_____Yes _____No

18. Please list *all* prescribed and/or over-the-counter medications (including aspirin and ibuprofen) that you take on a regular basis.

Please go to next page.

I have answered all the above questions truthfully to the best of my ability.

Signature of participant_______________________________________

Date____________

APPENDIX B

Informed Consent Form

The University of North Carolina at Greensboro

Consent to Act as a Human Participant

Project Title:
The Effects of Isometric and Dynamic Resistance Exercise on Post-Exercise Blood Pressure

Principal Investigator: Trey Williams

Project Advisor: Paul Davis, Ph.D.

Participant's Name:

____

Date of Consent:

____

Description and Explanation of Procedures:
The purpose of this research project is to study the effect of isometric (*static* or *still*) and dynamic resistance handgrip exercise on post-exercise blood pressure in normotensive and prehypertensive individuals. The effects of the two modes of exercise intensity will be compared. As a participant, you will to participate in both of the following exercise trials, each on different days:

- *Isometric Handgrip Exercise*: At the beginning of the study, your resting blood pressure will be measured and you will perform two maximal voluntary contractions (MVC - squeezing the dynamometer as hard as you can) for five seconds on the handgrip dynamometer with a two-minute rest period in between. The protocol will consist of 3 sets of sustained isometric handgrip with the non-dominant arm for 3 minutes at 30% MVC with a randomly chosen hand. There will be 3 minutes rest between sets.

- *Dynamic Resistance Handgrip Exercise*: The dynamic resistance handgrip exercise protocol will consist of 3 sets of 45 rhythmic contractions at 60% MVC with the non-dominant arm for 3 minutes. Each contraction will be held for 2 seconds, followed by a 2 second rest.

- *Control Session*: A control protocol will consist of quietly reading a magazine.

During each testing session, the following will also occur:

- Resting blood pressure will be monitored.
- Blood pressure will be monitored periodically for two hours after the completion of exercise.

To participate in this study, you *must:*
- Have a resting systolic (top number) blood pressure between <120 and 139 mm Hg

  AND/OR
- Have a resting diastolic (bottom number) blood pressure between <80 and 89 mm Hg

  Also
- Accurately fill out a health history questionnaire and have a medical clearance form read and signed by your personal physician

You *may not* participate in this study if you*:*
- Have a resting systolic blood pressure of 140 mm Hg or greater
- Have a resting diastolic blood pressure of 90 mm Hg or greater
- Exercise on a regular basis
- Use tobacco products
- Use illegal drugs
- Drink more than 2 alcoholic beverages per day
- Take medications known to affect blood pressure
- Have diabetes
- Are, or think you might be, pregnant
- Have a disease affecting the heart, kidneys, or any other major organ
- Have a muscle or bone condition that would affect your ability to perform handgrip exercise

The three testing sessions (isometric, dynamic resistance, control) will last approximately 3 hours each. The sessions will occur on different days, with a minimum of 3 days of rest between each.

Risks and Discomforts:
A very slight chance of heart attack, and even death, exists during exercise. The chance of such an incident will be minimized by screening, requiring physician's consent to participate, and maintaining a proper emergency protocol to include, if needed, cardiopulmonary resuscitation (CPR) and notification of the Emergency Medical Service (EMS). You should tell the experimenter immediately if you experience any unusual sensations during or after exercise. Since you do not have known heart, lung, or metabolic disease, do not smoke, and do not have severely high blood pressure, the potential benefit of participation most likely outweighs the risk.

Potential Benefits:
The greatest potential for benefit in this study is to better understand whether or not isometric and dynamic resistance exercises can help lower post-exercise blood pressure. Should the exercises result in lowered blood pressure, this study will support the practice of a very practical type of exercise (low time commitment, no special clothes required, not as strenuous as aerobic exercise) to lower cardiovascular risk. Having blood pressure reduced in this way may prevent or delay a person from having to eventually take blood pressure medication. It must be realized, however, that other types of exercise are more likely to cause other health benefits, such as weight loss.

Consent:
By signing this consent form, you agree that you understand the procedures and any risks and benefits involved in this research. You are free to refuse to participate or to withdraw your consent to participate in this research at any time without penalty or prejudice; your participation is entirely voluntary. Your privacy will be protected because you will not be identified by name as a participant in this project. Only members of the research team will have access to your records unless you give written permission for your information to someone else. Date from this experiment will be kept in a locked filing cabinet for at least five years after the study's completion and will then be exposed of by a paper shredder. In the event anyone involved in the study is exposed to your blood, your blood may need to be tested for evidence of hepatitis, HIV, or other infections.

The research and this consent form have been approved by the University of North Carolina at Greensboro Institutional Review Board, which insures that research involving people follows federal regulations. Questions regarding your rights as a participant in this project can be answered by calling Dr. Beverly Maddox-Britt at (336) 334-5878. Questions regarding the research itself will be answered by calling Trey Williams at (336) 227-7884 or by calling Dr. Paul Davis at (336) 334-3030. Any new information that develops during the project will be provided to you if the information might affect your willingness to continue participation in the project.

By signing this form, you are agreeing to participate in the project described to you by

____________________________________ (investigator).

____
Participant's Signature*

____
Witness to Signature

*****If participant is a minor or for some other reason unable to sign, complete the following:

Participant is _______ years old or unable to sign because:

____

_______________________________________.

____
Parent/Guardian Signature

APPENDIX C

Medical Consent Form

Medical Release Form

To the attending physician of ____:

Your patient has expressed interest in participating in our study entitled, "The Effects of Isometric and Dynamic Resistance Exercise on Post-Exercise Blood Pressure". In keeping with the guidelines of the American College of Sports Medicine, since most of our study participants will possess at least two cardiovascular disease risk factors, we are asking that all subjects obtain their physician's approval before participation. Please read the study description below and complete the release form if, in your medical judgment, this individual shows no contraindication to study participation.

Inclusion Criteria:

- Resting systolic blood pressure of <120 and 139 mm Hg
  and/or
- Resting diastolic blood pressure of <80 and 89 mm Hg

Exclusion Criteria:

- Resting systolic blood pressure ≥140 mm Hg or resting diastolic blood pressure ≥90 mm Hg
- Regular exercise
- Use of tobacco products
- Use of illegal drugs
- Consumption of >2 alcoholic beverages per day
- Medication known to affect blood pressure
- Known or suspected pregnancy
- Known or suspected diabetes, cardiovascular disease, or target organ disease
- Any musculoskeletal condition that would affect the ability to perform prolonged isometric handgrip exercise

Study Protocol

Following screening, participants will randomly be assigned on different occasions to each of following three trials:

- *Isometric Handgrip Exercise*: At the beginning of the study, the resting blood pressure will be measured and the subject will perform two maximal voluntary contractions (MVC - squeezing the dynamometer as hard as possible) for five seconds on the handgrip dynamometer with a two-minute rest period in between. The protocol will consist of 3 sets of sustained isometric handgrip with the non-dominant arm for 3 minutes at 30% MVC. There will be 3 minutes rest between sets.

- *Dynamic Resistance Handgrip Exercise*: The dynamic resistance handgrip exercise protocol will consist of 3 sets of 45 rhythmic contractions at 60% MVC with the non-dominant arm for 3 minutes. Each contraction will be held for 2 seconds, followed by a 2 second rest.

- *Control Group*: A control protocol will consist of quietly reading a magazine.

Study Protocol - Testing
During each testing session, the following will also occur:

- Resting blood pressure will be monitored.
- Blood pressure will be monitored periodically for two hours after the completion of exercise.

Results from this investigation may potentially provide support for efficacy of a simple form of treatment for individuals at risk for hypertension, who have typically been assigned behavior modification recommended as first-line therapy. If you have any questions concerning the study's protocol, please feel free to contact the principal investigator:

Trey Williams
Master's Degree Candidate - The University of North Carolina at Greensboro
(336) 586-4384 (W)
(336) 227-7884 (H)
(336) 254-6834 (M)

Thank you for taking the time to consider your patient's participation in this study.

Please go to next page.

Release

I believe my patient to be capable of safely participating in the investigation, "Effect of isometric handgrip training on blood pressure of borderline and mildly hypertensive subjects", as described above.

Signature_______________________________

Print Name_________________________________

Date___________

Address____

____

APPENDIX D

Data Collection Form

Subject number: ______

Was food or caffeine ingested within 3 hrs of BP screening? Yes ____ No ____

Screening BP 1 (automated): SBP _____ DBP _____
Screening BP 1 (manual): SBP _____ DBP _____

Height _____ Weight _____

MVC of nondominant arm: _____

Blood pressure assessment

	Pre	Set 1	Set 2	Set 3	2.5	5	10	15	20	30	40	50	60	75	90
Iso SBP (L)															
Iso SBP (R)															
Iso DBP (L)															
Iso DBP (R)															
Dyn SBP (L)															
Dyn SBP (R)															
Dyn DBP (L)															
Dyn DBP (R)															
Ctl SBP (L)															
Ctl SBP (R)															
Ctl DBP (L)															
Ctl DBP (R)															

Iso = Isometric protocol
Dyn = Dynamic resistance protocol
Ctl = Control protocol