Using the Immediate Blood Pressure Benefits of Exercise to Improve Exercise Adherence: A Pilot Study

Amanda Zaleski
University of Connecticut - Storrs, amanda.zaleski@uconn.edu

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A single exercise session evokes blood pressure (BP) reductions that are immediate and persist for ≥24hr, termed postexercise hypotension (PEH). Self-monitoring of PEH may foster positive outcome expectations of exercise, and thus, enhance exercise adherence among adults with hypertension. **PURPOSE:** To compare the efficacy of self-monitoring of exercise (EXERCISE) versus exercise plus PEH (EXERCISE+PEH) to improve exercise adherence and BP control among adults with hypertension. **METHODS:** Adults with high BP were randomized to EXERCISE (n=12) or EXERCISE+PEH (n=12). Subjects underwent supervised, moderate intensity aerobic exercise training for 40-50min/session, 3d/wk for 12wk and were encouraged to exercise unsupervised at home ≥30min/d, 1-2d/wk. All subjects self-monitored exercise using a calendar recording method. EXERCISE+PEH also self-monitored BP before and after exercise. Adherence was calculated as [(# of exercise sessions performed ÷ # of possible exercise sessions) X 100%]. BP was measured pre- and post-training. **RESULTS:** Healthy, middle-aged (52.3±10.8y) men (n=11) and women (n=13) with hypertension (136.2±10.7/85.2±8.9mmHg) completed exercise training with 87.9±12.1% adherence. EXERCISE+PEH demonstrated greater adherence to supervised training (94.3±6.6%) than EXERCISE (81.6±13.2%; p=0.007). In addition, EXERCISE+PEH performed 32.6±22.5min/wk more unsupervised home exercise than EXERCISE (p=0.004), resulting in greater overall study exercise adherence (107.3±18.7%) than EXERCISE (82.7±12.2%; p=0.002). Post- versus pre-training, BP was reduced -7.4±11.3/-4.9±9.9mmHg (ps<0.025) with no statistical difference between EXERCISE (-5.2±13.3/-3.6±6.1mmHg) and EXERCISE+PEH (-9.9±11.3/-6.1±6.9mmHg; ps>0.344). **CONCLUSIONS:** This study is the first to demonstrate that PEH self-
monitoring is an efficacious tool to improve exercise adherence among adults with hypertension. Future research among a larger, more diverse sample is needed to confirm these novel findings and determine whether EXERCISE+PEH translates to better BP control relative to EXERCISE self-monitoring alone.

Keywords: postexercise hypotension, self-efficacy, antihypertensive lifestyle therapy, positive outcome expectations, self-management
Using the Immediate Blood Pressure Benefits of Exercise to Improve Exercise Adherence:  
A Pilot Study

Amanda L. Zaleski

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M.S. University of Connecticut, 2008

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Using the Immediate Blood Pressure Benefits of Exercise to Improve Exercise Adherence: A Pilot Study

Presented by

Amanda L. Zaleski, MS

Major Advisor

Linda S. Pescatello, PhD, FACSM
University of Connecticut, Department of Kinesiology

Co-Major Advisor

Beth A. Taylor, PhD, FACSM
University of Connecticut, Department of Kinesiology

Associate Advisor

Crystal Park, PhD
University of Connecticut, Department of Psychology

University of Connecticut
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hand. The results of this study have undoubtedly advanced our understanding of exercise adherence among individuals with hypertension; a feat that would have never been possible without each and every one of you.

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*Proclamation Educational Decree No. 29: Extracurricular activities are subject to review by the High Inquisitor.
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1.1 Introduction

1.2.1 Hypertension is a Major Public Health Problem

Hypertension is the most common, costly, and modifiable cardiovascular disease (CVD) risk factor in the United States (U.S.) and worldwide, affecting ≈103 million Americans (45.6%) and 1.39 billion adults (31%) worldwide. Since 2000, hypertension-related deaths have increased from 245,220 to 396,675 (62%) in the U.S., contributing to 10.4 million deaths worldwide over the past two decades. The estimated direct and indirect cost of hypertension are $46.4 billion, and this figure is projected to increase to $274 billion by the year 2030.

In addition, another ≈35% of Americans have elevated BP. Among adults with prehypertension, the progression to hypertension is rapid with about one of four adults with prehypertension developing hypertension within 5 years. The prevalence of hypertension increases substantially with age, with 77% of adults ≥50 yr and about 79% of adults ≥75 yr having hypertension. Indeed, among adults ≥50 yr of age, the lifetime risk of developing hypertension approaches 90%. Given baby boomers represent the fastest-growing age demographic of the U.S. population, reducing the proportion of individuals diagnosed with hypertension continues to be a major priority for all leading public health organizations. For these reasons, Healthy People 2020 has established hypertension as a high-priority, leading health indicator with national objectives to: a) increase the proportion of adults with hypertension whose blood pressure (BP) is under control by 18%; and b) reduce the proportion of adults diagnosed with hypertension by 10% by the year 2020.

1.2.2 Physical Inactivity is a Major Public Health Problem

The myriad of health benefits derived from regular physical activity are well established, yet only ~21% of Americans meet the national objectives for aerobic and muscle strengthening activities set forth by the Surgeon General. Worldwide, the prevalence of physical inactivity (35%) exceeds the prevalence of smoking (26%). Indeed, it is estimated
that physical inactivity has contributed to 5.3 million deaths thus far. This is unfortunate because participation in regular exercise is a key modifiable determinant of hypertension and is recognized as a cornerstone therapy for the primary prevention, treatment, and control of high BP.

Recent meta-analyses of randomized-controlled, intervention trials conclude that regular, aerobic exercise lowers resting systolic BP 5-7 mmHg, while resistance exercise lowers resting systolic BP 2-3 mmHg among individuals with hypertension. For these reasons regular, aerobic exercise is universally endorsed for the primary prevention and treatment of hypertension. Indeed, exercising as little as one day per week is as effective (or even more so) than pharmacotherapy for reducing all-cause mortality among those with hypertension. Despite the known antihypertensive benefits of aerobic exercise training, many people with hypertension do not adopt or maintain an exercise training program to lower their high BP. The underutilization of exercise for antihypertensive therapy underscores the need for novel lifestyle intervention strategies founded in health behavior theory to address motivation and adherence issues surrounding exercise, particularly for the prevention, treatment, and control of hypertension.

1.3.1 Self-Monitoring of Hypertension

Hypertension (defined as systolic BP ≥130 and/or diastolic BP≥80 mmHg or greater, taking antihypertensive medication, being told by a physician or health professional on at least two occasions that one has high BP, or any combination of these criteria) is a particularly unique condition in that there are no signs or symptoms associated with high BP levels. However, BP is a relatively easy and reliable vital sign to self-measure and interpret with the proper tools and education. Self-monitoring of BP is associated with greater BP control and lower cardiovascular and all-cause mortality rates compared to usual care. Major health organizations, such as the American Heart Association (AHA), European Hypertension Society, and British
Hypertension Society, recommend that individuals with hypertension utilize a home BP monitor to measure BP at least twice a day (once in the morning and once at night)\textsuperscript{1,11}. The most recent AHA Cardiovascular Health Consumer Survey reported ~54% of individuals with hypertension self-monitor their BP and the prevalence is higher for those greater than 65 years (~63%)\textsuperscript{30}. 

One behavioral strategy by which self-monitoring of BP among individuals with hypertension can improve BP control is by promoting \textit{self-management} of elevated BP. Self-monitoring of BP provides an immediate, objective measure of hypertension as a condition and as a biometric outcome, allowing the active participant to modify treatment regimens (i.e., antihypertensive medication) and interpret the magnitude of their modifications on BP\textsuperscript{31}. For example, McManus et al randomized 480 patients with uncontrolled BP to either self-monitoring of BP with self-titration of antihypertensive drugs or standard care and reported patients that engaged in self-monitoring experienced significant reductions in BP (-17.6mmHg) after 12 months compared to patients receiving usual care (-12.2mmHg; p<0.01)\textsuperscript{32}. Interestingly, to the best of our knowledge, this multifaceted approach has yet to be explored in combination with lifestyle interventions such as exercise. This is surprising given that lifestyle modifications are considered the first line of defense for the prevention, treatment, and control of high BP\textsuperscript{11}. There is preliminary support for the use of self-monitoring for hypertension

\section*{1.3.2 Using Post Exercise Hypotension as a Condition-Specific Self-Monitoring Strategy}

It is well established that aerobic exercise acutely reduces BP among adults with hypertension after a single, isolated exercise session that is immediate and persists for up to 24 hr after the exercise bout\textsuperscript{19,33-36}. This response is termed \textit{postexercise hypotension} (PEH)\textsuperscript{19}. Most recently, there have been several studies to support the notion that the reductions in BP experienced immediately following acute exercise are similar in magnitude to those experienced after chronic aerobic exercise training; an observation that suggests the BP benefits attributed to exercise training are largely the result of PEH\textsuperscript{37-41}. Indeed, BP reductions following aerobic
exercise translate to lower resting BP in as early as three sessions. These reductions in resting BP persist for a short amount of time before detraining occurs\textsuperscript{42,43}. Again, lending evidence to the notion that the BP reductions seen following aerobic exercise training (i.e., chronic) are largely the result of isolated, acute aerobic sessions. PEH is beginning to be recognized as a “window of opportunity” or screening tool to predict who is likely respond to aerobic exercise training and if so, of what magnitude\textsuperscript{44}.

PEH is an observable phenomenon that could also potentially serve as a condition-specific strategy to improve exercise adherence among adults in the early stages of hypertension. Condition-specific self-monitoring of BP before and after an isolated exercise session (i.e., PEH) provides immediate biometric feedback to an individual and provides reinforcement to the patient that BP is lower immediately following exercise (and for some time after) and allows the patient to link their exercise behavior with positive health outcomes\textsuperscript{31,45}. Self-monitoring of BP and physical activity in the management of hypertension could potentially be a promising tool to promote self-awareness, positive health behaviors, and shared-decision making, which are prerequisites to long-term exercise maintenance\textsuperscript{46}. Most notably, self-monitoring can serve as a major source of self-efficacy, which is central to many successful interventions founded on health behavior theory (Figure 1).

Figure 1. Proposed Theoretical Model of Postexercise Hypotension (PEH) as a Condition-Specific Biometric Tool to Moderate Exercise Adherence and Blood Pressure Outcomes
1.4.1 Specific Aims and Hypotheses

Surprisingly, no study has been done that leverages the use of PEH as a self-monitoring strategy to reinforce exercise adherence and BP outcomes among individuals with hypertension. Thus, the present study seeks to examine the clinical utility of PEH as a self-monitoring tool to increase overall exercise levels and lower BP among adults with hypertension. The Primary Aims of the present study are to:

**Primary Aim 1:** Examine the efficacy of two different types of self-monitoring, traditional exercise (EXERCISE) and traditional exercise with BP self-monitoring (EXERCISE+PEH) to increase exercise adherence and improve BP control among adults with hypertension.

**Hypothesis 1:** EXERCISE+PEH self-monitoring will increase exercise adherence and improve BP control more than EXERCISE self-monitoring alone.

**Primary Aim 2:** To assess the feasibility (i.e., interest, acceptability, retention, and satisfaction) of traditional exercise (EXERCISE) and traditional exercise plus BP self-monitoring...
(EXERCISE+PEH) to increase exercise adherence and improve BP control among adults with hypertension.

**Hypothesis 2:** Participants will find both types of self-monitoring interesting and acceptable. However, retention in and satisfaction with will be greater with EXERCISE+PEH than EXERCISE as evidenced by increased exercise adherence and improved BP control with EXERCISE+PEH than EXERCISE.

1.5.1 References


2.1 Review of the Literature

2.1.1 Clinical Exercise Physiology: Hypertension Book Chapter


2.1.2 Hypertension

Hypertension affects ≈103 million Americans (45.6%)\textsuperscript{1,2} and 1.39 billion adults (31%) worldwide\textsuperscript{3}. In addition, another ≈12% of Americans have elevated BP\textsuperscript{3}. The relationship between BP and cardiovascular disease (CVD) risk is linear, continuous, and consistent starting at 115/75 mmHg. Lifestyle therapies are an integral part of management of hypertension, with regular, aerobic exercise recognized as a “polypill” that mutually supports other lifestyle modifications and positively improves many aspects of overall health. Regular aerobic exercise can reduce BP by 5-7 mmHg among individuals with hypertension; BP reductions that rival the magnitude of those obtained with first line antihypertensive medications and lower CVD risk by 20-30%\textsuperscript{4-6}. Exercising as little as one day per week is as effective (or even more so) than pharmacotherapy for reducing all-cause mortality among those with hypertension\textsuperscript{7}. Furthermore, a recent meta-analysis of major exercise and drug trials showed no statistically detectable difference between exercise and drug interventions for coronary heart disease and diabetes and physical activity interventions were more effective than drug interventions for the secondary prevention of stroke mortality\textsuperscript{8}. For these reasons, the American College of Sports Medicine (ACSM) recommends that individuals with hypertension engage in moderate intensity, aerobic exercise 5-7d/wk, supplemented by resistance exercise 2-3 d/wk and flexibility exercise ≥2-3 d/wk\textsuperscript{9}. 
2.1.3 Mechanisms for the BP Lowering Effects of Exercise

An isolated bout of aerobic exercise results in immediate reductions in systolic BP of 5-7 mmHg that persist for up to 24 hr or PEH\textsuperscript{10}. Physiological responses to acute or short-term exercise translate into functional adaptations that occur during and for some time following an isolated exercise session; a phenomenon termed the last bout effect\textsuperscript{11}. It has been previously hypothesized that frequent repetition of acute aerobic exercise sessions produces permanent functional and structural adaptations, forming the exercise training response\textsuperscript{11}. These persistent alterations in structure and function remain for as long as the training regimen is continued and then dissipate quickly, returning to pre-training values\textsuperscript{12,13}. Most recently, there have been several studies to support the notion that the reductions in BP experienced immediately following acute exercise are similar to and highly correlated to those experienced after chronic aerobic exercise training; an observation that suggests the BP benefits attributed to exercise training are largely the result of PEH\textsuperscript{14-18}.

Liu et al. were the first to perform a study designed to determine whether PEH could be used to predict the BP response to exercise training among middle-aged men (n=8) and women (n=9) with prehypertension\textsuperscript{14}. Participants completed a 30 min acute aerobic exercise session at moderate intensity (65\% VO\textsubscript{2}max) prior to beginning a supervised, 8 wk aerobic exercise training program, performed 4 d/wk for 30 min per session at 65\% VO\textsubscript{2}max. Following exercise training, BP (SBP/DBP) was reduced to similar magnitudes after acute (7/4 mmHg) and chronic (7/5.2 mmHg) exercise, and the BP response to acute exercise was strongly correlated with the BP response to exercise training (SBP, r=0.89; DBP, r=0.75)\textsuperscript{14}. This finding was subsequently confirmed Hecksteden et al. in a small sample of overweight to obese middle-aged men and women with prehypertension\textsuperscript{15}. Together, these findings support the long held notion that PEH may account for a significant portion of the magnitude of the BP reduction attributed to exercise training\textsuperscript{14-18}.
2.1.4 Utilizing PEH as a Condition-Specific Strategy to Improve Health Behavior

PEH is now considered an expected physiological response to exercise\textsuperscript{19}. For this reason, individuals with hypertension are encouraged to exercise on most days of the week in order to benefit from the acute effects of aerobic exercise on BP\textsuperscript{20}. Although there is heterogeneity in the magnitude of PEH, reductions in BP immediately following exercise appear to be most pronounced in individuals who stand to benefit the most (i.e., those with higher BP compared to normal BP)\textsuperscript{21,22}. Despite the known antihypertensive benefits of regular aerobic exercise, this knowledge alone does may not always evoke health-related behavior change\textsuperscript{23}. Numerous individual and structural level factors influence the likelihood that an individual will adopt and adhere to an exercise prescription or program\textsuperscript{9,23}. Individualized exercise interventions are often more successful than broad, population based programs\textsuperscript{24,25}. However, such interventions are often costly and time intensive, highlighting the need for personalized interventions that can be easily delivered by clinicians. While there are several condition-specific barriers of hypertension that could be deleterious to positive behavior change (i.e., asymptomatic, low cue to action), hypertension also presents with many condition-specific facilitators that can be exploited to improve health behaviors\textsuperscript{26,27}. One such condition-specific facilitator is PEH; a naturally occurring phenomenon that occurs in ~80% of patients with hypertension\textsuperscript{20} and represents a potentially underutilized, but promising tool to evoke and reinforce behavior change in individuals with high BP.

2.1.5 Self-Monitoring of BP as a Strategy to Improve Self-Efficacy for Exercise

Technological advances have allowed BP measuring devices to become almost universally accessible for personal use and as such are available as a free or low-cost, convenient, portable, and user-friendly means to monitor BP\textsuperscript{28}. Measurement of BP takes less than one minute to obtain, and represents an immediate, non-invasive, objective measure of hypertension as a condition and as a biometric outcome\textsuperscript{29}. Furthermore, BP assessment is
relatively easy to record and interpret, thus making it easy for one to temporally measure other internal and/or external conditions, such as exercise\(^\text{30}\). As such, self-monitoring of hypertension is a viable, personalized approach to improve health-related behaviors, with minimal clinician oversight and cost required of both the patient and the clinician, alike\(^\text{28-30}\). PEH is an established physiological response to exercise. Therefore, regular self-monitoring of BP before and after exercise allows individuals with hypertension to self-measure and immediately interpret the magnitude of their individual exercise behaviors on their BP.

Preliminary support for the use of self-monitoring to improve self-efficacy for exercise can be found in other disease conditions such as type II diabetes mellitus\(^\text{31,32}\). Allen et al. examined the feasibility of glucose self-monitoring to improve physical activity levels, hemoglobin A1c, and other CVD risk factors among 52 sedentary, men and women with obesity and type 2 diabetes mellitus over 8 wk. Allen et al. reported subjects performing glucose self-monitoring engaged in 5 min more per day in moderate intensity, physical activity and 5 min less per day in sedentary behavior compared to the control group receiving education only. The glucose self-monitoring group also improved hemoglobin A1c, body mass index (BMI), and systolic BP whereas the control group did not. Health behavior models suggest increased patient involvement in disease management results in increased self-efficacy\(^\text{33}\), or situation-specific self-confidence, that improves adherence to treatment and results in beneficial changes in a variety of health behaviors such as diet\(^\text{34,35}\) and exercise\(^\text{36,37}\). Similar to the promising findings of Allen et al.\(^\text{31,32}\), PEH self-monitoring could be a viable, condition-specific strategy to improve self-efficacy for exercise and BP control among individuals with elevated BP or established hypertension\(^\text{29,30}\).

2.2.1 References


3.1 Manuscript

Chapter 3 presents the main findings of the present study in manuscript format to be submitted for publication to the *Journal of Hypertension*. Additional methodology not provided within the main manuscript is presented in Chapter 4 and a broader discussion of the results is presented in Chapter 5.
Using the Immediate Blood Pressure Benefits of Exercise to Improve Exercise Adherence Among Adults with Hypertension

Amanda L. Zaleski, MS¹,², Beth A. Taylor, PhD, FACSM¹,², Crystal A. Park, PhD³, Lucas Porto Santos, MS⁴, Gregory Panza, MA¹,², Melody Kramarz, BS¹, Kyle McCormick, BS¹, Paul D. Thompson, MD, FACSM, FACC, FAHA², Antonio B. Fernandez, MD², Ming-Hui Chen, PhD⁵, Bryan Blissmer, PhD⁶, Kim M. Deluca, PhD, MPH⁷, Linda S. Pescatello, PhD, FACSM, FAHA¹

¹Department of Kinesiology, University of Connecticut, Storrs, CT, USA, ²Department of Preventive Cardiology, Hartford Hospital, Hartford, CT, USA, ³Department of Psychology, University of Connecticut, Storrs, CT, USA, ⁴Exercise Pathophysiology Laboratory, Hospital de Clínicas de Porto Alegre, Porto Alegre, RS, Brazil and Graduate Program in Cardiology and Cardiovascular Sciences, Faculty of Medical Sciences, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil, ⁵Department of Statistics, University of Connecticut, Storrs, CT, USA, ⁶College of Health Sciences, University of Rhode Island, Kingston, RI, USA ⁷Department of Human Development and Family Studies, University of Connecticut, Storrs, CT, USA

Corresponding author:
Amanda Zaleski, MS, Department of Kinesiology, University of Connecticut, Gampel Pavilion, Storrs, CT 06269, USA

Email: amanda.zaleski@hhchealth.org, Tel: 1 860 972 3454, Fax: 1 860 545 2882

Running Title: Postexercise Hypotension and Exercise Adherence
Abstract

A single exercise session evokes blood pressure (BP) reductions that are immediate and persist for ≥24 hr, termed postexercise hypotension (PEH). Self-monitoring of PEH may foster positive outcome expectations of exercise, and thus, enhance exercise adherence among adults with hypertension. **PURPOSE:** To compare the efficacy of self-monitoring of exercise (EXERCISE) versus exercise plus PEH (EXERCISE+PEH) to improve exercise adherence and BP control among adults with hypertension. **METHODS:** Adults with high BP were randomized to EXERCISE (n=12) or EXERCISE+PEH (n=12). Subjects underwent supervised, moderate intensity aerobic exercise training for 40-50 min/session, 3 d/wk for 12 wk and were encouraged to exercise unsupervised at home ≥30 min/d, 1-2 d/wk. All subjects self-monitored exercise using a calendar recording method. EXERCISE+PEH also self-monitored BP before and after exercise. Adherence was calculated as [(# of exercise sessions performed ÷ # of possible exercise sessions) X 100%]. BP was measured pre- and post-training. **RESULTS:** Healthy, middle-aged (52.3±10.8 y) men (n=11) and women (n=13) with hypertension (136.2±10.7/85.2±8.9 mmHg) completed exercise training with 87.9±12.1% adherence. EXERCISE+PEH demonstrated greater adherence to supervised training (94.3±6.6%) than EXERCISE (81.6±13.2%; p=0.007). In addition, EXERCISE+PEH performed 32.6±22.5 min/wk more unsupervised home exercise than EXERCISE (p=0.004), resulting in greater overall study exercise adherence (107.3±18.7%) than EXERCISE (82.7±12.2%; p=0.002). Post- versus pre-training, BP was reduced -7.4±11.3/-4.9±9.9 mmHg (ps<0.025) with no statistical difference between EXERCISE (-5.2±13.3/-3.6±6.1 mmHg) and EXERCISE+PEH (-9.9±11.3/-6.1±6.9 mmHg; ps>0.344). **CONCLUSIONS:** This study is the first to demonstrate that PEH self-monitoring is an efficacious tool to improve exercise adherence among adults with hypertension. Future research among a larger, more diverse sample is needed to confirm these novel findings and determine whether EXERCISE+PEH translates to better BP control relative to EXERCISE self-monitoring alone.
Keywords: antihypertensive lifestyle therapy, positive outcome expectations, postexercise hypotension, self-efficacy, self-management
Introduction

Hypertension is the most common, costly, and modifiable cardiovascular disease (CVD) risk factor, affecting ≈103 million Americans (45.6%)\textsuperscript{1-3} and 1.39 billion adults (31%) worldwide\textsuperscript{4}. Participation in regular exercise is a key modifiable behavioral determinant of hypertension, and thus, is recommended by all professional organizations as cornerstone lifestyle therapy for the primary prevention, treatment, and control of hypertension\textsuperscript{1,5,6}. Aerobic exercise also acutely reduces blood pressure (BP) among adults with hypertension after a single, isolated exercise session. These BP reductions are immediate, persist for ≥24 hr after the exercise bout, and are termed \textit{postexercise hypotension} (PEH)\textsuperscript{7-11}. Yet only ~40% of U.S. adults with hypertension achieve the recommended amount of ≥150 minutes of leisure-time aerobic exercise per week\textsuperscript{12}. The poor adherence to exercise as antihypertensive therapy underscores the need for novel behavioral strategies that increase the motivation to exercise, and possibly exercise adherence, among adults with hypertension.

Hypertension is a unique health condition in that there are no signs or symptoms associated with high BP levels\textsuperscript{13}. However, the advent of home BP monitoring has enabled BP to be a relatively easy and reliable vital sign to self-assess and track with the proper tools and education\textsuperscript{14,15}. As such, major health organizations including the American College of Cardiology (ACC), American Heart Association (AHA), European Society of Hypertension, British Hypertension Society, and Hypertension Canada recommend that adults with hypertension utilize a home BP monitor to measure BP at least twice daily\textsuperscript{1,16-18}. Self-monitoring of BP is associated with greater BP control and lower CVD and all-cause mortality rates compared to usual care\textsuperscript{19-22}. Furthermore, self-monitoring of BP can be the “cornerstone of decision making”\textsuperscript{23} as awareness of suboptimal BP values can act as a cue to action to inform needed changes in pharmacological and lifestyle treatment regimens through shared-decision making between the patient and healthcare provider\textsuperscript{24-28}.
Health behavior models suggest increased patient involvement in disease management results in increased self-efficacy, or situation-specific self-confidence, that improves adherence to pharmacological and lifestyle treatments and results in beneficial changes in a variety of health behaviors such as medication, diet, and exercise habits. Surprisingly, no study has been reported that leverages PEH as a condition-specific self-monitoring behavioral strategy to improve exercise adherence and BP control among adults with hypertension. PEH is an observable, well-documented physiological response to exercise. Therefore, health condition-specific self-monitoring of BP before and after an exercise session has the potential to provide immediate feedback that BP is lower following exercise (and for some time after), allowing a person to link their exercise behavior with the positive health outcome of lower BP as a result of exercise. Observing immediate exercise-induced reductions in BP or PEH may increase an individual’s positive outcome expectancies and self-efficacy for exercise, thereby serving as a behavioral strategy to increase exercise motivation, and possibly exercise adherence, among adults with hypertension.

The present study sought to examine the efficacy of two different types of self-monitoring: exercise only (EXERCISE) and exercise plus BP self-monitoring (EXERCISE+PEH) among adults with hypertension. We hypothesized that adults using BP and exercise self-monitoring (EXERCISE+PEH) would increase exercise adherence and improve BP control more than exercise self-monitoring alone (EXERCISE). As a secondary aim, we sought to assess the acceptability, helpfulness, relevance, and satisfaction of EXERCISE and EXERCISE+PEH self-monitoring.

Methods

Study Overview

A detailed schedule of the procedures is provided in Figure 1. Sedentary (n=24), adults ≥18 yr with elevated- to established hypertension were enrolled into ‘Blood Pressure Utilizing Self-Monitoring after Exercise study or PULSE’. Participants were randomly assigned to either
an exercise only (EXERCISE; n=12) or exercise plus BP self-monitoring (EXERCISE+PEH) (n=12) group. All participants participated in a 12 wk supervised moderate intensity aerobic exercise training program 40 min/d for 3 d/wk. In addition, they were encouraged to exercise at home ≥30 min/d for 1-2 d/wk. All participants self-monitored exercise with a traditional calendar recording method and heart rate (HR) monitor. In addition to traditional exercise self-monitoring (EXERCISE), individuals in the EXERCISE+PEH group were given a home BP monitor to assess home BP twice daily (in the morning upon awakening and in the evening) and prior to and after voluntary home exercise sessions. Resting BP, peak oxygen consumption (VO₂peak), physical activity, dietary and salt intake, and antihypertensive medication adherence were measured before and after the 12 wk supervised exercise training program. In addition, integrated social-cognitive predictors of exercise that included questionnaires on exercise self-efficacy, barriers self-efficacy, outcome expectations for exercise, exercise intention, and affective responses to exercise were measured before and after the 12 wk supervised exercise training program. Four weeks following the completion of exercise training, self-reported exercise levels were assessed during a telephone interview in both groups. Among EXERCISE+PEH only, self-monitoring of BP was also self-reported during this telephone interview. All participants provided written informed consent from the Institutional Review Boards of the University of Connecticut and Hartford Hospital.

Study Population

Adults (n=24) ≥18 yr with elevated BP to established hypertension defined by the updated ACC/AHA criteria as SBP ≥130 mmHg or DBP ≥80 mmHg or taking antihypertensive medication regardless of BP, with a SBP <160 mmHg and DBP <100 mmHg were enrolled. Ambulatory BP was used to determine further study inclusion if BP values met the definition of being a ‘PEH responder’ such that average 24hr ambulatory SBP or DBP was ≥2 mmHg lower after Visit 2 (i.e., GEST) than after Visit 1 (i.e., Control) according to the previous criteria established by our
Participants were free of diagnosed cardiovascular, pulmonary, renal, metabolic, or other chronic diseases or depression; were non-smokers for at least 6 mo prior to entry; consumed <2 alcoholic drinks daily; and were physically inactive defined as engaging in formal exercise ≤ 2d/wk.

Other than antihypertensive medications, participants taking medications that influenced BP such as inhaled or oral steroids, nonsteroidal anti-inflammatory agents, aspirin, and nutritional supplements with the exception of a 1-a-day vitamin, cold medications, and herbal supplements were asked to discontinue these medications for the duration of the study. Prescription medications were discontinued only after receiving the prescribing physician’s approval. Study participants using antihypertensive medications were included if they reported taking the same medication for at least 3 mo. Participants with osteoarthritis and orthopedic problems were not enrolled if these conditions compromised their ability to exercise. Participants with a past medical history of cancer-related lymphedema were not enrolled due to the increased risk of infection and/or pain experienced with repeated BP assessment. Participants were also not enrolled if that they were seeking to gain or lose weight due to the confounding influence of weight loss and dietary intake on BP\textsuperscript{13,36,37}. Women confirmed that they were not pregnant, lactating, or planning to become pregnant. Women using hormone-altering contraception that was administered in a bolus (e.g., Depo-Provera) with a “tapering” dose effect (i.e., peak hormone concentrations followed by slow elimination) were excluded due to the potential influence of variable circulating estrogen levels on BP\textsuperscript{38}.

Study Procedures

Visit 1: Orientation Session (Control)

Height and weight were measured using a calibrated balance beam scale to calculate body mass index (BMI). Waist circumference was measured at the height of the iliac crest using a non-distensible Gulick tape measure\textsuperscript{39}. After a minimum of 15 min of seated rest, resting BP
was measured in the laboratory according to AHA standards using a BPTRU monitor (BPTRU Medical Devices; Coquitlam, Canada) three times, 5 min apart in each arm\textsuperscript{40}. If resting SBP was 120-<160 and/or DBP was 80-<100 mmHg for unmedicated individuals or SBP was <160 mmHg and DBP was <100 mmHg for medicated individuals, an ambulatory BP monitor (Oscar2 automatic noninvasive ambulatory BP monitor, Suntech Medical Instruments Inc., Raleigh, NC) was attached to the participant on their nondominant arm by a trained investigator\textsuperscript{7,9,10,41}. Prior to attaching the ambulatory BP monitor, a calibration check was done with a mercury sphygmomanometer using a t-tubule ensuring that three monitor readings agreed within 5 mmHg of the sphygmomanometer readings. The ambulatory BP monitor was programmed to record BP at regular intervals three times per waking hour and two times per sleeping hour. Participants were instructed to leave the laboratory and proceed with normal activities, not to exercise, and to keep their arm still and extended at their side while ambulatory BP measurements were being taken. Participants kept a standard journal to record activities performed during each measurement, any unusual physical or emotional events, and sleep and wake times. The next morning the monitor was removed and returned with the accompanying journal and then reviewed by a study investigator. Computerized ambulatory BP reports were considered acceptable if ≥80% of the BP readings were obtained. Ambulatory BP readings with SBP >220 mmHg or DBP >130 mmHg were omitted according to the manufacturer’s exclusion criteria. Ambulatory BP was used to determine further study inclusion if average overall BP values met the ambulatory BP criteria for hypertension of SBP ≥130 and/or DBP ≥80 mmHg for unmedicated individuals\textsuperscript{42}. Assuming ≥80% of the BP readings were obtained, medicated individuals automatically qualified as meeting the criteria for hypertension by nature of being on an antihypertensive medication, regardless of BP\textsuperscript{42}.

To minimize inter-tester variability, all BP assessments were measured by a single investigator (ALZ). All resting BP assessments in the laboratory were made using the same BP
monitor throughout the study (BPTRU Medical Devices; Coquitlam, Canada). All ambulatory BP assessments were made using the same ambulatory BP monitor (Oscar2 automatic noninvasive ambulatory BP monitor) for each subject and throughout the study (i.e., Visits 1, 2, 3, and 4). To minimize the confounding effects of circadian variation on BP, all study visits were completed by 10am with an average ambulatory BP monitor attachment time of 8:15±0:36am.

**Visit 2: Peak Cardiopulmonary Graded Exercise Stress Test**

Visit 2 was scheduled with the same investigator and time of day as Visit 1 and separated by at least 48hr. Resting HR (HR\text{rest}) was collected in the supine position after a 5 min rest period using the GE Case Exercise Testing ECG System (GE Healthcare, Wauwaposa, WI). Participants then wore a respiratory apparatus (Parvomedics TrueOne 2400 metabolic cart, Parvomedics Corp, Sandy, UT, USA) to collect expired oxygen and carbon dioxide via the breath-by-breath collection method. Following a 2-5min seated stabilization period, participants performed a peak cardiopulmonary graded exercise test (GEST) using the Balke protocol on a Trackmaster treadmill (Full Vision, Inc., Newton, KS) to determine VO\textsubscript{2}\text{peak}. The Borg rating of perceived exertion (RPE) on the six to 20 scale\textsuperscript{43} and exercising BP were recorded every 3 min, while HR was measured continuously. HR\text{max} was defined as the highest HR recorded by the GE Case Exercise Testing ECG System during the GEST. Of note, HR\text{rest} and HR\text{max} established Visit 2 were later used to determine exercise training intensity loads as described in detail below.

At the end of each GEST, participants were attached to the same ABP monitor following the same protocol as Visit 1. The next morning the monitor was removed and returned with the accompanying journal and reviewed by the investigator. Again, these ambulatory BP value were used to determine further study inclusion if BP values met the definition of being a ‘PEH responder’ (i.e., average 24hr ambulatory SBP or DBP was ≥2 mmHg lower after Visit 2.
compared to Visit 1) \(^7-11\). Of note, Visits 1 and 2 were performed in random order to control for any potential influence visit order may have on BP\(^{44}\).

**Visit 3: Randomization Visit**

Participants who continued to qualify were administered validated questionnaires to assess whether EXERCISE and EXERCISE+PEH self-monitoring favorably modulated measures of integrated social-cognitive predictors of exercise\(^{45}\). In addition, participants were asked to maintain their usual lifestyle habits throughout study participation and were administered validated questionnaires to assess physical activity, dietary and salt intake, and antihypertensive medication adherence. These questionnaires included:

**Integrated Social-Cognitive Predictors of Exercise**

**Self-Efficacy for Exercise:** Two instruments were used to measure the two primary types of self-efficacy for exercise. The first was a measure of task self-efficacy that assesses an individual’s confidence to perform incrementally more challenging bouts of aerobic exercise\(^{46}\). This instrument has 10 questions in which participants rate their confidence for exercise on a scale from 0 to 100 and has been shown to be valid and reliable for use with adults\(^{47}\). Scores were averaged to calculate a task efficacy score. The second is a measure of barriers for self-efficacy\(^{48}\). This instrument, shown to be valid and reliable in adults\(^{49}\), is composed of 11 questions each depicting a barrier to exercise. Participants were asked how confident they were on a scale from 0 to 100 that they could exercise despite the barrier described in the question (e.g., how confident are you that you can exercise when you have a cold?). Scores were averaged to give a total exercise confidence score.

**Outcome Expectations for Exercise:** The Outcome Expectations for Exercise Scale reflects an individual’s beliefs about the outcomes associated with engaging in exercise\(^{50}\). This instrument is composed of 9 questions that participants rated on a 5 point scale from strongly
agree to strongly disagree. Scores were averaged to give a total outcome expectations for exercise score\textsuperscript{50}.

**Affective Responses to Exercise:** This instrument is a reliable and validated 12 question scale assessing three general categories of subjective responses to exercise stimuli: positive well-being (e.g., great), psychological distress (e.g., miserable), and fatigue (e.g., tired)\textsuperscript{51}. For each question on the scale, participants rated how strongly they were experiencing each feeling along a 7 point Likert scale ranging from 1 (not at all) to 7 (very much so).

**Intention to Exercise:** Overall exercise motivation and intention were assessed with two questions by Blanchard et al.\textsuperscript{52}: "I intend to attend my scheduled exercise classes", rated on a 7 point scale from 1 strongly disagree to 7 strongly agree; and "My goal during my exercise program is to attend", rated on a 7 point scale from 1 (some scheduled exercise classes) through 4 (most scheduled exercise classes) and through 7 (every scheduled exercise class). Response scores were averaged to obtain a composite index of intention to exercise, which has demonstrated good reliability and predictive validity for exercise adherence\textsuperscript{52}.

**Physical Activity**

**Paffenbarger Physical Activity Questionnaire:** The Paffenbarger Physical Activity Questionnaire is an eight-item instrument validated to measure self-reported weekly duration and intensity of habitual physical activity over the past year\textsuperscript{53}. Physical activity volume [metabolic energy equivalents (MET)-hour-week\textsuperscript{−1}] was derived from a given MET value for time spent in sitting, sleeping, and light, moderate, and vigorous intensity physical activity\textsuperscript{53}.

**Dietary and Salt Intake**

All participants were asked to maintain their usual diet, and drink caffeinated [< 480 ml (2 cups)] and alcoholic (<2 drinks per day) beverages in moderation throughout study participation. Usual dietary and alcohol intake was assessed with the Block Questionnaire\textsuperscript{54} which assesses fat,
fiber, fruit and vegetable intake in a one-page survey. Scores were added and a cumulative
fruit/vegetable and meat/fat score was calculated. The Rapid Eating and Activity Assessment for
Patients (REAP) questionnaire was administered to assess intake of dairy, fruits and
vegetables, snacks and sweets, fats and oils, sodium, and alcohol\textsuperscript{55}. For each item on the list,
participants described their food consumption frequencies in an average week. Responses were
coded as “usually/often” (2), “sometimes” (1), and “rarely/never” (0). Scores were added and an
average food consumption frequency score was calculated for each food category. Habitual
dietary salt intake was assessed using the Salt Intake Questionnaire; a 42-item, brief food
frequency questionnaire validated in multiple ethnicities and across the lifespan\textsuperscript{56}. Average daily
dietary salt intake was calculated using a validated scoring system\textsuperscript{56} derived from the sodium
content of the listed food item and frequency of consumption.

**Antihypertensive Medication Adherence**

Participants who were taking antihypertensive medications were monitored for
medication adherence throughout the study using the Eight-Item Morisky Medication Scale
(MMAS-8) and the Medication Possession Ratio (MPR) determination\textsuperscript{57}. The MMAS-8 is a
validated questionnaire consisting of eight questions of which the first seven items are Yes/No
responses while the last item is a 5-point Likert response\textsuperscript{58}. Scores were added with possible
scores ranging from 0 (high adherence) to 1-2 (medium adherence) and 3-8 (low adherence).
The MPR assessment is an objective measure of medication adherence and is calculated by
determining the proportion of days of drug supply obtained over the fixed refill interval (i.e.,
study period) \(X\) 100 for a possible score of 0 (low adherence) to >100 (high adherence)\textsuperscript{57}.

At the end of Visit 3, participants were randomized to either the EXERCISE \((n=12)\) or
EXERCISE+PEH \((n=12)\). Of note, all participants (EXERCISE and EXERCISE+PEH) engaged
in exercise training and self-monitoring of exercise. In addition to exercise training and self-
monitoring of exercise (EXERCISE), EXERCISE+PEH also engaged in self-monitoring of BP described in detail below.

Exercise Training and Self-Monitoring of Exercise (EXERCISE and EXERCISE+PEH)

All participants began a progressive 12wk, supervised moderate intensity aerobic exercise training program for 3 d/wk at Hartford Hospital (Hartford, CT, USA). The duration of each exercise session gradually increased from 15 to 40 min during the first 4 wk of training. An additional 5 min warm-up and cool-down was included in each exercise session so that the total time of each workout progressed to total 50 min. Participants exercised between 40-60% of their heart rate reserve [HRR; (HR\text{max}-HR\text{rest}) + HR\text{rest}] obtained from the peak cardiopulmonary GEST (Visit 2). Treadmill-based exercise (i.e., walking, jogging) was recommended as the primary mode of training; however, participants had the option to utilize a Monark 893E Digital Cycle Ergometer (Stockholm, Sweden) to minimize the possibility of orthopedic overuse injuries and prevent boredom with using the same exercise modality.

All participants were given a Polar FT7 HR monitor (Polar Electro Oy, Kempele, Finland) at the beginning of the supervised exercise training program to self-monitor their exercise. Participants were trained to log the details of each workout and any additional exercise they engaged in during the study (i.e., unsupervised) on the Timeline Follow Back (TLFB) log\textsuperscript{59}. TLFB is a reliable and validated self-report tool that uses a calendar diary method to record daily exercise habits over a specified time in which participants record the frequency, intensity, time, and type of the exercise they perform\textsuperscript{59}. The Polar FT7 HR monitor data and TLFB log were downloaded and reviewed with the participants weekly by study investigators.

Exercise training frequency, intensity, time, and type (or FITT) were recorded for supervised, unsupervised, and supervised plus unsupervised exercise training over the course of 12wk. Frequency (d/wk) was calculated as the average of total number of days exercised
number of weeks (12wk). The subjective rating of intensity of each workout was calculated as the average rating reported during each exercise session using the Borg scale of perceived exertion taken every 5 min throughout the exercise bout\textsuperscript{43}. The objective intensity of each workout was measured by utilizing data downloaded from the Polar FT7 HR monitor for the calculation of average training: HR, % of HR\textsubscript{max} obtained during the baseline GEST (%HR\textsubscript{max}), %HRR, and absolute %VO\textsubscript{2}peak. In addition, weekly training load was determined using the training impulse (TRIMP) which multiplies the duration of a training session by the average HR achieved during that session, weighted for exercise intensity as %HRR. The TRIMP calculation for each workout is: for men, duration of training session x %HRR x 0.64x\textsuperscript{0.92x%HRR}; and for women, duration of training session x %HRR x 0.86x\textsuperscript{1.67x%HRR}. Time was recorded as the average training time per session in minutes (total training time ÷ # training sessions). Type of supervised exercise was coded as treadmill or cycle ergometer and reported as a percentage of the total exercise sessions (# of sessions performed on treadmill or cycle ergometer ÷ total exercise sessions performed X 100%).

Exercise adherence to the 12 wk supervised portion of the aerobic exercise training program was calculated as the percent of supervised exercise sessions completed divided by the total number of supervised sessions possible ( # of supervised sessions performed ÷ total number of possible supervised sessions X 100%). In this calculation, the total number of possible sessions was calculated as: 3 supervised exercise training days per wk for 12 wk = 36 sessions with a maximum possible adherence of 100% (e.g., 36÷36 X100% =100%).

Exercise adherence to the 12 wk supervised and unsupervised aerobic exercise training program was calculated as the percent of supervised and unsupervised (i.e., home) exercise sessions completed divided by the total number of supervised sessions possible ( # of supervised + unsupervised sessions performed ÷ 36 X 100%). In this calculation, the total number of possible sessions was 36 sessions following established protocols in the
literature and to directly compare adherence to supervised versus supervised plus unsupervised components of the aerobic exercise training program. Of note, in this measure of adherence, it was possible to have supervised plus unsupervised adherence >100% (e.g., 40 ÷ 36 X 100% = 111%).

Attrition (i.e., drop out) from the training program was defined as failing to attend >72% of the possible number of 36 exercise sessions (i.e., missing 10 or more of the possible 36 training sessions), and/or missing six consecutive sessions. Participants were contacted if they began to fall behind in the number of weekly supervised exercise sessions of 3 per wk for 12 wk via email and/or telephone, and a plan was developed to get them back on schedule. Participants that knew in advance that they would miss a few of the exercise sessions were encouraged to train 4 d/wk for several weeks to compensate for the missed sessions.

Self-Monitoring of BP (EXERCISE+PEH only)

In addition to supervised exercise training and self-monitoring of exercise as described above (EXERCISE), participants in the EXERCISE+PEH group (n=12) were given a home BP monitor (Omron MEM-705CPN, Omron Health Care, Bannockburn, IL) and trained in its use. Participants were instructed to measure BP twice daily (i.e., upon waking and in the evening around the same time of day) in the non-dominant arm following a 5 min period of seated rest. If participants missed a BP reading, they were encouraged to take it when they remembered, even if it was close to their next regularly scheduled BP reading. In order to measure BP on the unsupervised exercise days, participants were instructed to sit quietly and measure BP in their nondominant arm three times 1 min apart, 10 min before and 10 min after the unsupervised exercise sessions performed at home. At the initial training and every three weeks thereafter (to total four times throughout the exercise training period), participants were asked to demonstrate competency in the self-measured BP technique and were reassessed for cuff size by measuring arm circumference. In the event participants did not demonstrate proper self-measured BP
assessment, the research assistant discussed and demonstrated proper technique with the subject until the subject was using proper technique which happened on just three occasions. In addition, participants were provided a copy of the subject instructions for home BP assessment to reference at home.

Participants recorded their home BP readings using the AHA ‘Check. Change. Control. Tracker®’ (previously known as Heart360®) web-enabled, patient-centered BP monitoring tool (https://www.ccctracker.com/aha). Check. Change. Control. Tracker® allows patients to track and record their BP from home utilizing Microsoft HealthVault; a secure and encrypted platform that communicates patient data to a pre-designated healthcare provider which, in this case, was a member of the PULSE investigative team. Participants entered their BP readings and self-generated graphs of BP in the morning, evening, and before and after home exercise which were reviewed with the study investigators on a weekly basis. A sample graph of the home BP readings can be found in SDC 1. In addition, researchers were trained with an IRB approved standardized script (SDC 2) to communicate and/or react to BP assessments taken after each exercise session to minimize the influence of individual and/or researcher verbal cues on the subjects’ reaction to their BP responses to exercise.

Visits 4 and 5: Post Supervised Exercise Training Testing

After the completion of supervised exercise training, the control and GEST sessions previously conducted at baseline were repeated at the same time of day as Visits 1 and 2, within 24-72hr of the last exercise training session, to minimize the confounding effects of acute exercise and detraining. Visits 4 and 5 were performed in random order to control for any potential influence visit order may have on BP. Additionally, all questionnaires were re-administered. For process evaluation, investigators assessed the perceived acceptability, helpfulness, relevance, and satisfaction of EXERCISE and EXERCISE+PEH self-monitoring by interviewing participants using an IRB approved standardized form (SDC 3) that was developed
in accordance with standard qualitative evaluation methodology for health interventions. All process evaluation questions were administered one-on-one and open-ended participant responses were transcribed verbatim.

4wk Post-Supervised Exercise Training Follow Up

Four weeks after the completion of supervised exercise training, participants completed a telephone-based study exit interview to assess longer-term exercise maintenance. Participants were queried on their current levels of self-reported exercise (i.e., frequency, intensity, time, and type or FITT) using the TLFB via memory recall. The percentage of exercise volume the participants were presently engaging in relative to the average of the last 4wk of supervised exercise training sessions was calculated as: average time X frequency of exercise 4wk following exercise training ÷ average time X frequency during last 4wk of exercise training X 100%). Individuals in EXERCISE+PEH were also queried on whether they were still engaging in daily self-monitoring of BP with a “yes” or “no” response.

Statistical Analyses

Data are reported as mean ± standard deviation. Shapiro-Wilk tests were used to determine if data were normally distributed. Analysis of variance (ANOVA) tested baseline demographic, questionnaire, and BP differences between groups. Chi-square tests tested baseline categorical demographic characteristics between groups. In order to assess, the ambulatory BP response to aerobic exercise training, repeated measures ANOVA (RMANOVA) compared BP before and after exercise training measured during the control visits (Visits 1 or 2 vs. Visit 4 or 5) at hourly intervals under ambulatory conditions over 19hr. Ambulatory BP data were averaged over hourly intervals for “awake” (hours 1 to 10), “sleep” (hours 11 to 19), and “19 hr” (hours 1 to 19) BP. The BP response to aerobic exercise training was calculated in two ways: (1) in the laboratory (post training resting BP – pre training resting BP) during the control visits (Visits 1 or 2 vs. Visit 4 or 5); and (2) under ambulatory conditions (post training...
ambulatory BP – pre training ambulatory BP) following the control visits (Visits 1 or 2 vs. Visit 4 or 5) over the awake, sleep, and 19 hr. Paired-samples t-tests tested changes in resting BP measured in the laboratory and ambulatory BP over the awake, sleep, and 19 hr before and after training. Multiple variable linear regression examined correlates of the BP response to exercise training (i.e., baseline SBP, baseline BMI, age). Paired-samples t-tests tested changes in questionnaire data mean scores before and after training. Qualitative transcription data of the open ended responses obtained during process evaluation were synthesized independently by two investigators using a thematic mapping approach in Microsoft Excel. The response to each question was analyzed and summarized for content and coded as either positive, negative, or neutral towards EXERCISE and EXERCISE+PEH self-monitoring with an inter-reliability of 100%. All statistical analyses were performed using the Statistical package for the Social Sciences (SPSS) 23.0 program for Windows (SPSS Inc, Chicago, IL) with p≤0.05 established as the level of significance.

Results

Subject Characteristics Before Exercise Training

The study sample (n=24) consisted of healthy, overweight to obese, mostly Caucasian (75%), middle-aged (range 32-72 yr) men (n=11) and women (n=13) with stage 1 hypertension (resting BP 136.2±10.7/85.2±8.9 mmHg) for a self-reported duration of 6.2±5.9 yr. Half of the sample were taking antihypertensive medications (Table 1). Pre-exercise training cardiorespiratory fitness assessed by VO₂peak was considered “fair” according to the ACSM reference standards for both men and women of this age. There were no significant differences in resting BP (Table 1), ambulatory BP (Table 2), or any other characteristics between groups (Table 1, ps>0.097) pre-exercise training, with the exception that adults in EXERCISE+PEH were on average ~9 yr older than adults in EXERCISE (p=0.032) however, age was not a
significant covariate when examined in the linear regression model for exercise adherence or change in BP.

The Supervised Exercise Training Program

All (100%) training sessions were performed in the Exercise Physiology Laboratory at Hartford Hospital with an average ambient temperature and humidity of 71.4±2.5°F and 19.6±14.4%, respectively. Exercise training characteristics (i.e., FITT and adherence) are provided in Table 3. On average, participants engaged in 35.1±2.9 min of moderate to vigorous (61.2±8.0%HRR, 95% CI: 57.7-64.6), treadmill-based (95.5±9.1%) aerobic exercise 2.6±0.4 d/wk for 12 wk. There were no adverse exercise training related injuries reported throughout the duration of the study.

The change in relative VO\textsubscript{2}peak tended to be 1.7±1.0 mL/kg•min\textsuperscript{-1} higher following 12 wk of aerobic exercise training (p=0.112); while the % relative change in VO\textsubscript{2}peak from baseline increased 7.9% (p=0.048). Similarly, absolute VO\textsubscript{2}peak tended to be 0.2±0.4 L•min\textsuperscript{-1} higher following 12 wk of aerobic exercise training (p=0.094). The ACSM age-and-sex specific normative VO\textsubscript{2}peak percentiles increased from “fair” to “good” following 12 wk aerobic exercise training (p=0.041). There were no differences in exercise training induced changes in relative, absolute, or ACSM age-and-sex specific normative VO\textsubscript{2}peak percentiles between EXERCISE and EXERCISE+PEH groups (ps<0.304).

The Blood Pressure Response After versus Before Exercise Training

Resting: Among the total sample, resting SBP and DBP measured in the laboratory were -7.4±11.3 mmHg (p=0.004) and -4.9±9.9 mmHg (p=0.025) lower, respectively, following versus before 12wk of aerobic exercise training (Table 2). There was no statistically significant difference in the change in resting SBP following versus before 12wk of aerobic exercise training between EXERCISE (-5.2±13.3 mmHg) and EXERCISE+PEH (-9.9±11.3 mmHg;
Likewise, there was no statistically significant difference in the changes in resting DBP following versus before 12wk of aerobic exercise training between EXERCISE (-3.6±12.5 mmHg) and EXERCISE+PEH (-6.1±6.9 mmHg; p=0.552).

Ambulatory: Among the total sample, average awake, sleep and 19hr ambulatory SBP were not different following versus before aerobic exercise training (ps>0.264). Similarly, average awake, sleep, and 19hr ambulatory DBP were not significantly different following aerobic exercise training compared to baseline or between groups (ps>0.102).

Exercise Adherence

Supervised Exercise Training

On average, EXERCISE+PEH demonstrated greater adherence to the supervised aerobic exercise training sessions (94.3±6.6%) compared to EXERCISE (81.6±13.2%; p=0.007). These significant group differences in adherence were reflected in exercise frequency, such that EXERCISE+PEH attended supervised, aerobic exercise training sessions +0.4±0.1 d/wk more than EXERCISE (Table 3; p=0.004). There were no differences in any measures of objective intensity (i.e., HR, %HR$_{max}$, %HRR, %VO$_2$peak), subjective intensity (i.e., RPE), volume (i.e., TRIMP), or average training session time between groups (ps>0.429). Similarly, there were no differences in training modality, with a majority of training sessions performed on the treadmill in EXERCISE (96.3±9.3%) and EXERCISE+PEH (94.8±8.1%; p=0.641) and the remaining ~5% of training sessions performed on a cycle ergometer.

Unsupervised Exercise Training

In addition to attending supervised aerobic exercise training sessions 3 d/wk, subjects were encouraged to perform home based (unsupervised) aerobic exercise 1-2 d/wk while wearing the Polar FT7 HR monitor for verification. On average, individuals engaged in a total of 5.4±5.1 unsupervised training sessions over the course of 12 wk (Table 3). Among the total
sample, 12 individuals (50%) reported at least one verified home-based exercise training 
session, with EXERCISE+PEH (n=10) accounting for a significantly greater portion of those who 
performed additional exercise sessions at home compared to EXERCISE (n=2; $X^2=10.7$, 
p=0.002).

**Supervised Plus Unsupervised Exercise Training**

On average, participants engaged in 37.9±12.4 min of moderate to vigorous 
(60.5±8.8 %HRR) aerobic exercise 2.9±0.6 d/wk for 12 wk with an overall adherence of 
94.9±20.9%. On average, individuals in EXERCISE+PEH exercised ~1 d/wk (0.73±0.5 d/wk) for 
~30 min/wk (32.6±22.5 min/wk) more than individuals in EXERCISE (ps<0.002), resulting in 
greater overall adherence to aerobic exercise training (107.3±18.7%) compared to EXERCISE 
(82.7±12.2; p=0.002).

**Four Week Follow Up to the Exercise Training**

At 4wk post exercise training follow up, participants among the total sample reported 
maintaining exercise training for 1.9±1.5 d/wk with adults in EXERCISE+PEH reporting greater 
exercise frequency (2.6±1.7 d/wk) than adults in EXERCISE (1.3±1.1 d/wk; p=0.045). Among 
the total sample, average “time per session” was 29.4±18.9 min, with no difference between 
EXERCISE+PEH (34.2±18.3 min) compared to EXERCISE (24.6±19.1 min; p=0.223). Sum 
total, at 4wk post exercise training follow up, adults in EXERCISE+PEH were still engaging in 
~70% (73.9±54.1%) of their supervised exercise training volume (frequency x time) compared to 
EXERCISE (33.3±28.7%, p=0.032; Figure 2).

Among adults in EXERCISE+PEH (n=12), ~58%, or seven subjects, reported 
maintenance of BP self-monitoring. These individuals who reported maintenance of BP self-
monitoring at follow-up (n=7) also reported greater maintenance of exercise (45.0±7.1 min for
3.6±1.3 d/wk) compared to adults who did not report maintenance of BP self-monitoring (19.0±18.8 min for 1.2±1.3 d/wk; ps<0.01).

**Integrated Social-Cognitive Predictors of Exercise, Physical Activity, Diet, and Medication Adherence Questionnaires Before and After Training**

Changes in the various measures of integrated social-cognitive predictors of exercise after versus before exercise training are presented in Table 4. There were no baseline differences in any of these measures with the exception that EXERCISE+PEH (74.2±25.5%) possessed higher baseline self-efficacy to overcome exercise barriers than EXERCISE (49.9±20.9%; p=0.043). Among the total sample, after versus before exercise training, there were favorable changes in measures of: exercise self-efficacy (+17%), barrier self-efficacy (+15%), outcome expectations for exercise (+7%), feelings of psychological wellbeing in response to exercise (+12%), feelings of psychological distress in response to exercise (-36%), and feelings of fatigue in response to exercise (-39%) (ps<0.044). After versus before exercise training, group differences emerged such that individuals in EXERCISE+PEH reported greater increases in psychosocial wellbeing in response to exercise (p=0.07) and intention to exercise compared to EXERCISE (p=0.002).

There were no baseline differences between EXERCISE and EXERCISE+PEH in measures of habitual physical activity, dietary and salt intake, or antihypertensive medication adherence (ps>0.179). In general, the study sample spent a majority of their time during the day sitting (~7 hr/d) and engaging in light intensity physical activities (~6 hr/d; e.g., office work, driving, personal care), with the remainder of their time during the day spent in moderate intensity physical activities (~4 hr/d; e.g., housework, yard work, regular walking), and sleeping (~7 hr/d). Self-reported consumption frequency of U.S. pyramid food groups were as follows: dairy (sometimes), fruits/vegetables (usually), meat (sometimes), snacks and sweets (rarely to sometimes), fats and oils (sometimes), sodium (rarely), and alcohol (rarely). Estimated average
salt intake was 1595.0±1018.3 mg/d, which is consistent with U.S. recommendations for individuals with hypertension (1,500 mg/d)\textsuperscript{67,68} and substantially lower than the average daily salt intake of the general population (3,400 mg/d)\textsuperscript{68}. Average medication adherence among individuals taking antihypertensive therapy (n=12) among the total sample was medium to high (MMAS-9 score: 2.2±1.6, MPR: 95.5±5.9\%). Post study, there were no changes in self-reported habitual physical activity levels, dietary and salt intake, and antihypertensive medication adherence among the total sample (p=0.751) or between groups (p=0.576), with the exception that the total sample reported ~0.5±1.8hr more of vigorous intensity activity per day, consistent with undertaking an exercise training program.

**Feasibility and Acceptability of Exercise and Blood Pressure Self-Monitoring**

Our secondary aim was to assess participants' perceived acceptability, helpfulness, relevance, and satisfaction of using exercise and BP self-monitoring. Several recurring themes and observations emerged among the total sample and by group. These results are presented in detail in SDC 4 and briefly summarized below.

*Exercise self-monitoring:* All participants (EXERCISE and EXERCISE+PEH) engaged in exercise training and self-monitoring of exercise using a traditional diary recording method with the TLFB. Among the total sample (n=24), a majority of subjects (21 or ~88\%) were satisfied with the TLFB and found it to be a helpful and relevant tool to self-monitor exercise. Narrative analysis revealed that the TLFB log was: 1) helpful as a tool for self-verification of exercise; and 2) useful as a tool to support accountability to a third party (i.e., the research team). There were no notable differences in perceived acceptability, helpfulness, relevance, or satisfaction between groups. Individuals in both groups found the TLFB extremely easy to use, however, 10 (42\%) participants found it to be time consuming and eight (33\%) noted that a mobile, application-based tool (i.e., app) or wearable device would greatly improve likability and adherence for exercise self-monitoring.
**BP self-monitoring:** In addition to exercise training and self-monitoring of exercise, EXERCISE+PEH engaged in self-monitoring of BP using a home BP monitor twice daily and before and after any home exercise. Among EXERCISE+PEH (n=12), a majority of participants (11 or 92%) found self-monitoring of BP to be an extremely helpful, easy, and valid tool to improve overall health. In general, individuals in EXERCISE+PEH described increased awareness of the interrelatedness among exercise and BP and positive outcome expectations for exercise. Self-monitoring of BP: 1) gave them **reassurance** and peace of mind; 2) facilitated **medical oversight** and communication that led to additional peace of mind; and 3) increased locus of control and served as a **cue to action** for increased exercise adherence.

**Discussion**

To the best of our knowledge, this study is the first rigorously designed randomized-controlled trial to test the hypothesis that using BP self-monitoring as a health condition specific behavioral strategy will increase exercise adherence and improve BP control among adults with hypertension. Our noteworthy findings are that we found adults using BP self-monitoring demonstrated greater adherence to a 12 wk supervised, moderate to vigorous intensity, aerobic exercise training program than those that did not, 94% versus 82%, respectively. Furthermore, adults using BP self-monitoring also demonstrated greater levels of unsupervised home exercise. When combining the 12 wk supervised and unsupervised components of the aerobic exercise training program, adults using BP self-monitoring exercised ~1 d/wk for ~30 min **more** than adults who did not, resulting in greater overall adherence to the 12 wk, supervised and unsupervised aerobic exercise training, 107% versus 83%, respectively. Finally, 1 month after completing the 12 wk aerobic exercise training program, adults using BP self-monitoring were still engaging in nearly 75% of the amount of exercise they performed during the supervised aerobic exercise training, while those not using BP self-monitoring were engaging in only 33% of the amount of exercise they performed during the supervised aerobic exercise training. These
results are the first to verify our long held notion, as well as that of others, that self-monitoring of BP may favorably impact exercise adherence\textsuperscript{6,69} and may serve an efficacious condition-specific behavioral strategy to increase exercise adherence among adults with hypertension.

Putting our findings into clinical context, using BP as a condition specific behavior strategy while self-monitoring exercise compared to self-monitored exercise only resulted in an additional 30 min or 1 day more of aerobic exercise per wk. Given that exercising as little as 1 day per week is as effective (or even more so) than pharmacotherapy for reducing all-cause mortality among those with hypertension\textsuperscript{70}, this additional amount of exercise is clinically important. We intentionally designed our RCT to have both groups using exercise self-monitoring, a proven interventional behavioral strategy to increase exercise adherence. Indeed both groups were highly adherent to the supervised aerobic training program (~88%). We added BP as a form of condition specific self-monitoring to one of the groups, compared it to an active control group using a proven exercise self-monitoring intervention to increase exercise adherence, and still found BP self-monitoring to increase exercise adherence above and beyond exercise self-monitoring alone. These novel findings highlight the promise of using BP self-monitoring as a condition-specific behavioral strategy to increase the physical activity levels of adults with hypertension who generally do not engage in the amount of exercise needed to lower their high BP.

Many trials that have been successful in evoking favorable exercise behavior change in a supervised laboratory setting are unable to demonstrate successful maintenance of exercise in the home setting, if reported at all\textsuperscript{71}. Another noteworthy finding was the demonstrated persistence of the BP self-monitoring group to engage in greater amounts of unsupervised exercise at home for an additional month following the conclusion of the supervised aerobic exercise training program. To the best of our knowledge, there is limited research on the differential determinants of exercise adoption versus exercise maintenance for individuals with
hypertension and if these determinants change over time. Previous qualitative investigations in other clinical populations, have reported that the most important facilitators to initiate exercise in the early adoption phase are social support, expectation for future health benefits, and increased sense of well-being\textsuperscript{72}. The most important facilitators to maintain exercise in the longer-term are social support, noticeable improvements in health, enjoyment, and behavioral strategies such as self-monitoring\textsuperscript{72}. Consistent with short and longer-term facilitators, among adults with hypertension using BP self-monitoring, about 60\% of those who reported maintenance of BP self-monitoring at one month of follow-up also reported exercising 2.2 hours more on a weekly basis than adults who did not report maintenance of BP self-monitoring. These results suggest that not only is BP self-monitoring an important facilitator to evoke behavior change at the early adoption phase, but may also be a transferrable behavioral strategy that carries over across multiple time points to facilitate longer-term exercise maintenance.

Our findings of the value of BP as a condition specific behavioral strategy to increase exercise adherence among adult with hypertension are consistent with similar investigations in other clinical populations. Allen et al. examined the efficacy of glucose self-monitoring to improve exercise adherence among 52 men and women with type II diabetes mellitus\textsuperscript{73,74}. The authors reported that subjects using glucose self-monitoring showed improved self-efficacy for exercise, engaged in 5 min/d more physical activity than those not using glucose self-monitoring than those not using glucose self-monitoring. If extrapolated, this volume of exercise would equate to \(\sim 30-35\) min/wk, consistent with our findings of 30 min/wk. As demonstrated by Allen et al., increased patient involvement in disease management results in increased self-awareness and self-efficacy which may serve as a mechanism to reinforce self-management behaviors, such as exercise\textsuperscript{73,74}. As such, we posited that self-monitoring of BP before and after exercise would foster positive outcome expectations that allowed adults with hypertension to link their
exercise behavior to the “reward” of lower BP and enhance their self-efficacy or confidence for exercise resulting in increased exercise adherence\textsuperscript{24,35} (Figure 3). Centering on this theoretical model, we administered validated questionnaires to assess whether exercise and BP self-monitoring would favorably modulate a variety of measures of integrated social-cognitive predictors of exercise. We found that both forms of self-monitoring resulted in favorable changes in barriers self-efficacy, exercise self-efficacy, outcome expectations, and affective responses to exercise after versus before aerobic exercise training. Interestingly, adults using BP self-monitoring experienced greater increases in: a) self-reported feelings of psychosocial wellbeing in response to exercise; and b) increased intention to exercise compared to those not using BP self-monitoring. It is well documented that acute positive psychological responses to exercise strongly predict exercise adherence and is an important determinant of long-term exercise maintenance\textsuperscript{75-77}. It is possible that BP self-monitoring of the immediate changes in BP or PEH and the immediate increased feelings of psychosocial wellbeing that result from an acute exercise session enabled the subjects with hypertension to link their exercise behavior with the positive health outcome of lower BP as a result of exercise\textsuperscript{24,35} and explain the greater exercise adherence seen among adults using BP self-monitoring versus those who did not.

One noteworthy finding was that both forms of self-monitoring resulted in BP reductions on the order of \textasciitilde 7.5/5 mmHg with no detectable difference between groups. However, it is important to note that individuals in EXERCISE+PEH lowered resting BP (SBP/DBP) by \textasciitilde 10/6 mmHg; reductions approximately twice in magnitude of those in EXERCISE (\textasciitilde 5/3.5 mmHg). While these differences in BP did not achieve statistical significance, the magnitude of these BP reductions are clinically meaningful. Estimation models derived from large scale meta-analyses, indicate that a reduction in SBP of \textasciitilde 5 mmHg, as seen in EXERCISE, rivals that of taking one antihypertensive drug and translates to a relative risk of stroke of 0.78 for adults comparable in age to our study population\textsuperscript{78}. A reduction in SBP of \textasciitilde 10 mmHg, as seen in
EXERCISE+PEH, rivals that of taking two antihypertensive drugs and translates to a relative risk of stroke of 0.61; conferring an additional relative risk reduction of stroke on the order of -17%\textsuperscript{78} compared to EXERCISE. Nonetheless, future RCTs among a larger and more diverse population are needed to determine if using BP self-monitoring as a behavioral strategy translated to improved BP control.

A secondary aim of the present study was to assess the feasibility (i.e., interest, acceptability, retention, and satisfaction) of exercise and BP self-monitoring. Consistent with our hypothesis, participants in the present study found both types of self-monitoring interesting, helpful, relevant, easy, and recommendable. However, retention in and satisfaction were greater among individuals using BP self-monitoring as evidenced by greater exercise adherence, intention to exercise, and self-reported exercise maintenance at 4wk follow-up. Specifically, adults using BP self-monitoring were partial to receiving reassurance derived from regular BP assessment, medical oversight, and cue to action. These encouraging findings are timely as a new and emerging growing body of evidence has hinted towards self-monitoring as a promising future direction for chronic disease management. Technological advances have allowed BP measuring devices to become almost universally accessible for personal use and as such are available as a free or low-cost, convenient, portable, and user-friendly means to monitor BP\textsuperscript{63}. The most recent AHA Cardiovascular Health Consumer Survey reported ~54% of individuals with hypertension self-monitor their BP and the prevalence is higher for those greater than 65 years (~63%)\textsuperscript{15}. BP assessment is relatively easy to record and interpret, thus making it easy for one to temporally measure other internal and/or external conditions, such as exercise\textsuperscript{24}. In addition to the convenience and accessibility of home BP devices, home BP monitoring circumvents the shortcomings of clinic BP assessment by allowing BP to be measured multiple times over a 24 hr period and under normal conditions of daily living. Indeed, BP derived under conditions of free living is a superior predictor of CVD morbidity and mortality and can provide
additional information, such as the influence of lifestyle modifications such as exercise on BP, that are beyond the capabilities of clinic BP\textsuperscript{79,80}.

Limitations

There are several limitations to the present study. We acknowledge that our interpretations are based on a small investigation and larger studies are required to confirm these encouraging findings. Further, we did not perform a comprehensive analysis of moderators of exercise behavior such as perceived risk of disease, family support, and stress, among others. There are a myriad other factors that may influence exercise behavior and/or BP. However, we made every attempt to monitor the maintenance of lifestyle behaviors throughout the study. Lifestyle and antihypertensive medication adherence questionnaires suggested that participants were diet and medication stable throughout the duration of their participation. Last, the possibility exists that the screening procedures allowed for misclassification of a ‘PEH responder’ as approximately 20% of adults with hypertension do not elicit PEH for reasons that are unclear (i.e., PEH nonresponders)\textsuperscript{11}. Indeed, while individuals exhibited PEH (SBP≤2 mmHg lower after exercise compared to before) 85.2±21.4% of the time, three individuals exhibited PEH 50%, 50%, and 67% of the time. Nevertheless, the data indicate that even individuals that demonstrated low frequency and/or magnitude of PEH at home did not appear to have adherence, BP outcomes, or qualitative feedback that differed from individuals with high frequency and/or magnitude of PEH.

Despite the noted limitations, this study possesses several strengths. To the best of our knowledge, the present study is the first rigorously designed randomized-controlled trial to examine our hypothesis that BP self-monitoring will enhance exercise adherence and improve BP control among adults with hypertension. The study population is representative of patients for whom exercise and BP self-monitoring would be clinically indicated. Technical error was minimized by having all study BP assessments performed by a single investigator (ALZ) at the
same time of day using the same ambulatory BP monitor for the same subject throughout the study duration. All study visits were performed in random order to control for any potential influence visit order may have on BP\textsuperscript{44}. Finally, all training sessions were scheduled with the same supervising research assistant and in one single training facility to minimize any external influences on the primary outcome variables.

**Conclusion**

This study is the first to demonstrate that using condition-specific BP self-monitoring is an efficacious behavioral strategy to improve exercise adherence among adults with hypertension. Indeed, we found that adults with hypertension who self-monitored their BP, daily and before and after aerobic exercise, were \textasciitilde24\% more adherent to a 12 wk structured aerobic exercise training program. In addition, those adults using BP self-monitoring maintained 37\% more exercise at one month follow up than those who were not using BP self-monitoring. These preliminary results are intriguing and merit confirmation among a larger sample to determine whether increased exercise adherence owing to BP self-monitoring translates into improved BP control.

**Acknowledgments**

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References


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Table 1. Baseline Subject Characteristics (±SD) Among the Total Sample and by Group

<table>
<thead>
<tr>
<th></th>
<th>Total Sample (n=24)</th>
<th>EXERCISE (n=12)</th>
<th>EXERCISE+PEH (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>52.3±10.8</td>
<td>47.7±10.2</td>
<td>56.9±9.6*</td>
</tr>
<tr>
<td>Sex (% men)</td>
<td>46%</td>
<td>33%</td>
<td>58%</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>30.1±4.8</td>
<td>29.9±5.6</td>
<td>30.3±3.9</td>
</tr>
<tr>
<td>Waist Circumference (cm)</td>
<td>102.1±11.8</td>
<td>103.7±15.4</td>
<td>100.5±6.8</td>
</tr>
<tr>
<td>Resting SBP (mmHg)</td>
<td>136.2±11.2</td>
<td>137.0±11.2</td>
<td>135.3±10.5</td>
</tr>
<tr>
<td>Resting DBP (mmHg)</td>
<td>85.2±8.9</td>
<td>86.7±11.2</td>
<td>83.8±6.1</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>75.1±9.8</td>
<td>78.4±10.3†</td>
<td>71.8±8.5</td>
</tr>
<tr>
<td>Duration of Hypertension (yr)</td>
<td>6.2±5.9</td>
<td>5.5±5.9</td>
<td>6.9±6.1</td>
</tr>
<tr>
<td>Medication Use (%)</td>
<td>50</td>
<td>58†</td>
<td>42‡</td>
</tr>
<tr>
<td>VO₂peak (mL/kg•min⁻¹)</td>
<td>27.3±7.5</td>
<td>25.3±8.7</td>
<td>29.3±5.7</td>
</tr>
</tbody>
</table>

*Abbr: BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate; VO₂peak, peak oxygen consumption; †Angiotensin II receptor blocker (n=3), ACE/β-blocker combination (n=3), Diuretic (n=1); ‡Angiotensin II receptor blocker (n=3), ACE inhibitor (n=1), ARB II receptor blocker (n=1); *p<0.05, EXERCISE vs. EXERCISE+PEH; †p=0.097, EXERCISE vs. EXERCISE+PEH.
Table 2. Resting and Ambulatory Blood Pressure and Heart Rate (±SD) Before and After 12wk Exercise Training Among the Total Sample

<table>
<thead>
<tr>
<th>BP and HR Measures</th>
<th>Pre (n=24)</th>
<th>Post (n=24)</th>
<th>Post-Pre (n=24)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Laboratory</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laboratory SBP (mmHg)</td>
<td>136.2±10.7</td>
<td>128.8±10.8</td>
<td>-7.4±11.3</td>
<td>0.004</td>
</tr>
<tr>
<td>Laboratory DBP (mmHg)</td>
<td>85.2±8.9</td>
<td>80.3±9.4</td>
<td>-4.9±9.9</td>
<td>0.025</td>
</tr>
<tr>
<td>Laboratory HR (bpm)</td>
<td>75.1±9.9</td>
<td>74.3±15.5</td>
<td>-0.8±15.6</td>
<td>0.781</td>
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<tr>
<td><strong>Ambulatory</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBP Awake (mmHg)</td>
<td>143.9±6.9</td>
<td>141.9±10.6</td>
<td>-2.0±10.6</td>
<td>0.314</td>
</tr>
<tr>
<td>SBP Sleep (mmHg)</td>
<td>130.3±9.2</td>
<td>133.5±13.1</td>
<td>3.2±13.2</td>
<td>0.264</td>
</tr>
<tr>
<td>SBP 19hr (mmHg)</td>
<td>137.5±6.6</td>
<td>137.9±11.0</td>
<td>0.4±11.0</td>
<td>0.820</td>
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<tr>
<td>DBP Awake (mmHg)</td>
<td>86.2±6.7</td>
<td>85.3±6.8</td>
<td>-0.9±6.9</td>
<td>0.624</td>
</tr>
<tr>
<td>DBP Sleep (mmHg)</td>
<td>74.3±5.9</td>
<td>77.7±7.9</td>
<td>3.4±7.9</td>
<td>0.102</td>
</tr>
<tr>
<td>DBP 19hr (mmHg)</td>
<td>80.5±5.7</td>
<td>81.7±6.5</td>
<td>1.2±6.5</td>
<td>0.455</td>
</tr>
<tr>
<td>HR Awake (mmHg)</td>
<td>80.2±14.8</td>
<td>78.6±15.2</td>
<td>-1.6±15.2</td>
<td>0.263</td>
</tr>
<tr>
<td>HR Sleep (mmHg)</td>
<td>73.4±12.9</td>
<td>71.6±12.6</td>
<td>-1.8±12.6</td>
<td>0.259</td>
</tr>
<tr>
<td>HR 19hr (mmHg)</td>
<td>76.9±13.2</td>
<td>75.3±13.7</td>
<td>-1.6±13.7</td>
<td>0.212</td>
</tr>
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Table 3. Exercise Training Profile (±SD) of the Total Sample and by Group

<table>
<thead>
<tr>
<th>Training Characteristics</th>
<th>Total Sample (n=24)</th>
<th>EXERCISE (n=12)</th>
<th>EXERCISE+PEH (n=12)</th>
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<tbody>
<tr>
<td><strong>Supervised Exercise Training</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>FITT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency (d/wk)</td>
<td>2.6±0.4</td>
<td>2.4±0.4</td>
<td>2.8±0.2*</td>
</tr>
<tr>
<td>Intensity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>129.1±15.5</td>
<td>131.2±17.9</td>
<td>126.9±13.2</td>
</tr>
<tr>
<td>%HRmax</td>
<td>78.8±4.8</td>
<td>79.6±5.4</td>
<td>78.0±4.2</td>
</tr>
<tr>
<td>%HRR</td>
<td>61.2±8.0</td>
<td>61.3±8.3</td>
<td>60.9±8.1</td>
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<tr>
<td>%VO2</td>
<td>65.1±7.3</td>
<td>66.3±8.3</td>
<td>63.9±6.1</td>
</tr>
<tr>
<td>RPE</td>
<td>12.4±1.2</td>
<td>12.4±0.9</td>
<td>12.5±1.4</td>
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<tr>
<td>TRIMP (bpm∙min)</td>
<td>4187.5±980.9</td>
<td>4095.3±1041.7</td>
<td>4279.8±953.1</td>
</tr>
<tr>
<td>Time (min/session)</td>
<td>35.1±2.9</td>
<td>34.0±3.3</td>
<td>36.1±2.2</td>
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<tr>
<td>Type</td>
<td>Aerobic</td>
<td>Aerobic</td>
<td>Aerobic</td>
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<tr>
<td>Adherence (%)</td>
<td>87.9±12.1</td>
<td>81.6±13.2</td>
<td>94.3±6.6*</td>
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<tr>
<td><strong>Unsupervised Exercise Training at Home</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Number of Subjects Reporting at Least One Verified*n Exercise Session at Home During 12wk Study Period (n)</td>
<td>12</td>
<td>2</td>
<td>10*</td>
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<tr>
<td><strong>FITT</strong></td>
<td>Total Sample (n=12)</td>
<td>EXERCISE (n=2)</td>
<td>EXERCISE+PEH (n=10)</td>
</tr>
<tr>
<td>Frequency (d/wk)</td>
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<td>0.4±0.4</td>
<td>0.5±0.4</td>
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<td>Intensity</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>120.4±14.9</td>
<td>118.0±0.0</td>
<td>120.9±16.4</td>
</tr>
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<td>%HRmax</td>
<td>65.6±9.7</td>
<td>64.5±1.5</td>
<td>65.8±10.7</td>
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<tr>
<td>%HRR</td>
<td>50.7±15.3</td>
<td>45.9±3.7</td>
<td>51.6±16.7</td>
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<tr>
<td>%VO2</td>
<td>44.5±15.1</td>
<td>42.7±2.5</td>
<td>44.8±16.7</td>
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<tr>
<td>Time (min/session)</td>
<td>42.5±15.6</td>
<td>45.5±3.5</td>
<td>42.5±17.2</td>
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<tr>
<td>Type</td>
<td>Aerobic</td>
<td>Aerobic</td>
<td>Aerobic</td>
</tr>
<tr>
<td><strong>Supervised Plus Unsupervised Exercise Training</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FITT</strong></td>
<td>Total Sample (n=24)</td>
<td>EXERCISE (n=12)</td>
<td>EXERCISE+PEH (n=12)</td>
</tr>
<tr>
<td>Frequency (d/wk)</td>
<td>2.9±0.6</td>
<td>2.4±0.5</td>
<td>3.2±0.6*</td>
</tr>
<tr>
<td>Intensity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>128.5±15.8</td>
<td>130.9±18.1</td>
<td>126.1±13.6</td>
</tr>
<tr>
<td>%HRmax</td>
<td>78.4±5.0</td>
<td>79.2±5.5</td>
<td>77.6±4.6</td>
</tr>
<tr>
<td>%HRR</td>
<td>60.5±8.8</td>
<td>60.9±8.9</td>
<td>60.0±9.1</td>
</tr>
<tr>
<td>%VO2</td>
<td>64.5±7.8</td>
<td>66.1±8.4</td>
<td>64.5±7.8</td>
</tr>
<tr>
<td>Time (min/session)</td>
<td>37.9±12.4</td>
<td>34.1±3.3</td>
<td>41.8±16.7†</td>
</tr>
<tr>
<td>Type</td>
<td>Aerobic</td>
<td>Aerobic</td>
<td>Aerobic</td>
</tr>
<tr>
<td>Adherence (%)</td>
<td>94.9±20.9</td>
<td>82.7±12.2</td>
<td>107.3±18.7*</td>
</tr>
</tbody>
</table>

*Excluding 5 min warm up and 5 min cool down. †Verified with Polar FT7 HR monitor.

Abbr: ExRx FITT; Exercise Prescription Frequency, Intensity, Time, Type; HR, heart rate; HRR, heart rate reserve; VO2, oxygen consumption; RPE, rating of perceived exertion; TRIMP, training impulse; *p<0.05, EXERCISE vs. EXERCISE+PEH; †p=0.130, EXERCISE vs. EXERCISE+PEH
Table 4. Integrated Social-Cognitive Predictors of Exercise Before and After 12wk Aerobic Exercise Training Among the Total Sample (n=24) and by Group

<table>
<thead>
<tr>
<th>Measure</th>
<th>Scale</th>
<th>Before Exercise Training</th>
<th>After Exercise Training</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total Sample</td>
<td>EXERCISE</td>
</tr>
<tr>
<td>Exercise Self-Efficacy</td>
<td>0% (not confident at all) to 100% (highly confident)</td>
<td>81.3±18.3</td>
<td>77.0±18.7</td>
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<tr>
<td>Barriers Self-Efficacy</td>
<td>0% (not confident at all) to 100% (highly confident)</td>
<td>62.3±26.0</td>
<td>49.9±20.9</td>
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<tr>
<td>Outcome Expectations</td>
<td>1 (strongly disagree) to 5 (strongly agree with the stated benefit of exercise)</td>
<td>4.4±0.5</td>
<td>4.2±0.5</td>
</tr>
<tr>
<td>Affective Responses to</td>
<td>4 (not at all), 16 (moderately), to 28 (very much so)</td>
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<td></td>
</tr>
<tr>
<td>Exercise</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psychological Wellbeing</td>
<td></td>
<td>21.0±4.6</td>
<td>20.9±4.6</td>
</tr>
<tr>
<td>Psychological Distress</td>
<td></td>
<td>7.4±3.9</td>
<td>7.0±3.6</td>
</tr>
<tr>
<td>Fatigue</td>
<td></td>
<td>13.9±6.8</td>
<td>14.2±6.3</td>
</tr>
<tr>
<td>Intention to Exercise</td>
<td>1 (low) to 7 (strong exercise intention)</td>
<td>6.8±0.5</td>
<td>6.6±0.7</td>
</tr>
</tbody>
</table>

*p<0.05, pre vs. post; **p<0.01, Δ EXERCISE vs. EXERCISE+PEH; †p=0.07, Δ EXERCISE vs. EXERCISE+PEH
Figures

Figure 1. Study Diagram

Visit 1 or 2: Control
- BP
- Anthropometrics
- 24hr ABPM

Visit 1 or 2: GEST
- BP
- GEST
- 24hr ABPM

Visit 3: Randomization
Lifestyle Questionnaires

Supervised Aerobic Exercise Training (12wk)

EXERCISE (n=12)
3d/wk; 40-60%HRR; 40min and encouraged to engage in ≥2d/wk home based aerobic exercise. All participants perform traditional self-monitoring of exercise.

EXERCISE+PEH (n=12)
3d/wk; 40-60%HRR; 40min and encouraged to engage in ≥2d/wk home based aerobic exercise. All participants perform traditional self-monitoring of exercise plus self-monitoring of BP am, pm, and before and after home exercise sessions.

Visit 4 or 5: Control
- BP
- Anthropometrics
- 24hr ABPM

Visit 4 or 5: GEST
- GEST
- 24hr ABPM
- Lifestyle questionnaires
- Process evaluation

Telephone Exit Interview (Post 4wk)
Assessment of current exercise levels and BP self-monitoring

1In random order. Abbr: BP, blood pressure; ABPM, ambulatory blood pressure monitor; GEST, graded exercise stress test; PEH, postexercise hypotension; HRR, heart rate reserve
Figure 2. Percent of Supervised Exercise Training Maintained at 4 wk Follow Up Among the Total Sample (n=24) and by Group

*p<0.05, EXERCISE vs. EXERCISE+PEH
Figure 3. Proposed Theoretical Model of Blood Pressure Self-Monitoring as a Condition-Specific Behavioral Strategy to Moderate Exercise Adherence and Blood Pressure Outcomes

In this theoretical model, self-monitoring of BP fosters positive outcome expectations that allow individuals with hypertension to link their exercise behavior to the "reward" (i.e., lower BP) and enhance their self-efficacy or confidence for exercise.
Supplemental Digital Content 1. Example of Self-Monitored BP Readings in the Morning, Evening, and Before and After Exercise in an EXERCISE+PEH Participant During Week 6 of Exercise Training

BP levels lower after exercise and remain lower until ~Mon am
Supplemental Digital Content 2. Researcher Script for Blood Pressure Changes after Exercise

Blood pressure is expressed by two numbers: systolic over diastolic. Systolic (the top number) represents the **highest** pressure against the blood vessel walls when the heart contracts. Diastolic pressure (the bottom number) is the **lowest** pressure in the blood vessel, and occurs when the heart is re-filling and at rest.

Blood pressure is very labile, meaning that it is constantly changing to adjust to internal and external factors such as eating, sleeping, stress, and physical activity. In general, systolic blood pressure increases during exercise in order to meet the physical demands of exercise and deliver more oxygenated blood to working muscles, heart, and brain. Immediately after exercise, blood pressure will decrease again; however, this decrease varies from person to person and even within the **same** person will vary from day to day.

After exercise, some individuals will experience a decrease in blood pressure back down to pre-exercise levels, while others will experience a decrease in blood pressure even lower than pre-exercise levels. Even within the same individual, these changes can vary from day to day and is an expected response to exercise.
Supplemental Digital Content 3. Process Evaluation

Open-ended questions that will be asked of study participants regarding the feasibility of using PEH as a self-monitoring strategy include those below. Please note that bolded questions will be asked of all study participants and the unbolded of only participants in the EXERCISE+PEH group.

How much did you like using the time line follow back to record the amount of exercise you did?

How much did you like using the home blood pressure monitor to take your blood pressure before and after you exercised?

How helpful to you was it recording the amount of exercise you did on the time line follow back?

How helpful to you was it using the home blood pressure monitor to take your blood pressure before and after you exercised?

How difficult was it to record the amount of exercise you did on the time line follow back?

How difficult was it to use the home blood pressure monitor to take your blood pressure before and after you exercised?

How likely would you be to continue recording the amount of exercise you did on the time line follow back after the study ends?

How likely would you be to continue to use the home blood pressure monitor to take your blood pressure before and after you exercised after the study ends?

How likely would you be to continue exercising after recording the amount of exercise you did on the time line follow back?

How likely would you be to continue exercising after using the home blood pressure monitor to take your blood pressure before and after you exercised?

How likely would you be to recommend recording the amount of exercise you did on the time line follow back to a friend?

How likely would you be to recommend using the home blood pressure monitor to take your blood pressure before and after you exercised to a friend?

What did you particularly like about recording the amount of exercise you did on the time line follow back?

What did you particularly like about using the home blood pressure monitor to take your blood pressure before and after you exercised?
Is there anything you would change regarding recording the amount of exercise you did on the time line follow back?

Is there anything you would change regarding using the home blood pressure monitor to take your blood pressure before and after you exercised?

*Exercise self-monitoring (i.e., TLFB):* Among the total sample (n=24), a majority of individuals (21 or ~88%) were satisfied with the TLFB and found it to very easy, helpful, and relevant as a tool to self-monitor their physical activity. There were no notable differences in perceived benefit between groups. Of note, three participants were ambivalent as they felt they “already knew what they had to do and didn’t feel the need to write it [exercise] down, but it didn’t bother them”, however, there were no participants that disliked the tool. Narrative analysis revealed three major themes:

1) A majority of participants (22 or 92%) found the TLFB to be a helpful tool for self-verification of weekly exercise sessions. One participant (EXERCISE group) stated, “I loved seeing what I was accomplishing and that every minute added up to mean something.” Similarly, another participant (EXERCISE+PEH group) stated, “I liked seeing that I was achieving a goal every week and that I was ‘all set’ in terms of if I was doing enough or not.” Another participant noted, “I just think it’s so nice to see it all there. It makes me feel proud at the end of the day.”

2) Many participants (11 or 46%) found the TLFB to be particularly useful for a method of accountability. Notably, three individuals referred to feelings of anticipated guilt as a powerful motivator to exercise. For example, one participant (EXERCISE+PEH group) stated, “The TLFB was very helpful. That little log helped me get out of bed in the morning knowing that I would feel guilty if I didn’t check that box off for the day!”. Similarly, a second participant (EXERCISE group) stated, “I liked proof to my doctor that I was trying my hardest. I can’t wait to show her”. A third participant (EXERCISE group) stated, “It was helpful for me to see in front of my face what I was doing or NOT doing. It was very good at making me guilty! (laughs)".
3) Interestingly, 100% of the training sessions were independent, one-on-one sessions, yet three participants (all male) mentioned that the TLFB was helpful to them for the perceived competition. For example, one participant (EXERCISE group) stated, “I’ll admit that I did like feeling proud of reaching my goals. How many other people were making it 100% of the time? I’m competitive that way. That motivates me if I know I’m the one making every week despite the snow and everything else going on.”

**PEH self-monitoring:** Among EXERCISE+PEH (n=12), a majority of participants (11 or 92%) found PEH self-monitoring to be an extremely helpful, easy, and valid tool to increase exercise adherence and for overall health. In general, individuals actively engaged in PEH self-monitoring described increased awareness of the interrelatedness of exercise, daily BP, and PEH through daily, individualized feedback and reinforcement. Exploratory narrative analysis revealed three major themes:

1) Almost all participants (11 or 92%) stated that BP/PEH self-monitoring gave them reassurance and peace of mind that their chronic condition was under control. One participant stated, “Seeing that my values were much more in the green than red gave me peace of mind when I have so much going on right now. One less thing to worry about.” Similarly, a second participant stated, “I did like the reassurance that my blood pressure was not as high as I thought it was on a rough day or what have you.” A third participant stated, “Seeing the numbers go down as a direct result of exercise-especially at night helped me sleep better, I’ll tell you that!.”

2) Many (6 or 50%) participants noted that a unique aspect of PEH self-monitoring was the medical oversight component. Individuals found the AHA web-enabled, patient-centered BP monitoring tool *in combination* with weekly BP review sessions with the study coordinator to be an extremely important component of PEH self-monitoring. For
example, one participant stated, “It's nice to see everything going on and that someone has an eye on it, too”. Similarly, a second participant noted, “I will definitely continue to do this and hopefully share this with my doctor. I think this would be most helpful to him.” A third participant stated, “Knowing that someone else knows it's [BP] good is good as I'm not always sure what is borderline and what’s not.”

3) A third common theme of PEH self-monitoring was increased locus of control and the use of BP as a tool for cue to action. For example, one participant stated, “I liked taking my blood pressure daily and seeing it change after exercise. I would notice it creep up and the fact that I had control over that was reassuring to me”. Similarly, a second participant stated, “I liked that I know daily what my blood pressure is and that it is in line with what it should be. It never caused me any worry. It never made me feel anxiety. Whatever it is, it is, but once I know what it is, it gives me the opportunity to do something.” A third participant quantified this sentiment by stating, “I think knowing my blood pressure probably encourages me to exercise about one more session a week”.

Both groups were given the opportunity to suggest areas of improvement or aspects of exercise/PEH self-monitoring that they disliked. Individuals among both groups found the TLFB extremely easy to use, however, (10 or 42%) participants found it to be time consuming and 8 or 33% noted that a mobile, application-based tool (i.e., app) or wearable device would greatly improve likability and adherence for exercise self-monitoring. Similarly, 6 or 50% individuals in EXERCISE+PEH found daily BP assessment to be very time consuming and 4 or 17% noted that they would continue to use BP self-monitoring only “once in a while as a check in”. One participant noted, “It was not difficult, it's just time consuming. You gotta take the five minutes to do it and that’s time out of your day each time.” Some (4 or 17%) individuals noted that a mobile app would improve usability and adherence to BP/PEH self-monitoring. For example, one participant stated, “I wouldn’t change anything unless there was a way my numbers could be
transferred immediately to an app or something. Do they make that?” A second participant stated, “I think I would make the BP log electronic for those who are on-the-go.”

To summarize, both groups found both types of self-monitoring interesting, helpful, relevant, easy, and recommendable. Anecdotally, conversations with individuals in EXERCISE+PEH were more positive in nature as the focus was on BP as a health biomarker rather than their exercise as a health behavior. There were more discussions of “positive” concepts such as cue to action and motivation versus feelings of guilt or proving accountability to their physician and/or research team (i.e., subservient role).
4.1 Methodology

Additional methodology not relevant to the main manuscript is provided below, including, local recruitment and enrollment procedures, subject payment, and detailed power estimates calculated by Dr. Chen, Department of Statistics, University of Connecticut.

4.1.1 Recruitment

Potential study participants were recruited from the surrounding community with direct mailings and posting of flyers, BP screenings, media advertisements, electronic social media (i.e., Facebook), previous studies, and from places of work and college campuses with the posting of flyers, BP screenings, listservs, class announcements, and newsletters. Every effort was made to target populations in the early stages of hypertension as this is a susceptible population for whom lifestyle interventions such as exercise are critical to prevent the progression of hypertension and its associated sequelae\textsuperscript{1-5}.

Individuals who expressed interest in the research study were invited to participate in a phone screening questionnaire to determine eligibility. Among the 76 participants who were phone screened (Figure 1), 45\% of individuals failed due to: inability to commit to time requirements (n=10); presence of a excluding chronic condition (n=9); lost to follow up (n=6); concomitant medication that could potentially influence BP (n=5); and no self-reported hypertension (n=4). Of the remaining participants who enrolled (n=42), an additional 18 participants (or \~43\%) were removed from the study due to: time commitment (n=8); orientation BP too low (n=5); failure to achieve 80\% of the ambulatory BP readings (n=2); unstable BP (n=2); and testing site inconvenience (n=1), resulting in a total study sample of n=24.
Of the total sample, ~63% were Hartford Hospital employees, which may have influenced training related outcomes due to convenience and accessibility. However, this is not likely as training adherence was similar between employees (89.3±7.7%) versus non-employees (85.6±17.5%; p=0.487).

4.1.2 Testing Timeline

Following IRB approval on 10/18/16, subject testing began on 10/28/16 as a “soft opening” to complete Wave 1 or n=6 subjects. Following completion of Wave 1, a majority of subjects (Waves 2-4, n=18) were recruited from the time period 4/2017 to 4/2018. Based on our study, similar future trials can plan to comfortably enroll ~3 subjects per month, excluding holidays and barring extreme winter conditions that proved to be a barrier for some potential participants to commit to training in the winter months.
4.1.3 Subject Incentives

Subject incentives were allocated from a generous grant from the Office of the Vice President Scholarship Facilitation Fund. Following the completion of Visits 1 and 2, participants were paid $25. Following completion of exercise training, participants were paid $50. Following completion of Visits 3 and 4, participants received a final payment of $25 to total $100 for the completion of the entire study. Beginning January 1, 2018, participants that would not otherwise travel to and from the testing site at least 3 d/wk Mon-Sat (i.e., non-hospital employees) were also compensated for parking at the rate of $2 per exercise training days ($2 x 36) to total $72. This addition was made based on subject feedback from Wave 1 of testing indicating that site parking expenses were a major barrier to recruitment and retention as 65% of patients who initially expressed interest in the study declined to screen for the study due to this economical barrier. Sum total, PULSE expended $2,860.00 for subject incentives.

4.1.4 Sample Size and Power Calculations

Please note that PULSE was a pilot study to collect important, time-sensitive preliminary data for a NIH/NHBLI R01 1A resubmission 1 R01 HL130135-01 that was requested by the reviewers to demonstrate the feasibility and clinical utility of using PEH as a self-monitoring strategy to increase exercise adherence and improve BP control. We acknowledge this pilot study may be underpowered to answer its primary research question.

Sample size calculations were based upon the primary outcome dependent variables of the exercise adherence and the BP response variables to supervised exercise training. Based upon our previous work with supervised training studies and that of the literature, we assumed attritions rate of 20 and 33% for the EXERCISE+PEH and EXERCISE groups, respectively. Sample size calculations also account for the observation that 20% of adults with hypertension do not elicit PEH from reasons that are unclear (i.e., PEH nonresponders). For these calculations we defined attrition from the supervised exercise training program as failing to
attend >75% of 3 sessions per wk for 12 wk (i.e., missing 10 or more of the possible 36 training sessions). The magnitude of the BP response to acute (i.e., PEH) and chronic (i.e., training) is similar\textsuperscript{10}. Thus, our power calculations used the estimates of the change in ambulatory BP after acute exercise minus the non-exercise control condition over the awake hr from the PI’s most recent PEH work\textsuperscript{11-13}. Then, the overall effect size defined as the overall difference in the change in ambulatory BP after minus before exercise from the non-exercise control condition over the awake hours between the two groups was calculated using the estimates of the change in ambulatory BP and the above attrition rates for exercise adherence. Using a small equivalence margin for the BP response to supervised exercise training variable in our primary aim, the minimum sample size was determined to achieve a statistical power of 80% to detect a medium effect size with a significance threshold of p=0.05/2 for multiplicity adjustment (Table 1).

For the proposed two-stage model, we developed a sample size calculation formulation. Let $\delta$ denote the overall effect size. We conducted a test for the two-sided hypotheses: $H_0$: $\delta = 0$ vs $H_1$: $\delta \neq 0$. We assumed subjects who complete $\geq$27 exercise sessions would exhibit the BP differences shown in Table 1; whereas subjects that do not complete any of the required number of exercise sessions (i.e., 0 sessions completed) will not exhibit a change in the BP response variable after vs before supervised exercise training. For subjects that complete 1 to 26 sessions, we used a fractional reduction to calculate the estimated BP change to exercise training depending on how many sessions were completed. We used the estimated differences and SDs in Table 1, the equivalence margin of SD/5\textsuperscript{14}, and a 20% attrition rate for the EXERCISE+PEH group, and 33% for the EXERCISE group in our sample size calculation. For SBP, a sample size of 49 subjects in each group was sufficient to achieve 80% power to detect an effect size of $\delta=4.90$ mmHg with a significance level of 0.05/2. Using the DBP estimates that are more than sufficient to power the sample for SBP, a sample size of 52 subjects in each
group would be needed to achieve a statistical power of 80% to detect an effect size of $\delta=3.25$ mmHg with a significance threshold.

<table>
<thead>
<tr>
<th>Ambulatory BP Dependent Variable</th>
<th>Control Change (Mean ± SD)</th>
<th>Acute Exercise Change (Mean ± SD)</th>
<th>Difference</th>
<th>Sample Size Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBP (mmHg)</td>
<td>24.681±11.481</td>
<td>18.684±11.285</td>
<td>5.997±10.502</td>
<td>49</td>
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<tr>
<td>DBP (mmHg)</td>
<td>9.830±7.200</td>
<td>6.199±7.668</td>
<td>3.630±7.201</td>
<td>52</td>
</tr>
</tbody>
</table>

Table 1. Estimated differences in the mean values of the ambulatory BP response dependent variable based on our most recent PEH work accounting for attrition and subjects not exhibiting PEH, and the corresponding required sample size calculated assuming statistical power of 80% and significance threshold of 0.05/2 for multiplicity adjustment. All data are reported as X±SD.

4.1.5 Health Behavioral Theories Underlying Condition-Specific Self-Monitoring to Improve Exercise Adherence and Improve BP

Following the biomedical model in the treatment of hypertension, individuals who are diagnosed with elevated BP are prescribed antihypertensive therapy (i.e., pharmacological or lifestyle) and assumed to adhere this prescription for the duration of this lifelong condition. In this model, the patient is the passive, subordinate recipient of care, as the clinician treats the “pathogen” (i.e., hypertension). However, this model fails to appraise the individual “host” of disease, which is critically important given that human behavior moderates chronic conditions such as hypertension, both acutely and chronically. More realistic theoretical models of health behavior, such as the Social Cognitive Theory and the Health Belief Model, are widely utilized and serve as the basis of many health behavior interventions designed to control, treat, and manage hypertension. A fundamental component of many health behavior theories is the concept of self-monitoring. Self-monitoring of a chronic condition, such as hypertension, enables the individual to self-measure BP (as the primary outcome variable), and temporally measure other internal and/or external conditions; interpret the “data”; and adjust internal and/or
external conditions (i.e., lifestyle factors, help-seeking behaviors) in order to change the result of the primary outcome variable (i.e., BP)\textsuperscript{15}.

In our theoretical model (Figure 2), we combine several theories of health behavior models and propose that in addition to the reference standard of traditional self-monitoring of exercise, BP self-monitoring fosters positive outcome expectations that allow individuals with hypertension to link their exercise behavior to the “reward” (i.e., lower BP) and enhance their self-efficacy or confidence for exercise. Borrowing from the seminal work of Hagger and Chatzisarantis\textsuperscript{16}, the individual components and constructs of this model are referred to as “integrated” as the model draws from several theories of health psychology that aim to explain psychological moderators of exercise, namely Social-Cognitive Theory and the Health Belief Model. Specifically:

Social-Cognitive Theory is based on the notion of “triadic reciprocation”, meaning that the 1. individual, 2. behavior, and 3. environment all interact and the net result can either facilitate or negatively influence outcomes\textsuperscript{17,18}. Central to Social-Cognitive Theory is the concept of self-efficacy (i.e., one’s belief or confidence in their capability to successfully carry out an action such as exercise) will further promote success in obtaining higher levels of exercise by improving outcome expectations (i.e., anticipatory results of a behavioral and the value placed on those results) and success derived-motivation\textsuperscript{19}. Self-monitoring of physical activity levels can serve as a significant source of self-efficacy by increasing both task self-efficacy and barriers self-efficacy. Logging physical activity allows the individual to repeatedly track their behavior over time and inform themselves (upon introspective evaluation) that they are able to consistently and longitudinally demonstrate this behavior and overcome daily obstacles. Improvements in task self-efficacy might further increase barriers self-efficacy by improving confidence and increasing positive outcome expectations. Similarly, if an individual purchases a home BP monitor, he/she is more likely to use it and self-monitoring of BP over time will
facilitate ownership and empowerment of hypertension as a condition, thus improving motivation and frequency of the behavior. One important concept in Social-Cognitive Theory is self-regulation or a person’s ability to set goals and monitor and modify the stage of progress towards those goals. Thus, successful self-regulation depends in part on the truthfulness (i.e., verification) of self-monitoring in relation to the performance of the targeted behavior rather than simply “logging” activity.

The Health Belief Model is founded on the idea that readiness to act and motivation are influenced by the patient’s beliefs surrounding susceptibility to the condition and their perceived benefits of avoiding it\(^20\). Therefore, a sedentary individual who is achieving suboptimal levels of physical activity will take action if they believe a sedentary lifestyle is harmful to their health; that being harmed by a sedentary lifestyle can happen to them; changing their behavior to increase physical activity will benefit them directly; increasing physical activity levels will have greater benefits than the barriers to physical activity themselves; and there is a cue to action to change.

The Health Belief Model is focused on motivation or intention (i.e., the extent to which one will invest effort to pursue an action)\(^16\), therefore, self-monitoring of physical activity can serve as a cue to action by seeing their current levels of physical activity are below the reference standard. Similarly, individuals who see that their BP is above optimal levels through self-monitoring, may take this information as a cue to action to decide if hypertension is harmful to their health and from there decide if behavior change will be of benefit to their perceived circumstances.
The integration of these health behavior constructs are summarized in Figure 2. Condition-specific self-monitoring of BP before and after an exercise session should enable individuals with hypertension to see PEH, and conclude BP is lower on exercise than non-exercise days. Self-monitoring both the behavior and outcome fosters positive outcome expectations that allow individuals to clearly link the activity (i.e., exercise) to the “reward” (i.e., lower BP\textsuperscript{17,18}, and enhance a person’s self-efficacy or confidence for exercise. Possessing positive outcome expectations and self-efficacy are important prerequisites for an individual to adopt and maintain a regular exercise program\textsuperscript{17,18,21}. Furthermore, the use of an immediate, condition-specific biometric outcome (i.e., PEH) can be a powerful motivator for behavior change given the consistency, and timeliness of the human tendency to engage in hyperbolic discounting, which is the preference for smaller, immediate rewards (i.e., lower BP as a result of PEH on a daily, immediate basis) over larger, future rewards (i.e., lower BP as a result of exercise training over months and years).
4.1.6 Selection and Justification of Measures of Integrated Social-Cognitive Predictors of Exercise

Before and after the study, participants were administered validated questionnaires to assess whether exercise or BP self-monitoring favorably modulated measures of integrated social-cognitive predictors of exercise that were informed by our theoretical model (Figure 2). Specifically, these measures included:

**Self-Efficacy for Exercise:** Two instruments were used to measure the two primary types of self-efficacy for exercise. The first was a measure of task self-efficacy that assesses an individual’s confidence to perform incrementally more challenging bouts of aerobic exercise\(^{21}\). This instrument has 10 questions in which participants rate their confidence for exercise on a scale from 0 to 100 and has been shown to be valid and reliable for use with adults\(^{23}\). Scores were averaged to calculate a task efficacy score. The second is a measure of barriers for self-efficacy\(^{24}\). This instrument, shown to be valid and reliable in adults\(^{25}\), is composed of 11 questions each depicting a barrier to exercise. Participants were asked how confident they were on a scale from 0 to 100 that they could exercise despite the barrier described in the question (e.g., how confident are you that you can exercise when you have a cold?). Scores were averaged to give a total exercise confidence score.

**Outcome Expectations for Exercise:** The Outcome Expectations for Exercise Scale reflects an individual’s beliefs about the outcomes associated with engaging in exercise\(^{26}\). This instrument is composed of 9 questions that participants rated on a 5 point scale from strongly agree to strongly disagree. Scores were averaged to give a total outcome expectations for exercise score\(^{26}\).

**Affective Responses to Exercise:** This instrument is a reliable and validated 12 question scale assessing three general categories of subjective responses to exercise stimuli: positive well-being (e.g., great), psychological distress (e.g., miserable), and fatigue (e.g., tired)\(^{27}\). For
each question on the scale, participants rated how strongly they were experiencing each feeling along a 7 point Likert scale ranging from 1 (not at all) to 7 (very much so).

*Intention to Exercise:* Overall exercise motivation and intention were assessed with two questions by Blanchard et al. 28: “I intend to attend my scheduled exercise classes”, rated on a 7 point scale from 1 strongly disagree to 7 strongly agree; and “My goal during my exercise program is to attend”, rated on a 7 point scale from 1 (some scheduled exercise classes) through 4 (most scheduled exercise classes) and through 7 (every scheduled exercise class). Response scores were averaged to obtain a composite index of intention to exercise, which has demonstrated good reliability and predictive validity for exercise adherence. 28

### 4.1.7 References


5.1.1. Discussion

The overall purpose of this dissertation was to examine the clinical utility of BP self-monitoring as a behavioral strategy to increase overall exercise adherence and lower BP among adults with hypertension. To achieve this purpose, 24 adults with hypertension underwent supervised, moderate intensity aerobic exercise training for 40-50 min/session 3 d/wk for 12 wk and were encouraged to exercise at home unsupervised ≥30 min/d for 1-2 d/wk. All participants self-monitored exercise using a traditional calendar recording method previously validated by our laboratory (EXERCISE), while participants randomized to EXERCISE+PEH also self-monitored BP daily and before and after exercise. We also sought to assess the feasibility (i.e., interest, acceptability, retention, and satisfaction) of EXERCISE and EXERCISE+PEH self-monitoring. This chapter serves as a synthesis and conclusion of the findings. It is organized in the following section format: overview of the specific aims and hypotheses and summary of relevant findings; discussion on the impact of our findings as they relate to the current state of the literature and our laboratory; and suggestions for future lines research.

5.2.1. Specific Aims, Hypotheses, and Relevant Findings
Primary Aim 1: To examine the efficacy of two different types of self-monitoring, traditional exercise self-monitoring (EXERCISE) and traditional exercise with BP self-monitoring (EXERCISE+PEH) to increase exercise adherence and improve BP control among adults with hypertension.

Hypothesis 1: EXERCISE+PEH self-monitoring will increase exercise adherence and improve BP control more than EXERCISE self-monitoring alone.

Relevant Findings: Consistent with our hypothesis, individuals in EXERCISE+PEH exercised ~1 d/wk for ~30 min more than individuals in EXERCISE, resulting in greater overall adherence to aerobic exercise training (107%) compared to EXERCISE (83%). At 4wk post exercise training follow up, adults in EXERCISE+PEH were still engaging in ~70% of their supervised exercise training volume compared to EXERCISE (33%). These volumes of exercise were even greater among those who were still maintaining self-monitoring of BP at home (45 min for 3.6 d/wk) compared to adults who were not (19 min for 1.2 d/wk). Both forms of self-monitoring resulted in BP reductions on the order of ~7.5/5 mmHg with EXERCISE+PEH lowering resting BP (SBP/DBP) by ~10/6 mmHg; reductions twice in magnitude than those seen in EXERCISE (~5/3.5 mmHg), though this difference did not achieve statistical significance.

Primary Aim 2: To assess the feasibility (i.e., interest, acceptability, retention, and satisfaction) of traditional exercise self-monitoring (EXERCISE) and traditional exercise plus BP self-monitoring (EXERCISE+PEH) to increase exercise adherence and improve BP control among adults with hypertension.

Hypothesis 2: Participants will find both types of self-monitoring interesting and acceptable. However, retention in and satisfaction with will be greater with EXERCISE+PEH than EXERCISE as evidenced by increased exercise adherence and improved BP control with EXERCISE+PEH than EXERCISE.
**Relevant Findings:** Consistent with our hypothesis, individuals in EXERCISE and EXERCISE+PEH found both types of self-monitoring interesting, helpful, relevant, easy, and recommendable. However, retention in and satisfaction were greater among individuals in EXERCISE+PEH than EXERCISE as evidenced by greater exercise adherence, intention to exercise, and self-reported exercise maintenance at 4wk follow-up.

5.3.1 *Impact of the Findings on the Current Literature*

*Contributions to Science at the University of Connecticut*

The present study adds to a long list of significant contributions that members and leaders of the Health and Fitness Research Laboratory (HFRL; PI: Pescatello) have made to the field of exercise science. Broadly, the underlying theme of a majority of these research contributions is to improve the clinical utility of exercise as a simple, inexpensive lifestyle therapy to prevent, treat, and manage a variety of chronic diseases and health conditions, particularly hypertension. The present study had the good fortune to be able to employ many tools, templates, and methods that were developed and rigorously tested by many researchers and students prior to PULSE (i.e., medical health screening, ambulatory/clinic BP assessment, cardiopulmonary stress testing, PEH responder determination, accelerometry, and the development of the exercise training program). Owing to these efforts, PULSE builds upon the knowledge derived from these studies and expands our research agenda to be the first study of its kind from the HFRL to apply and integrate evidence-based behavioral theory to an exercise training study design. This novel and exciting venture generated newly formed internal and external collaborations; mastery of new research tools and techniques (i.e., AHA ‘Check. Change. Control. Tracker®’, Polar V800® HR monitors, Polar Flow® software, Polar FT7® HR monitors, Omron HEM-705CP® BP monitors, lifestyle questionnaires, IRB approved subject instructions, reaction scripts, and qualitative assessment); and invaluable pilot data that will ultimately inform future external grant submissions.
Contributions to Existing Lines of Research: Exercise and Hypertension

The ACSM recommends that individuals with hypertension engage in moderate intensity (40-59% $\text{VO}_2 \text{R}$ or HRR; RPE 12-13 on a 6-20 scale), aerobic exercise training $\geq 30$ min/d, 5-7 d/wk, to total $\geq 150$ min/wk\(^1\). In the present study, participants engaged in $37.9 \pm 12.4$ min of moderate to vigorous (60.5±8.8 %HRR), aerobic exercise, 2.9±0.6 d/wk, for 12 wk. Of note, this FITT excludes warm up and cool down and represents a combination of both supervised and unsupervised aerobic exercise. While the frequency component is lower than the FITT recommendations for individuals with hypertension, this volume of exercise would be equivalent to meeting the recommendations for healthy adults (aerobic exercise training $\geq 30$ min, $\geq 5$d/wk to total $\geq 150$ min/wk; vigorous intensity (60-<90% $\text{VO}_2 \text{R}$ or HRR), aerobic exercise training $\geq 20$ min/d, $\geq 3$d/wk to total $\geq 75$ min/wk; or a combination of the two). These findings are consistent with emerging work published from our laboratory group that suggest more vigorous levels of exercise lower BP to greater levels than lower levels of physical exertion among adults with hypertension\(^2\). Nevertheless, this volume of exercise was more than sufficient to result in reductions of resting BP on the order of -7.5/-5 mmHg; reductions that are similar in magnitude to other studies in the literature\(^3\). Consistent with previous findings from the HFRL, baseline SBP explained ~50% of the variability in the change in laboratory SBP from baseline with individuals with baseline SBP $\geq 140$ mmHg experiencing reductions in laboratory SBP greater in magnitude (-14.9±5.2 mmHg) compared to individuals with baseline SBP <140 mmHg (-3.7±11.8 mmHg; p=0.019). Although there is heterogeneity in the chronic BP training response, this study demonstrates once again that reductions in BP appear to follow “law of initial values” with the most pronounced BP reductions occurring in individuals who stand to benefit the most (i.e., those with higher BP compared to normal BP)\(^4,5\).

One ancillary finding emerged from this study such that individuals with lower BMI experienced greater reductions in SBP following exercise training. Due to the nature of our pilot
study and the fact that it would ultimately be underpowered to examine weight loss as a covariate, we made the decision to have our sample be weight stable a priori. We are unable to speculate on this finding as there is limited research reporting that the BP reductions following aerobic exercise training among obese individuals with hypertension are independent of weight loss. However, the implications of these findings are significant, given that individuals who are overweight or obese are 2-2.5x more likely to have hypertension than individuals who are normal weight. Weight loss of as little as 1 kg corresponds to reductions in systolic BP of 1.2 mmHg and diastolic BP by 1.0 mmHg, and these reductions occur in a time and dose dependent manner.

Contributions to New Lines of Research: BP Self-Monitoring

In recent years, there has been growing support for the use of BP self-monitoring as a condition specific behavioral strategy to improve BP control among individuals with hypertension. Home BP self-monitoring alone results in clinically meaningful reductions in BP on the order of ~3 mmHg, and a recent large scale meta-analysis reported greater BP reductions (~6 mmHg) when BP self-monitoring is combined with a co-intervention (i.e., lifestyle coaching, medication titration) compared to self-monitoring alone. A recent large scale meta-regression examined the effectiveness of behavioral techniques to increase exercise participation and revealed that interventions that employed self-monitoring were significantly more effective than all other interventions. Notably, self-monitoring of BP among individuals with hypertension can improve BP control by promoting self-management of elevated BP. For example, McManus et al. randomized 480 patients with uncontrolled BP to either self-monitoring of BP with self-titration of antihypertensive drugs or standard care and reported patients that engaged in self-monitoring experienced significant reductions in BP (~17.6 mmHg) after 12 months compared to patients receiving usual care (~12.2 mmHg). Interestingly, to the best of our knowledge, this multifaceted approach had yet to be explored in combination with lifestyle interventions such as exercise prior to PULSE. This is surprising given that lifestyle modifications are considered the
first line of therapy for the prevention, treatment, and control of high BP. We have long suspected that patients with hypertension be made aware of PEH and instructed how to modulate its exercise effects\textsuperscript{1,13}. However, to the best of our knowledge, this is the first study designed to test the hypothesis that self-monitoring of BP may be an efficacious condition-specific behavioral strategy to increase exercise adherence among adults with hypertension.

5.4.1 Future Research

PULSE was a small, but rigorously designed pilot study which now establishes proof-of-concept to inform Phase-II or next step RCTs. As is the case with any high-quality study with novel findings, the results have “asked more questions than answered”. Summarized below is a prioritized list of logical future directions aimed to explore via several research questions that merit further investigation.

**Larger RCT:** These preliminary results are encouraging and warrant confirmation among a larger sample to determine whether increased exercise adherence owing to BP self-monitoring translates into improved BP control. Based upon our previous work with supervised training studies and that of the literature\textsuperscript{14,15}, a sample size of 49 subjects in each group would achieve 80% power to detect an effect size of $\delta=4.90$ mmHg with a significance level of 0.05.

**Longer RCT:** The present study examined exercise training adherence and BP outcomes following 12 wk supervised aerobic exercise training with a 4 wk follow up period. To determine long-term persistence would require more frequent follow up visits, maintenance of the TLFB log, and/or secure remote data transfer of patient-level data to the investigative team.

**Manipulation of FITT:** Recent research from our group indicates that various other exercise modalities may be as effective as aerobic exercise training as stand-alone antihypertensive lifestyle therapy among those with hypertension. Based on our findings, the influence of BP self-monitoring on exercise adherence and BP outcomes in response to a dynamic resistance
exercise\textsuperscript{16}, concurrent\textsuperscript{17}, and/or yoga (\textit{Wu Y, et al., In press}) training program would merit full investigation in the near future.

\textit{Non-Exercise Control Group}: Due to the already established BP lowering effects of aerobic exercise among individuals with hypertension, we employed an “active control” or comparator condition as opposed to a “placebo control” (i.e., non-exercise). This study design allowed us to examine the influence of BP self-monitoring (in combination with exercise self-monitoring) head-to-head with exercise self-monitoring alone. However, our laboratory group has previously reported that studies that employ an active control reduce the effectiveness of the exercise intervention being studied as the allocation to active control may be an intervention itself\textsuperscript{17}. For example, our recent meta-analysis on the influence of concurrent exercise training on BP among individuals with hypertension revealed that concurrent exercise training elicited BP reductions of \(~1\) mmHg when compared with the active content control groups and \(~5\) mmHg when compared with the non-exercise or wait-list control groups. Nevertheless, based on the model of inferiority, we can almost certainly assume that BP self-monitoring is at least as equally effective as exercise self-monitoring alone and provides proof-of-concept for a larger trial to first establish non-inferiority and then test superiority.

\textit{Inclusion of Co-Morbid Conditions}: Aerobic exercise is recognized as a “polypill” that serves as a mutual support of other lifestyle modifications that improve overall health. The present study excluded individuals with cardiovascular, metabolic, and/or pulmonary conditions. However, hypertension rarely occurs in isolation and 80\% of patients with hypertension have additional CVD risk factors\textsuperscript{18}. Patients with comorbid hypertension may exhibit different and possibly greater impacts of BP self-monitoring on multiple underlying CVD risk factors that were not assessed in the present study. Once assessed, the utility and generalizability of exercise and BP self-monitoring for improved exercise adherence and BP control may be extended to other chronic diseases or conditions. Nevertheless, the results of the present study are
promising and in support of both exercise and PEH self-monitoring for the reduction of resting BP among individuals who are apparently healthy other than their hypertension.

**Different Platform of Delivery:** Qualitative assessment indicated that individuals using BP self-monitoring were partial to receiving reassurance derived from regular BP assessment, medical oversight, and cue to action. Individuals in the present study were afforded supervised exercise training 3 d/wk by Master level Exercise Physiologists; weekly BP and exercise log reviews; and unlimited access to medical personnel in a hospital setting. However, such interventions are often costly, time intensive, and not reimbursable by insurance, highlighting the need for personalized self-management interventions that can be easily delivered by clinicians. In particular, telehealth monitoring or app-based mobile platforms could potentially circumnavigate these barriers.

**Million Dollar Study:** If I had all the money in the world (or at least ~$35,000), I would propose to replicate PULSE as an “e-supervised”, mobile exercise training study (mPULSE) to determine if our findings can be replicated in a real world, clinical scenario. Briefly, individuals with hypertension would be randomly assigned to an exercise self-monitoring (EXERCISE, n=50) or exercise plus BP self-monitoring (EXERCISE+BP, n=50) group (Figure 1). All subjects will receive an Apple watch to measure background physical activity and planned exercise 24 hr/d for 1 yr. Following a 2 wk familiarization and baseline physical activity collection period, all subjects will receive the ACSM exercise prescription for individuals with hypertension, 12 wk, progressive exercise training program. In the initial 12wk phase, participants will be e-supervised via weekly, web-based interactions, after which contact will be discontinued to assess long term maintenance. Additionally, subjects in the BP self-monitoring group will receive one baseline education session designed to properly instruct the subject on how to self-measure daily BP and PEH during a supervised, standardized exercise session and record it using the QardioArm BP monitor and Apple Watch Qardio App. Physical activity levels (i.e.,
daily non-exercise activity thermogenesis), planned exercise, resting HR, home BP, and clinic/laboratory BP will be measured before (on site visit), 12wk, 6mo (on site visit), and 1 yr (on site visit) time points to assess short and long term exercise adherence and BP outcomes.

Figure 1. Proposed Future Study Design for mPULSE

![Diagram showing study design]

Adults with Hypertension (n=100) → EXERCISE (n=50) → EXERCISE+BP (n=50)

Visit 1: Baseline BP and randomization
2 wk Apple Watch familiarization and baseline PA assessment
Educational exercise session to demonstrate and self-measure PEH
12 wk exercise training with e-supervision
*EXERCISE+BP only

Visit 2: 6mo BP
Visit 3: 12mo BP

5.5.1. Future Prioritized Research Questions from the PULSE Dataset

PULSE represents a labor-intensive, innovative, and successful RCT owing to the efforts of multiple dedicated collaborators across various disciplines, including the UConn Departments of Kinesiology, Psychological Sciences, Health and Human Services, and Statistics; Hartford Hospital Department of Cardiology; and University of Rhode Island Department of Kinesiology. As such, there remain several opportunities for subsequent analyses ripe for exploration. The below outlined research questions expand upon the well-established research agenda of the HFRL; the results of which may ultimately inform pending grant applications and research priorities in the near future.
1. Examine the reproducibility of PEH following 12wk aerobic exercise training.

*Rationale:* To the best of our knowledge, no study has explored the reproducibility of PEH before and after aerobic exercise training. It is estimated that ~20% of individuals do not demonstrate PEH. It is possible that patient level characteristics such as fitness (i.e., VO\textsubscript{2}\text{peak}) or exercise-training related reductions in BP moderate this clinical phenomenon and warrant investigation.

2. Examine the relationship between the BP response to a GEST and PEH among the total sample and among individuals treated and untreated for hypertension with antihypertensive therapy.

*Rationale:* The BP response to a GEST is an independent predictor for future incident hypertension\textsuperscript{19}. Individuals with normal BP that experience an exaggerated SBP response to maximal exercise are at a 2-4x heightened future risk of developing hypertension and CVD\textsuperscript{20,21}. Previous research of the lab group has shown that the peak systolic BP on a GEST may be used to characterize which men with hypertension will have decreased systolic BP after acute submaximal aerobic exercise\textsuperscript{22}. Recent research by Chant et al. has suggested that antihypertensive treatment fails to control BP during a GEST, suggesting an amplified pressor response to exercise among individuals taking medication, despite controlled resting BP\textsuperscript{23}. To the best of our knowledge, the association between peak SBP on a GEST and PEH among individuals taking antihypertensive medication has yet to be examined. Along these same lines, previous work of the lab group explored the influence of biomarkers such as a baseline vitamin D on the peak SBP to a GEST\textsuperscript{24}. While vitamin D was not assessed in PULSE, other novel clinical biomarkers (i.e., HRV) may provide additional insight into mechanisms underlying an exaggerated BP response to a GEST among individuals with hypertension.
3. Explore HRV before and after aerobic exercise training and the contribution of HRV to PEH.

*Rationale:* PEH is an established response to exercise, however, the mechanisms underlying this clinical phenomenon remain unclear. Recent results from study, *The Influence of Cardiorespiratory Fitness on Firefighter Cardiovascular Health Under Conditions of Heavy Physical Exertion (FIT and FIRED UP)* study examined the ambulatory BP and HRV responses following a GEST among firefighters and demonstrated these markers to be highly correlated (Chilorez B., et al., unpublished). It is well documented that exercise training improves cardiac rhythm regulation and HRV. However, whether exercise-induced improvements in HRV modulate PEH remain to be examined.

4. Examine the fidelity and reliability of PEH in the laboratory and at home.

*Rationale:* Two of the 10 individuals in EXERCISE+PEH did not engage in any additional unsupervised exercise or PEH self-monitoring before and after exercise at home. Nevertheless, the study design did account for this limitation by ensuring that individuals in EXERCISE+PEH assessed BP twice daily (am and pm) so that any acute influence of previous supervised exercise training sessions (i.e., last bout effect) should have been apparent throughout the study as PEH persists for ≥24 hr. However, it is unclear if home BP can discern between PEH on exercise days and transient increases in BP on non-exercise days. Further, it is unclear if PEH demonstrated in the laboratory under controlled conditions (GEST-Control) translates to PEH in the laboratory after supervised exercise training sessions and PEH at home after unsupervised exercise training sessions.

5. Compare the examine the influence of objective physical activity patterns via accelerometry (Actical® Physical Activity Monitor) on the BP response to a GEST compared to control.
Rationale: The contribution of daily physical activity patterns on acute ambulatory BP reductions following a GEST compared to control have yet to be reported on. Several studies have administered physical activity questionnaires (i.e. Paffenbarger, diary method), however, these measures are self-reported and crude estimates of physical activity. We hypothesize that physical activity patterns will be similar during control versus GEST and do not contribute to the PEH response to acute bout of exercise. The null hypothesis is that 24hr physical activity is lower following a GEST, which may explain lower BP values following PEH compared to control perhaps due to other non-physiological factors such as residual fatigue from a GEST that could be verified or ruled out with an accelerometer.

6. Examine the relationship between postexercise hypotension and the chronic blood pressure training response to a 12 wk aerobic exercise training program.

Rationale: PEH is an established physiological response to exercise. Most recently, there have been several studies to support the notion that the reductions in BP experienced immediately following acute exercise are similar in magnitude to those experienced after chronic aerobic exercise training; an observation that suggests the BP benefits attributed to exercise training are largely the result of PEH\textsuperscript{25-29}. As such, PEH is beginning to be recognized as a “window of opportunity” or screening tool to predict who is likely respond to aerobic exercise training and if so, of what magnitude\textsuperscript{30}. Thijs Vonk, Visiting Scholar from Radboud University Nijmegen, has begun this important analysis. However, there may be several smaller projects that do not serve the main manuscript well, but that may be useful for an Honor’s project in the near future.

5.6.1. Expanded Limitations

Approximately 20% of adults with hypertension do not elicit PEH for reasons that are unclear (i.e., PEH nonresponders)\textsuperscript{34}. The present study excluded PEH nonresponders through gold standard methodology (i.e., ambulatory BP assessment) and utilizing a study definition of PEH that was determined a priori (i.e., ABP following the GEST ≤2 mmHg compared to control).
Nevertheless, the possibility exists for the misclassification of PEH. Among individuals in EXERCISE+PEH that engaged in unsupervised aerobic exercise at home (n=10), individuals exhibited PEH (SBP≤2 mmHg lower after exercise compared to before) 85.2±21.4% of the time with an average BP (SBP/DBP) reduction of -9.0±6.9 / -4.7±5.2 mmHg (ranging from -19 to 2 mmHg) 10min following unsupervised aerobic exercise compared to 10min before (i.e., PEH; ps<0.019). While PEH at home occurred 86-100% of the time for 7 individuals, there were 3 (or 30%) individuals who demonstrated PEH at home only 50%, 50%, and 67% of the time; consistent with the literature³⁴ (Figure 2). Interestingly, individuals that demonstrated low frequency and/or magnitude of PEH at home did not appear to have adherence, BP outcomes, or qualitative feedback that differed from individuals with high frequency and/or magnitude of PEH begging the question, does the frequency and magnitude of PEH matter as much as PEH self-monitoring process itself?

Figure 2. Frequency of PEH Demonstrated at Home Before and After Unsupervised Exercise Among EXERCISE+PEH (n=10)
5.7.1 Conclusions

Hypertension is the most common, costly, and modifiable CVD risk factor in the U.S. and world. The ACSM and other major health organizations recommend that individuals with hypertension engage in ≥30min of moderate intensity aerobic exercise 5-7 d/wk\(^1\) on the basis that regular aerobic exercise leads to reductions in resting BP of 5-7 mmHg\(^1,31,32\). Nevertheless, a large majority of adults with hypertension fall short of these recommendations\(^33\), calling into importance the development of novel behavioral strategies aimed to increase exercise participation and adherence. This study is the first to demonstrate that using condition-specific BP self-monitoring used in combination with exercise self-monitoring is an efficacious behavioral strategy to improve exercise adherence among adults with hypertension. Most notably, exercise levels and BP reductions experienced among adults using exercise and BP self-monitoring were above and beyond those experienced by adults using exercise self-monitoring alone. Indeed, we found that adults with hypertension who self-monitored their BP, daily and before and after aerobic exercise, were ~24% more adherent to a 12 wk structured aerobic exercise training program than those who only used exercise self-monitoring alone. In addition, those adults using BP in addition to exercise self-monitoring maintained 37% more exercise at one month follow up than those who were not using BP self-monitoring. These preliminary results are intriguing and merit confirmation among a larger sample to determine whether increased exercise adherence owing to BP self-monitoring translates into improved BP control. If proven successful, self-management of hypertension through exercise and BP self-monitoring has the potential to have a substantial impact on the public health burden of CVD in the US, and world.

5.7.1 References


### 6.1.1 Appendices


#### 6.3.1 Appendix B: Phone Screen Questionnaire

**The Phone Screening Red Flags**

The purpose of the Phone Screening is to screen the qualifications of a potential subject for the study. When reviewing the Phone Screening look for the following that may be red flags that will either qualify the subject with permission from their primary care physician or disqualify the subject altogether:

**Medications**: Other than antihypertensive medications, any prescription medication that alters BP such as inhaled or oral steroids, nonsteroidal anti-inflammatory agents, aspirin, hyperlipidemic medications, nutritional supplements with the exception of a 1-a-day vitamin, cold medications, oral contraceptives that are in the bolus form (i.e., depo provera), and herbal supplements. Any such medication would have to be discontinued for the duration of the study (with physician approval) and may also need a washout period. PI will contact the subject’s physician to discuss as needed.

**Exercise Frequency**: Since the study inclusion criteria specify subjects must be sedentary to physically inactive, subjects exercising ≥2x/wk cannot be included.
**Orthopedic conditions:** Make sure that the subject does not have any condition that would prevent them from exercising.

**Chest pain and shortness of breath:** If these boxes are checked on the screening form, obtain more information from the subject because these could be signs of heart disease or angina.

**Caffeine and Alcohol consumption:** If the participants reports that he consumes more than 2 cups of coffee a day then inform him that he can only consume 2 cups a day for the duration of the study. Alcohol consumption greater than 2 drinks a day is a red flag and should be discussed with the subject and team members regarding further action.

**Pregnancy and/or irregular menstruation:** women who are pregnant cannot be included.

**Once the study investigator has reviewed the phone screener and has followed the screening protocol, the phone screener is forwarded to the principal investigator (PI). The PI will contact the primary care physician of the subject if need be, and then will make the final determination of study qualifications.**
Phone Screening Form

Technician Name: ______________________ Date of Screen: ______________

**FIRST READ THE FOLLOWING TO THE SUBJECT:**

'FOR YOUR INFORMATION PEOPLE WHO CONSUME 2 OR MORE ALCOHOLIC DRINKS PER DAY ARE NOT ELIGIBLE TO BE IN THIS STUDY. ALSO, PEOPLE WHO HAVE USED COCAINE, MARIJUANA, AMPHETAMINES, OR OTHER ILLICIT DRUGS IN THE LAST 6 MONTHS ARE NOT ELIGIBLE TO BE IN THIS STUDY.'

1.) What is your age?
   If < 21 → Go to ☺
   If ≥21 years → Go to Q2
   DOB: _________________________

2.) What is your gender?
   ☐ Male
   ☐ Female

3.) What is your height? ____ft, ____in

4.) What is your weight? _________lbs.

5.) Calculate BMI: ______________kg/m²

6.) What is your blood pressure?
   ☐ Normal (ie, SBP≤120 and DBP≤80mmHg) →
       Go to ☺
   ☐ Elevated (ie, SBP≥120-159 and/or DBP≥80-99mmHg) → Go to Q7
   ☐ High (ie, SBP≥160 and/or DBP≥100mmHg) → Go to ☺☺

7.) Do you smoke?
   ☐ Yes → Go to ☺
   ☐ No → Have you ever smoked_________________________
       If smoked in past 6 months→ Go to ☺
       If not smoked in past 6 months→ Go to Q8

8.) How many times did you exercise in the past 2 months? __________
   ☐ ≥15 → Go to ☺
   ☐ ≤15 → Go to Q9

9.) How much caffeine do you drink on a daily basis?
    ____________________________
    ☐ ≥2 cups of coffee → Note that you can drink a maximum of 2 cups/day of coffee or the equivalent while in this study

10.) Are you currently taking blood pressure-lowering medication or have you been treated for high blood pressure in the past?
    ☐ Yes → describe_________________________
        ☐ NO → Go to Q11

11.) Have you ever been diagnosed with a metabolic disease (such as diabetes or thyroid problems)?
    ☐ Yes → Go to ☺
    ☐ No → Go to Q12

12.) Have you ever been diagnosed with asthma or any other pulmonary or respiratory disease?
    ☐ Yes → describe_________________________
        ☐ NO → Go to Q13

13.) Do you suffer from depression?
    ☐ Yes → Go to ☺
    ☐ No → Go to Q14

14.) Have you ever been diagnosed with any chronic diseases or illnesses?
    ☐ Yes → list condition, continue screening and get PI approval
    ☐ NO → Go to Q15

15.) Do you routinely take medications or supplements for any reason? (refer to medication list on cover page)
    ☐ Yes → list med AND condition, go to Q16 or ☺
    ☐ NO → Go to Q16
16.) Do you have any heart conditions that require medications or restriction of activity? (i.e. stroke, MI, diagnosed CAD)
   □ Yes → Go to ☺
   □ No → Go to Q17

17.) Have you had any injuries or surgeries on your back, hips, knees, or ankles that would prevent you from safely exercising?
   □ Yes → describe__________________________________________
   **if too severe and limiting, go to ☺
   □ NO → Go to Q18

18.) Have you had cancer within the last 5 years?
   □ Yes → Go to ☺
   □ No → Go to Q19

19.) Have you ever had liver or kidney disease?
   □ Yes → Go to ☺
   □ No → Go to Q20

20.) Women only: What form of birth control do you currently use?
   □ Deproprovera or “bolus” type contraceptive → Go to ☺
   □ None or daily hormone altering contraceptive → Go to Q21

21.) Women only: Have you been menstruating regularly for the past year?
   □ Yes → Go to Q23
   □ No →
   describe__________________________________________
   ____________________________________________

22.) Women only: Are you pregnant or planning to become pregnant in the next 3 months?
   □ Yes → Go to ☺
   □ No → Go to Q24

23.) Have you ever fainted or felt light-headed while having blood drawn? Has anyone ever had a hard time drawing your blood?
   □ Yes → Go to Q25 (“FYI” for site staff only)
   □ No → Go to Q25

24.) Does this caller meet all criteria for participation?
   □ Yes → Go to ☺
   □ No → Go to ☺

☺ = “Thank you for your interest in the study, but unfortunately you do not qualify.”
☺☺= “Thank you for your interest in the study, but unfortunately you do not qualify. We strongly recommend you make sure you are seeing a physician regarding treatment for your high blood pressure.”
☺☺☺ = “It looks like you would be a good candidate for this study. Let me tell you a little more about it.”

“If you are serious about participating in this study, we would like to invite you to come to our office at the University of Connecticut or Hartford Hospital for an interview. Would you like to do this?”
   □ No → Thank you for your interest.
   □ Yes → Continue below:

   Name _________________________________________
   Primary Phone#_________________________________
   Alternate Phone#_______________________________
   Email _________________________________________
   How did you hear about the study?_____________________
   Visit 1 Scheduled: ______________________________
Description of Study:

In this study called PULSE we are examining the influence of exercise training on blood pressure in adults with high blood pressure using two types of self-monitoring of the amount you exercise and your blood pressure before and after exercise. The study involves four visits to Hartford Hospital and a 3 month exercise training program that will take a total of about 4 months to complete. The four visits to Hartford Hospital will last 1-3 hours. The supervised aerobic exercise training program will be conducted at Hartford Hospital for 3 days per week for 40-50 minutes per exercise session for 12 weeks. In addition, you will also be encouraged to exercise at home for 30 minutes or more 1-2 days per week which can involve primarily walking. After three of the visits at Hartford Hospital you will be asked to wear a blood pressure and heart rate monitor that will record your blood pressure and heart rate until the following morning. If you qualify and are interested in participating, we will ask you to attend an orientation session to explain the details of the study. Upon completion of the study you will be paid up to $100 to compensate you for your time and travel.