# THE ASSOCIATION OF OBJECTIVELY MEASURED PHYSICAL ACTIVITY ON BLOOD PRESSURE AND THE PREVALENCE OF HYPERTENSION IN AFRICAN ANCESTRY MEN

by

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**THE ASSOCIATION OF OBJECTIVELY MEASURED PHYSICAL ACTIVITY ON BLOOD PRESSURE AND THE PREVALENCE OF HYPERTENSION IN AFRICAN ANCESTRY MEN**

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## ABSTRACT

**Background**: Hypertension is a causal risk factor for cardiovascular disease and accounts for 7.5 million deaths per year, globally, with disproportionately high rates in African ancestry populations. This study aimed to test the association of duration and intensity of objectively measured physical activity with blood pressure and prevalent hypertension in a sample of 310 Afro-Caribbean men.

**Methods**: Men for this study were from the Tobago Health Study and aged 50-89 years (mean 63 years). Systolic and diastolic blood pressures (SBP and DBP, respectively) were measured using an automated cuff, and hypertension was defined as SBP ≥ 140 mmHg, DBP ≥ 90 mmHg, or current use of antihypertensive medication. Physical activity was measured using the SenseWear Pro armband (SWA) worn at home for 4-7 days. We calculated daily step count and duration of waking time engaged in sedentary behavior (SB), light physical activity (LPA), and moderate to vigorous activity (MVPA). Multiple linear or logistic regressions were used to test for associations using the isotemporal substitution framework. Models were adjusted for SWA wear time, age, hypertension medication, alcohol consumption, smoking, comorbidities, family history of hypertension, and salt intake, and, additionally, for adiposity.

**Results**: Compared to SB, greater time spent engaged in LPA was associated with lower SBP adjusted for wear time ($p<0.05$), but this was attenuated after adjustment for age. Compared to SB, greater time spent engaged in LPA was associated with lower DBP and lower odds of hypertension, adjusted for wear time and age ($p<0.05$ for both). In unmedicated men, results for SBP and DBP were similar, but were also significant after adjustment for adiposity ($p<0.05$ for both). Greater step count was associated with lower odds of hypertension after full adjustment ($p<0.05$), but not after further adjustment for adiposity.

**Conclusions**: Replacing sedentary time with light activity was associated with lower blood pressures and odds of hypertension in older Afro-Caribbean men. The results are important to public health, adding evidence that increased physical activity could be beneficial in blood pressure management in this population.

## TABLE OF CONTENTS

## LIST OF TABLES

## PREFACE

I’d first like to thank the principal investigators, staff, and participants of the Tobago Health Study, whose hard work and cooperation made this research possible. I’d also like to thank my committee members, Drs. Bethany Barone Gibbs and Iva Miljkovic, whose insight, experience, suggestions, and feedback taught me so much and added so much value to this thesis. Finally, I’d like to extend a special thank you to my academic advisor and committee chair, Dr. Allison Kuipers, who helped me and taught me so much throughout the entire process, and constantly pushed me to write the best and most complete thesis I could. After working together for seven years, I still learn from Dr. Kuipers every day, and I look forward to working with her, as well as Drs. Barone Gibbs and Miljkovic, in the future.

# 1.0 INTRODUCTION

Hypertension is a chronic disease that is rapidly becoming one of the most common afflictions around the world.[1] Nicknamed the "silent killer" because it often presents no symptoms, it can damage a person's heart, kidneys, blood vessels, and brain.[2] It is associated with increased risk of many other cardiovascular diseases, and is a risk factor for metabolic diseases, such as diabetes and obesity, as well.[2]

While prevalence rates of hypertension are high among all races and ethnicities (40% globally[3]), they are disproportionately high in African ancestry populations.[1,4,5] It is unclear what is driving this difference, though hypotheses range from environmental effects, to lifestyle habits, to genetic factors.[6-10] African ancestry men and women have some of the highest rates of hypertension of any race/ethnicity in the global population,[5] as well as in all individual global regions.[4]

One possible lifestyle factor underlying the high global hypertension prevalence is the growing trend toward a more inactive lifestyle among people all over the world.[11] Researchers have consistently found a link between a lack of exercise and greatly increased risks of obesity, diabetes, and hypertension.[12-15] Physical activity is a modifiable lifestyle factor, and it is possible that even a modest increase in light activity could improve the quality of many lives and decrease the risk of morbidity and mortality by reducing the hypertension burden.

In this thesis, we will describe hypertension and the negative health outcomes associated with it. We will also review both risk and protective factors, such as lifestyle behaviors, race, and physical activity. Finally, we will outline the current study based on data from the Tobago Health Study, present the results, and discuss their significance and our conclusions.

# 2.0 HYPERTENSION

## 2.1 OVERVIEW

Hypertension, also known as high blood pressure, is a chronic disease defined by the force exerted by the blood against the vessel walls being too high over an extended period of time.[16] The heart pumps oxygenated blood through the circulatory system to tissues and organs throughout the body. As the heart pumps, it creates pressure that pushes the blood through arteries, capillaries, and veins.[2] Blood pressure is measured as two forces, first when the blood is pumped out of the heart and into the arteries: the systolic blood pressure (SBP); and, second, when the heart is at rest between beats: the diastolic pressure (DBP).[16] The tone and function of the vasculature directly impact pressure, as greater endothelial function allows the vessels to stretch and pressure to decrease[17]. Certain substances in the blood are involved in the regulation of this function, specifically nitric oxide (NO) and nitrogen dioxide ($NO_2$).[18] Hypertension is often referred to as the silent killer because it is a generally asymptomatic disease that silently damages the blood vessels, heart, brain, and kidneys if left untreated[2].

About 90% of cases of hypertension are termed "primary hypertension," because a single reversible cause cannot be identified.[2] In most patients with primary hypertension, however, identifiable behavioral factors contribute to the elevated blood pressure, and the most common modifiable behaviors are smoking, poor diet, and lack of exercise.[2] Since, at the systemic level, hypertension can result from functional defects of vasoconstriction/vasodilation and renal sodium retention/excretion,[2] lifestyle behaviors that can influence these pathways, like physical activity and sodium intake, are major targets for hypertension interventions.[2]

## 2.2 HYPERTENSION DEFINITION AND EPIDEMIOLOGY

The Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure (JNC7), which was published in 2003, established guidelines for defining new onset hypertension as consistent measurement of either SBP $\geq$ 140 mmHg or DBP $\geq$ 90 mmHg.[19] However in 2017, after recognizing the vascular impact of moderate blood pressures, the American Heart Association and American College of Cardiology announced new recommendations for the definition and treatment of hypertension. These guidelines call for four blood pressure categories, Normal, Elevated, Stage 1 Hypertension, and Stage 2 Hypertension. Stage 1 Hypertension lowers the blood pressure threshold for the diagnosis of hypertension to 130 mmHg for SBP or 80 mmHg for DBP.[20]

Hypertension is a causal risk factor for many cardiovascular diseases, which are the number one cause of death in the U.S., accounting for about ⅓ of all deaths.[1] The AHA estimates that about 92 million American adults, about 37%, are living with some form of cardiovascular disease, and the prevalence is greatest in Blacks with 47.7% of Black females and 46.0% of Black males having some form of cardiovascular disease.[1] The direct and indirect costs of cardiovascular diseases in the U.S. total nearly $300 million and are projected to increase to nearly $750 million by 2035.[1] Internationally, the World Health Report of 2008 estimated that high blood pressure caused 7.5 million deaths annually, accounting for 12.8% of all deaths.[4] It also accounted for 57 million disability-adjusted life years (DALYs) - 3.7% of all DALYs – an indicator of the global disease burden. It is estimated that the global prevalence of hypertension was nearly 1 billion in 2008, with the highest prevalence found in the African region, where it was 46%, as well as in all low-income countries.[4]

In the Caribbean, the prevalence of hypertension in 2007 was estimated to be 26% in populations aged 25 and older, and as high as 55% in populations aged 40 and older.[21] Statistics from the Caribbean Epidemiology Centre illustrate that hypertension was the 5$^{th}$ leading cause of death in 2000.[21] Additionally, three of the four leading causes of death were cerebrovascular disease, heart failure, and ischemic heart disease, which are known complications of hypertension.[21] With an enormous burden on global health, it is increasingly important that we find new ways of preventing and lowering the burden of high blood pressure that are accessible and beneficial to all people. A summary of independent Caribbean countries' demographics and rates of hypertension is presented in Table 1. These data demonstrate that the rates of hypertension in the Caribbean may not solely be tied to their racial demographics.

**Table 1. Race and Hypertension (HTN) Prevalence by Caribbean Nation, for Ages 30-70, Sorted by Descending HTN Prevalence**

| Country | % Black[22] | % HTN[23] |
|---|---|---|
| Dominica* | 86.6 | 38.5 |
| Barbados | 92.4 | 33.2 |
| Cuba | 9.3 | 33.0 |
| Grenada | 82.4 | 30.7 |
| St. Lucia | 85.3 | 30.5 |
| Dominican Republic | 15.8 | 29.9 |
| Jamaica | 92.1 | 29.5 |
| Trinidad and Tobago | 34.2 | 29.4 |
| St. Vincent and the Grenadines | 66.0 | 28.8 |
| Haiti | 95.0 | 27.2 |

*Race data were obtained from most recent individual census reports (2010-2011), hypertension prevalence was obtained from WHO's Noncommunicable Disease Report 2014.[22,23]*
**Latest Dominica race data from 2001*

## 2.3 RISK FACTORS OF HIGH BLOOD PRESSURE

A number of risk factors have been identified for hypertension. With increasing age, there is a continuous increase in blood pressure, specifically SBP.[24] Also, overall, males have a higher prevalence of hypertension than females throughout the world.[4] Smoking is a significant predictor of hypertension conferring up to 3 times increased risk of hypertension to smokers compared to non-smokers.[25,26] Blood pressure is also consistently higher in obese people compared to normal weight people [27-29] and obese people are at about 4 times increased risk of incident hypertension compared to normal weight individuals.[29-31] Family history of hypertension has also been found to be a significant risk factor of the disease, [32] suggesting that genetic pre-disposition may play a role in the development of hypertension. While age, sex, and genetic pre-disposition are non-modifiable risk factors, they allow us to assess each individual's risk of hypertension and are clinically important factors.

Race/ethnicity is also a significant risk factor for hypertension, with people of African ancestry having some of the highest rates of hypertension in the world.[1,4,5,20,21] However, there is no consensus on the reason for this racial/ethnic disparity. Some studies point to the impact of differences in environmental factors, such as socioeconomic status, diet, and health behaviors.[6,7,10] Other studies have identified potential genetic differences, in which specific genes known to be more commonly carried by Blacks are associated with higher renal retention of sodium and other pathways underlying hypertension.[8,9] While the specific cause of this racial/ethnic difference is unknown, it is clear that hypertension is a grave concern for African ancestry populations and, as such, research targeted to these high-risk populations is needed.

In addition to age, demographics, smoking, obesity, and genetics, diet contributes to a range of factors that are known to influence blood pressure. A positive association between cholesterol in the blood and blood pressure has been reported in several populations.[33-35] Glucose intake contributes to diabetes, which is a risk factor of hypertension due to the disease's effect on the kidneys.[36-38] However, the dietary factor with the largest impact on blood pressure is sodium intake.[39] Sodium ions are necessary for muscle contractions, including contraction of the blood vessels, which directly influences blood pressure. Too much sodium can lead to increased contraction of the vessels.[39] A meta-analysis of 50 studies found that a 1.8 g reduction in daily salt intake was associated with an average reduction in blood pressure of 5.0/2.7 mmHg in hypertensives and 2.0/1.0 mmHg in non-hypertensives,[40] suggesting that lowering salt intake should be considered as a lifestyle modification to control blood pressure, and that the impact of sodium should be considered in future research studies.

# 3.0 PHYSICAL ACTIVITY AS A PROTECTIVE FACTOR

## 3.1 OVERVIEW

It was not until relatively recently in the human timeline that physical activity became a planned phenomenon rather than a means of survival. Technology has changed the way humans live and has reduced the requirement for being physically active. Human genes were selected to optimize aerobic metabolic pathways and conserve energy, and this recent change in lifestyle behaviors has led, in part, to the increase in chronic diseases.[11]

As such, many clinical trials have attempted to increase planned physical activity, e.g., exercise, in order to improve health. There are two main recognized forms of exercise, aerobic exercise and resistance training, and there is evidence that their effects on cardiovascular health vary.[41-47] Exercise programs involving aerobic endurance training in adults with normal or elevated blood pressure have been shown to prevent the development of hypertension, with the greatest effect in those with elevated blood pressure.[47] Additionally, lower extremity focused aerobic exercise has been found to lower SBP by 7 mmHg and DBP by 6 mmHg in randomized control trials.[45] On the other hand, clinical trials including resistance exercise have produced mixed results, with many studies showing benefits to overall blood pressure;[41,43,46] yet, others showed negative effects on arterial stiffness, a consequence of elevated blood pressure.[42-44]

Understanding the effects of these different types of exercise is important for outlining lifestyle change recommendations to combat the rising rates of hypertension.

Mechanistically, the benefits on blood pressure derived from physical activity are most likely due to increases in nitric oxide (NO) and nitrogen dioxide ($NO_2$).[18] Beck et al. in 2013 observed that after both endurance and resistance interventions, levels of NO and $NO_2$ increased.[18] They also observed that prehypertensives showed significantly lower baseline levels of NO and $NO_2$ than normotensives.[18] Green et al. in 2004 reported similar findings, and suggested that the increases in nitric oxide are due to a homeostatic response to the shear stress caused by exercise.[17] They concluded that increased levels of NO are associated with improved endothelial function, which allows blood vessels to stretch and blood pressure to decrease.[17]

While any exercise may result in upregulation of NO, some studies have found that resistance training is associated with lower central arterial compliance, or increased arterial stiffening.[48] While the cause is not yet clear, some hypotheses exist. One hypothesis by Dobrin et al. is that extremely high blood pressure (as high as 320/250 mmHg) during bouts of high-intensity resistance training could alter arterial structure or arterial load-bearing properties of collagen and elastin, causing stiffer vessels.[48] Another hypothesis by Failla et al. states that increased nervous system activity may act to reduce arterial compliance by placing chronic restraint on the arterial wall.[49] These mechanisms are important to consider when studying physical activity and blood pressure.

## 3.2 TEMPORALITY OF THE EFFECT

The earliest known publication to report the protective effects of physical activity in hypertension prevention was written in 1968 by Paffenbarger et al. This study demonstrated that men who reported exercising more than 5 hours per week had a lower incidence of hypertension 20-30 years later in life.[15] Since then, many studies have been conducted and, in general, have reported results consistent with this pioneering publication. A synopsis of the existing literature on this topic is presented in the following paragraphs.

The temporality of physical activity's effects on hypertension and overall blood pressure has been studied to establish a cause and effect relationship. The first interventional study to explore this was published in 1970 by Boyer and Kasch, who demonstrated that an aerobic training program 2 days per week resulted in a longitudinal reduction in blood pressure in both hypertensive and normotensive men.[50] A narrative review on the temporal effect of physical activity on blood pressure was conducted by Börjesson et al in 2016. The review consisted of 27 randomized clinical trials for a total of 1480 hypertensive participants, and the intervention in each was regular moderate-to-vigorous physical activity. The authors found the intervention to be associated with an average decrease in blood pressure of 11 mmHg for SBP and 5 mmHg for DBP.[12] Similar results were found by several other studies that did not limit their participants to hypertensives.[50-52]

Longitudinal changes in fitness and fat have been found to have an association with the development of hypertension, as well. A study of South Korean men found that subjects whose cardiorespiratory fitness, measured as peak oxygen uptake, decreased over 5 years had a 72% increased risk of hypertension compared to subjects whose fitness level increased.[53] Similarly, a study of American adults of both sexes found that maintaining or improving cardiorespiratory fitness was associated with a lower risk of incident hypertension.[54] In the same study, increasing BMI and percent body fat, generally considered to be partially resulting from too little physical activity, were associated with greater risk of incident hypertension.[54]

## 3.3 DOSE-RESPONSE EFFECTS

Several studies have been conducted to investigate whether a dose-response relationship exists between increased physical activity and blood pressure reduction, but the results are not completely clear.[51,52,55] In this research, the "dose" of physical activity could refer to duration or intensity and there are studies that investigate each. In a study using NHANES data on children and adolescents, Mark et al. in 2008 found a significant inverse association between any physical activity and blood pressure and hypertension, but the dose-response effect of duration was small in non-sedentary participants.[51]

Similarly, Jennings et al., who in 1991 conducted a randomized study of equal intensity but varying duration in sedentary adults, found that the impact of the activity intervention resulted in a similar lowering of blood pressure (~10mmHg SBP and 7mmHg DBP) regardless of duration.[52] These results highlight that while regular exercise is important for overall health and cardiorespiratory fitness, blood pressure may benefit from even a small duration of any activity compared to a sedentary lifestyle.

In a study of the intensity dose-response effect, Shephard in 2001 conducted a systematic review of more than 200 physical activity studies related to many different health outcomes. He found agreement among studies that light-to-moderate intensity of aerobic activity was an appropriate minimal recommendation to improve population health,[55] and light-to-moderate activity is most effective in motivating sedentary individuals.[55] He also found that higher intensity activity was additionally beneficial for overall fitness by increasing lean mass and a person's ability to continue exercise.[55] However, he concluded that exercise-induced reduction of blood pressure seems to be independent of intensity, again suggesting that simply increasing light activity may be adequate in reducing blood pressure.[55]

## 3.4 EPIDEMIOLOGIC RESEARCH

In addition to effects on blood pressure and hypertension, population-based epidemiologic research has also focused on specific measurable components of aerobic physical activity and their impact on cardiometabolic health. These components can be measured using activity monitors that track acceleration, skin temperature, and heart rate, and provide accurate and objective data.[56,57] Increased step counts measured by pedometer have been associated with beneficial effects on many cardiometabolic indicators, including BMI, HbA1C, HOMA-IR, and intermuscular fat.[13,58] Total daily duration of both light physical activity (LPA, examples including light walking and household chores[59]) and moderate-to-vigorous physical activity (MVPA, examples including stair climbing, cycling, and running[59]) have shown favorable associations with insulin resistance, waist circumference, and lipid profiles,[13,14,60] with the greatest benefits seen in persons at greater risk of metabolic disease, such as prediabetics.[61] Sedentary time has also been repeatedly shown to be associated with negative cardiometabolic outcomes, such as greater LDL,[62] greater insulin resistance, triglycerides, waist circumference, and blood pressure,[61] and comorbidities such as obesity, diabetes, dyslipidemia, and hypertension.[14] However, the reliance on activity monitors in epidemiologic research means that resistance training is generally not considered in large scale studies.

Few studies have been conducted to study the effect of physical activity on blood pressure and hypertension in Black populations. A review published in 2006 only found 3 studies that studied the association between physical activity and incident hypertension in African Americans, and none of them produced a statistically significant association.[63] More recently, Diaz et al in 2017 reported a significant dose-response relation (p=0.032 for trend) between self-reported activity and incident hypertension in African Americans, with more active participants at lower odds of developing hypertension.[64] Hamer et al in 2017 studied objectively measured physical activity in a mixed ethnicity cohort of school teachers in Africa and found LPA was associated with lower blood pressure in a cross-sectional study.[65] These studies illustrate some similar findings to what has been seen in other populations, but are limited in their ascertainment of physical activity and their studied populations.

# 4.0 PURPOSE AND HYPOTHESIS

Taken together, the existing epidemiologic literature suggests that physical activity, even LPA, is important for maintaining healthy blood pressure levels and lowering risk of hypertension and future cardiovascular disease. However, there are many components of this hypothesis that remain to be clarified. Is activity the driving force behind this association, or is sedentary time? The available literature demonstrates that physical activity is a known protective factor and modifiable behavior, with evidence of benefits to many populations. However, these benefits have not been demonstrated in a population of primarily African ancestry, the subset of individuals at greatest risk for hypertensive disease and its complications. We know that there are different medication recommendations for Blacks based on their risk,[66] so perhaps a more tailored set of physical activity guidelines would provide an additional blood pressure reduction benefit, as well.

The Tobago Health Study is a unique longitudinal cohort study comprised of men of predominantly African ancestry from the island of Tobago. Table 2 illustrates the preliminary comparison of physical activity between Tobagonian men and similarly aged African American men from the MrOS study. Of note, we found that even though Tobagonian men recorded fewer steps and less time in more vigorous activity than African American men, they had nearly four-fold greater time spent in LPA, on average. Considering much of the literature has shown that even LPA has beneficial health effects compared to sedentary time, as we have shown above, the

Tobago Health Study is an ideal cohort to attempt to define the physical activity parameters most strongly associated with blood pressure and hypertension among high-risk Black individuals.

**Table 2. Comparison of Physical Activity Between Tobagonian Men and American Black Men**

| | Tobago Health Study Men (Aged 70+, N=79) | | MrOS Black Men (Aged 70+, N=96) | | p-value |
|---|---|---|---|---|---|
| | Mean | Std Dev | Mean | Std Dev | |
| Age | 75.0 | 4.7 | 77.1 | 4.5 | **0.0002** |
| Steps per Day | 3373.2 | 2344.1 | 4300.7 | 3045.8 | 0.0506 |
| Percent Sedentary (<1.5 METs, less sleep) | 75.4 | 12.4 | 86.9 | 9.4 | **<.0001** |
| Percent Light Activity (1.5-3.0 METs) | 21.6 | 11.2 | 6.2 | 3.5 | **<.0001** |
| Percent Moderate Activity (3.0-6.0 METs) | 2.7 | 2.7 | 6.4 | 6.0 | **<.0001** |
| Percent Vigorous Activity (6.0+ METs) | 0.2 | 0.5 | 0.5 | 1.0 | **<.0001** |
| Percent MVPA (3.0+ METs) | 2.9 | 3.0 | 6.9 | 6.5 | **<.0001** |

MET: Metabolic Equivalency of Task (1 kcal/kg/hour)[67]

We hypothesize that in our cohort of Afro-Caribbean adult men, greater time spent engaged in physical activity compared to non-sleeping sedentary time will be associated with lower SBP and DBP and prevalence of hypertension. We hypothesize that this will be true even after taking into consideration age, BMI, waist circumference, personal and family history of cardiovascular disease, diabetes, smoking status, alcohol consumption, and medication use. In secondary analyses, we will also explore the associations of step count and moderate-to-vigorous activity (MVPA) with blood pressure.

# 5.0 METHODS

## 5.1 TOBAGO HEALTH STUDY

Between 1997 and 2003, 3,170 previously unscreened men aged 40-79 were recruited for a population-based prostate cancer screening study on the Caribbean island of Tobago, Trinidad and Tobago.[68] To be eligible, men had to be ambulatory, noninstitutionalized, and not terminally ill. Recruitment for the survey was accomplished by flyers, public service announcements, and posters, informing health care workers at local hospitals and health centers, and word of mouth. Approximately 60% of all age-eligible men on the island participated, and participation was similar across the island parishes.[69] Participants from the Tobago Health Study are of homogenous African ancestry with low European admixture (<6%).[70] Between 2014 and 2016, 856 men were recruited for a follow-up clinic examination. About halfway through recruitment, the study added collection of armband based accelerometry data to objectively measure physical activity in these men. This is the basis of the current study, which includes 391 men with accelerometry and blood pressure data. The Institutional Review Boards of the University of Pittsburgh and the Tobago Ministry of Health and Social Services approved this study. All participants provided written informed consent before data collection.

## 5.2 PHYSICAL ACTIVITY DATA

Men were instructed to wear the SenseWear Pro Armband (SWA; BodyMedia, Inc., Pittsburgh, PA, USA) at all times, except when bathing or in water, for 4-7 days. The SWA was worn on the upper arm over the triceps muscle, and it measures acceleration, heat flux, skin temperature, and galvanic skin response.[71] Objective activity data were calculated using these measurements combined with user-entered data, such as age, sex, height, and weight, and recorded in one-minute epochs.[71] The calculations come from proprietary algorithms in the SenseWear software, which have been validated for measuring energy expenditure in a free-living environment against the gold standard, doubly-labeled water method (intraclass correlation coefficient = 0.80).[56] In sedentary behavior (SB) and LPA, the SWA had an even higher correlation with energy expenditure as measured by indirect calorimetry.[57] This is especially important for our population, who are older adults and engage mostly in LPA.

## 5.3 BLOOD PRESSURE MEASUREMENTS

Blood pressure readings were taken three times at the study visit using an automated blood pressure cuff (HEM705CP; Omron Healthcare, Inc, Vernon Hills, IL) while the participant was sitting and after 10 minutes of rest. The average of the 2$^{nd}$ and 3$^{rd}$ readings was used to determine mean SBP and DBP. Antihypertensive medication use was ascertained by self-report, as well as classification of all of a participant's current medications, which were brought to the study visit. Hypertension was defined as SBP $\geq$ 140 mmHg, DBP $\geq$ 90 mmHg, or current use of antihypertension medication.

## 5.4 OTHER TOBAGO DATA SOURCES

Standing height and waist circumference (WC) were measured twice using a wall-mounted stadiometer and flexible tape, respectively, and averaged to the nearest 0.1 cm. Weight was measured to the nearest 0.1 kg using a balance beam scale. Body mass index (BMI) was calculated as the ratio of weight to height squared ($kg/m^2$).

Standardized interviewer-administered questionnaires were used to collect demographic, health history, family history, and lifestyle information. Smoking was defined as current, former or never smokers. Former smokers were defined as men who had previously smoked more than 100 cigarettes, but are not currently smoking. Regular alcohol consumption was defined as drinking 4 or more drinks per week over the previous 12 months. Diabetes was defined using serum glucose levels (≥126 mg/dl) and/or diabetic medication use. Other prevalent comorbidities including cardiovascular disease, cancer, and kidney disease were self-reported. Diet was assessed using a food-frequency questionnaire with specific nutritional intake, including sodium (mg/day), being estimated for each food consumed.

Participants were also instructed to bring their current medication bottles. Each medication was recorded by the study interviewer and further classified using the WHO's ATC/DDD drug classification system (the Anatomical, Therapeutic, Chemical classification system with Defined Daily Doses)[72]. For this analysis, we will use information on medications for hypertension, diabetes and lipid modification.

## 5.5 STATISTICAL ANALYSIS

Data from the SWA were considered to be usable if the participant wore the armband for 10 waking hours of a given day, with sleep status determined by the SWA. Men were required to have usable data for 4 days to be included in the analysis. We examined the distribution of each physical activity variable for normality and outliers, and transformed the data as necessary. We tested differences in population characteristics by inclusion or hypertension status using two sample t-tests or Wilcoxon rank sum tests for continuous variables, as appropriate, and chi-square tests for categorical variables.

Because time is finite, time spent by an individual in one level of activity reduces the amount of time available for other levels of activity. To study the effects of time spent in different intensity levels of activity, we used the isotemporal substitution framework, an analytic technique created to study the effect of substituting one activity level for another. This method models each specific activity level, as well as the other levels they are displacing, controlling for the confounding effect of other activities. The interpretation of the results provided by this model are ideal for public health interventions and recommendations, and they can provide insight into the associations of different types of activity in a cross-sectional study design.[73,74]

For the current analysis, we were interested in the association of three levels of activity intensity on blood pressure and hypertension: sedentary behavior (SB, <1.5 METs), light physical activity (LPA, ≥1.5 METs and <3.0 METs), and moderate to vigorous physical activity (MVPA, ≥3.0 METs), the effects of which were scaled to 30 minutes per day for each. An example of a substitution model is expressed below:

$$\textit{Systolic BP} = (b_1)\ \textit{LPA} + (b_2)\ \textit{MVPA} + (b_3)\ \textit{total SWA wear time} + (b_4)\ \textit{covariates},$$

where $b_1$-$b_4$ are coefficients of respective activity level times or covariates. By eliminating sedentary time from this model, the $b_1$ and $b_2$ coefficients represent the effect of substituting 30 minutes of the corresponding activity in place of sedentary time while holding the other activity type and all covariates constant.[73] After our initial analyses produced differing directions of effect for LPA and MVPA, we decided not to combine them into a single measure of "any activity."

Linear and logistic regressions were used in conjunction with the isotemporal substitution framework to assess the associations of substituting 30-minutes of one type of activity for another type of activity with blood pressures and odds of prevalent hypertension. Additionally, we tested the association of daily step count – a common measure of physical activity – with blood pressures and prevalent hypertension using linear and logistic regressions without the isotemporal substitution framework. Models were first run adjusting only for SWA wear time (considered the minimally adjusted model), and additional covariates were added as follows: age was added first, followed by use of antihypertensive medication for models of blood pressure. The fully adjusted model included additional adjustment for preidentified covariates of interest, including alcohol consumption, smoking status, family history of hypertension, personal history of CVD, diabetes status, and salt intake. Finally, BMI and WC were added separately to the full model to assess each measures' differing confounding effect. The associations of physical activity with SBP and DBP were further assessed in the subset of men who were not using antihypertensive medication. All analyses were performed using SAS version 9.3 (SAS Institute, Cary, NC, USA).

# 6.0 RESULTS

Baseline characteristics of study participants are outlined in Table 3, with comparisons between men with valid physical activity data (≥10 hours awake per day for ≥ 4 days) and two groups: 1) men who wore the SWA but did not meet the minimum wear time requirement, and 2) men from the current Tobago Health Study visit who did not participate in SWA physical activity data collection. After adjustment for age, study participants who did not wear the SWA only had a lower likelihood of a positive family history of hypertension and greater salt intake, on average, than those with valid data (both $p<0.05$). No significant differences in baseline characteristics were found between men with valid data and men who wore the SWA but did not meet the minimum wear time requirement.

**Table 3. Baseline Characteristics, Stratified by Inclusion Status**

| | Study Participants | Participants who wore SWA but did not meet inclusion criteria (<4 usable days) | THS participants who did not wear SWA |
|---|---|---|---|
| N | 310 | 81 | 465 |
| Age | 62.8 ± 8.1 | 62.4 ± 7.0 | 65.4 ± 9.6‡ |
| Weight (kg) | 86.3 ± 16.3 | 84.1 ± 13.4 | 83.9 ± 15.5 |
| BMI (kg/m$^2$) | 28.1 ± 4.8 | 27.6 ± 4.0 | 27.3 ± 4.5* |
| Waist Circumference (cm) | 99.3 ± 12.9 | 96.6 ± 11.1* | 98.1 ± 12.9 |
| Alcohol Consumption (% ≥4 drinks per week) | 12.9% | 11.1% | 13.6% |
| Smoking Status (%) | | | |
| Current | 9.7% | 6.3% | 7.1% |
| Former | 21.6% | 20.0% | 20.4% |
| Family History of Hypertension (%) | 59.2% | 49.4% | 49.1%† |
| Personal History of CVD (%) | 5.8% | 4.9% | 9.3% |
| Diabetes (%) | 22.2% | 19.8% | 25.2% |
| Salt Intake (mg/day) | 2306.6 ± 934.2 | 2422.8 ± 919.0 | 2527.1 ± 1045.4‡ |
| Systolic BP (mmHg) | 143.2 ± 23.4 | 141.1 ± 21.7 | 141.9 ± 22.4 |
| Diastolic BP (mmHg) | 80.4 ± 12.2 | 79.6 ± 12.8 | 78.8 ± 12.2 |
| Hypertension Medication (%) | 41.9% | 33.3% | 43.4% |
| Hypertension Prevalence (%) | 59.7% | 56.8% | 65.8% |

*p<.10, †p<.05, ‡p<.01. P-values adjusted for age, except for the test for age, which was unadjusted.
Characteristics expressed as mean ± SD

Baseline characteristics are again presented in Table 4 for men in the current study, stratified by hypertension status. As expected, hypertensives were older, and even after adjustment for age, weighed more, had a wider waist and higher BMI, were more likely to have a positive family history of hypertension, and were more likely to be diabetic, than normotensive men (all $p<0.05$). Also, hypertensive men were generally less active than normotensive men, with 1300 fewer daily steps and ~10% less time spent engaged in any physical activity daily ($p<0.0001$ for both). Normotensive men spent, on average, 38.6% of their time in at least LPA, compared to only 28.4% among hypertensives. SWA wear time was not significantly different between hypertensives and normotensives.

**Table 4. Baseline Characteristics, Stratified by Hypertension Status**

| | Overall | Non-Hypertensives | Hypertensives |
|---|---|---|---|
| N | 310 | 125 | 185 |
| Age | 62.8 ± 8.1 | 60.6 ± 6.7 | 64.3 ± 8.6‡ |
| Weight (kg) | 86.3 ± 16.3 | 81.7 ± 14.0 | 89.4 ± 17.0‡ |
| BMI (kg/m$^2$) | 28.1 ± 4.8 | 26.7 ± 4.4 | 29.1 ± 4.8‡ |
| Waist Circumference (cm) | 99.3 ± 12.9 | 95.0 ± 12.1 | 102.3 ± 12.6‡ |
| Alcohol Consumption (% ≥4 drinks per week) | 12.9% | 10.4% | 14.6%* |
| Smoking Status (%) | | | |
| Current | 9.7% | 9.6% | 9.7% |
| Former | 21.6% | 22.4% | 21.1% |
| Family History of Hypertension (%) | 59.2% | 46.4% | 67.9%‡ |
| Personal History of CVD (%) | 5.8% | 3.2% | 7.6% |
| Diabetes (%) | 22.2% | 9.6% | 30.8%‡ |
| Salt Intake (mg/day) | 2306.6 ± 934.2 | 2201.6 ± 896.5 | 2377.6 ± 954.6* |
| *Physical Activity* | | | |
| Steps / day | 5405.6 ± 3015.2 | 6181.7 ± 2738.8 | 4881.2 ± 3086.5† |
| % Active Time | 32.5 ± 15.9 | 38.6 ± 15.8 | 28.4 ± 14.7‡ |
| % Sedentary Time | 67.5 ± 15.9 | 61.4 ± 15.8 | 71.6 ± 14.7‡ |
| % Light Activity | 27.0 ± 12.5 | 31.8 ± 12.5 | 23.8 ± 11.6‡ |
| % MVPA Time | 4.0 [1.6, 8.1] | 5.0 [2.7, 9.3] | 3.1 [1.0, 6.5] † |
| Daily Wear Time (hr) | 16.6 ± 1.4 | 16.4 ± 1.4 | 16.7 ± 1.3* |

*p<.10, †p<.05, ‡p<.01. P-values adjusted for age, except for age, which was unadjusted.
Characteristics expressed as Mean ± SD or Median [IQR]

Associations between physical activity and blood pressures are presented in Table 5. Greater daily step count was associated with lower SBP, but only in the minimally adjusted model (p=0.013). In addition, replacing 30 minutes of daily SB with LPA was associated with lower SBP in the minimally adjusted model (p=0.023). After adjustment for age, this association was somewhat attenuated (p=0.076). All associations between physical activity and SBP were attenuated after adjustment for antihypertensive use, and changed little after adjustment for additional potential confounders. MVPA was not associated with SBP in any model.

Similarly, greater daily step count and a 30-minute replacement of daily SB with LPA were associated with lower DBP in minimally adjusted models (p=0.049 and 0.033, respectively). These associations were somewhat stronger after adjustment for age, but were mostly attenuated after adjustment for antihypertensive use and other potential confounders. Similar to SBP, MVPA was not associated with DBP in any model.

**Table 5. Associations of Objectively Measured Daily Physical Activity on Blood Pressure**

| | Steps (per 1000) | 30 Min LPA replacing SB | 30 Min MVPA replacing SB | 30 Min MVPA replacing LPA |
|---|---|---|---|---|
| Systolic Blood Pressure | | | | |
| Model 1: minimal | **-1.10 (0.44)** † | **-0.84 (0.37)** † | -0.73 (0.84) | 0.11 (1.07) |
| Model 2: model 1 + age | -0.64 (0.48) | -0.67 (0.37) * | -0.40 (0.85) | 0.27 (1.07) |
| Model 3: model 2 + HTN meds | -0.05 (0.47) | -0.42 (0.36) | 0.30 (0.82) | 0.71 (1.02) |
| Model 4: full adjustment | -0.03 (0.48) | -0.38 (0.36) | 0.31 (0.82) | 0.69 (1.02) |
| Model 5: full + BMI | 0.06 (0.49) | -0.20 (0.41) | 0.39 (0.83) | 0.59 (1.02) |
| Model 6: full + waist | 0.01 (0.49) | -0.36 (0.40) | 0.33 (0.83) | 0.69 (1.03) |
| Diastolic Blood Pressure | | | | |
| Model 1: minimal | **-0.46 (0.23)** † | **-0.41 (0.19)** † | -0.53 (0.44) | -0.12 (0.56) |
| Model 2: model 1 + age | **-0.63 (0.25)** † | **-0.50 (0.19)** † | -0.70 (0.44) | -0.21 (0.56) |
| Model 3: model 2 + HTN meds | -0.26 (0.24) | -0.34 (0.18) * | -0.27 (0.42) | 0.07 (0.52) |
| Model 4: full adjustment | -0.21 (0.25) | -0.35 (0.18) * | -0.28 (0.42) | 0.07 (0.52) |
| Model 5: full + BMI | -0.11 (0.25) | -0.19 (0.21) | -0.21 (0.42) | -0.02 (0.52) |
| Model 6: full + waist | -0.14 (0.25) | -0.28 (0.21) | -0.25 (0.42) | 0.03 (0.52) |

*p<.10, †**p<.05,** ‡**p<.01**
Effects are presented as beta (standard error)
Minimal model adjusted only for wear time
Full model includes adjustment for wear time, age, HTN medications, alcohol consumption (>3 drinks per week), smoking status, family history of hypertension, personal history of CVD, diabetes status, and salt intake
SB: sedentary behavior (< 1.5 METs), LPA: light physical activity (≥1.5 and <3.0 METs), MVPA: moderate to vigorous physical activity (≥ 3.0 METs)

Because associations were so greatly attenuated by use of antihypertensive medication in the full set of men, we also tested the association of physical activity with SBP and DBP restricted to men who were not using antihypertensive medication (Table 6). In this subset, the association of replacing 30 minutes of daily SB with LPA was strongly associated with lower SBP and DBP, and was significant even after full confounder adjustment plus additional adjustment for WC or BMI (all p<0.05). For example, in fully adjusted models, replacing 30 minutes of SB with LPA daily was associated with 1.1 mmHg lower SBP (p=0.009) and 0.6 mmHg lower DBP (p=0.011) in these untreated men. However, neither step count nor MVPA were associated with SBP or DBP in any model.

**Table 6. Associations of Objectively Measured Daily Physical Activity on Blood Pressure, in Participants not using Antihypertensive Medication (N=130)**

| | Steps (per 1000) | 30 Min LPA replacing SB | 30 Min MVPA replacing SB | 30 Min MVPA replacing LPA |
|---|---|---|---|---|
| Systolic Blood Pressure | | | | |
| Model 1: minimal | -0.20 (0.49) | **-1.37 (0.38)** ‡ | 0.20 (0.78) | 1.57 (1.00) |
| Model 2: model 1 + age | 0.03 (0.51) | **-1.32 (0.39)** ‡ | 0.29 (0.79) | 1.61 (1.00) |
| Model 3: full adjustment | 0.05 (0.54) | **-1.31 (0.40)** ‡ | 0.37 (0.79) | 1.68 (1.00)* |
| Model 4: full + BMI | 0.28 (0.53) | **-0.95 (0.44)** † | 0.58 (0.79) | 1.53 (1.00) |
| Model 5: full + waist | 0.19 (0.53) | **-1.13 (0.43)** ‡ | 0.50 (0.80) | 1.63 (1.01) |
| Diastolic Blood Pressure | | | | |
| Model 1: minimal | -0.16 (0.26) | **-0.67 (0.20)** ‡ | -0.02 (0.41) | 0.65 (0.53) |
| Model 2: model 1 + age | -0.26 (0.27) | **-0.76 (0.20)** ‡ | -0.16 (0.41) | 0.60 (0.52) |
| Model 3: full adjustment | -0.23 (0.29) | **-0.77 (0.21)** ‡ | -0.12 (0.42) | 0.65 (0.54) |
| Model 4: full + BMI | -0.08 (0.28) | **-0.50 (0.23)** † | 0.04 (0.42) | 0.55 (0.53) |
| Model 5: full + waist | -0.12 (0.28) | **-0.59 (0.23)** † | 0.01 (0.42) | 0.59 (0.53) |

*p<.10, †**p<.05**, ‡**p<.01**
Effects are presented as beta (standard error)
Minimal model adjusted only for wear time
Full model includes adjustment for wear time, age, alcohol consumption (>3 drinks per week), smoking status, family history of hypertension, personal history of CVD, diabetes status, and salt intake
SB: sedentary behavior (< 1.5 METs), LPA: light physical activity (≥1.5 and <3.0 METs), MVPA: moderate to vigorous physical activity (≥ 3.0 METs)

Finally, the associations between activity and odds of prevalent hypertension are presented in Table 7. Greater daily step count was associated with lower odds of prevalent hypertension, and this association was significant even after full adjustment for potential confounders (p=0.040). Also, replacing 30 minutes of daily SB with LPA was associated with ~10% lower odds of prevalent hypertension even after full adjustment for potential confounders (p=0.002). However, these associations were attenuated after additional adjustment for either BMI or WC. MVPA was not associated with odds of prevalent hypertension in any model.

**Table 7. Associations of Objectively Measured Daily Physical Activity on Odds of Prevalent Hypertension**

| | Steps (per 1000) | 30 Min LPA replacing SB per day | 30 Min MVPA replacing SB per day | 30 Min MVPA replacing LPA per day |
|---|---|---|---|---|
| Model 1: minimal | **0.85‡ (0.79-0.93)** | **0.87‡ (0.81-0.93)** | 0.93 (0.80-1.07) | 1.07 (0.89-1.29) |
| Model 2: model 1 + age | **0.89† (0.82-0.97)** | **0.88‡ (0.82-0.95)** | 0.96 (0.82-1.12) | 1.09 (0.90-1.32) |
| Model 3: full adjustment | **0.90† (0.82-1.00)** | **0.89‡ (0.82-0.96)** | 1.00 (0.86-1.18) | 1.13 (0.93-1.39) |
| Model 4: full + BMI | 0.93 (0.84-1.03) | 0.94 (0.86-1.02) | 1.04 (0.88-1.23) | 1.11 (0.90-1.36) |
| Model 5: full + waist | 0.93 (0.84-1.03) | 0.93* (0.85-1.01) | 1.03 (0.88-1.22) | 1.12 (0.91-1.37) |

*p<.10, **†p<.05, ‡p<.01**

Effects are presented as Odds Ratio (95% Confidence Interval)

Minimal model adjusted only for wear time

Full model includes adjustment for wear time, age, HTN medications, alcohol consumption (>3 drinks per week), smoking status, family history of hypertension, personal history of CVD, diabetes status, and salt intake

SB: sedentary behavior (< 1.5 METs), LPA: light physical activity (≥1.5 and <3.0 METs), MVPA: moderate to vigorous physical activity (≥ 3.0 METs)

# 7.0 DISCUSSION

In summary, we found that in our sample of older, African ancestry Tobagonian men, greater duration of LPA in place of SB was associated with lower blood pressure and lower odds of prevalent hypertension, independent of age. These associations were attenuated or lost when controlling for antihypertensive use, and further attenuated when controlling for obesity or central adiposity. Replacing SB or light intensity activity with only MVPA showed no beneficial association with blood pressure measures or odds of prevalent hypertension.

The associations of replacing SB with LPA with lower blood pressures were even stronger in the subset of men who were not using antihypertensive medication. These associations remained significant even after full adjustment for potential confounders and obesity or central adiposity. These men were healthier, about 4 years younger, and on average had 16 mmHg lower SBP and 10 mmHg lower DBP, suggesting that there are benefits of physical activity on blood pressure even before blood pressure is too high. Medication dosage levels were not available for this analysis, which could add an additional level of uncontrolled confounding. The subset analysis demonstrates that the associations between physical activity and blood pressures are clearer without the confounding effect of antihypertensive medications.

These findings are consistent with many other studies[12,15,50-52,55] that found beneficial associations between longer duration, rather than greater intensity, of active time and blood pressure. Reducing sedentary time has been shown to be an important lifestyle change in reducing blood pressure and the risk of hypertension.[55] As with other studies,[52,55] we found that the intensity of physical activity is less important than the duration of sedentary time it replaces. Step count, a measure of light activity, was not significantly associated with blood pressure after adjustment for medication use in our study, but it was significantly associated with lower odds of prevalent hypertension before controlling for body size, a possible mediator of this association. Our findings are in accordance with many other studies[52,55,61,65] that suggest increasing light activity could be an easily accomplishable lifestyle modification for lowering blood pressure. The shear stress caused by any type of exercise has been shown to invoke a homeostatic response in the blood vessels, increasing the levels of NO and $NO_2$, which improve endothelial function and decrease blood pressure.[17] Additionally, increased movement and exercise has been shown to improve circulation, which could also lower blood pressure.[75]

Our study also produced null findings regarding the association between blood pressure and MVPA. This is not surprising given some previous studies' findings that higher intensity activity showed no additional benefit for blood pressure,[55,65] and some studies even found negative effects of higher intensity activity, such as weight lifting.[42-44,48,49] In fact, although none of the associations in the current study were significant at $\alpha=0.05$, our findings for replacing LPA with MVPA trended towards being associated with increased SBP, DBP, and odds of prevalent hypertension. Mechanistically, this could be due to the negative effects of high intensity activity on central arterial compliance.[48,49] It is also important to note that our population was older, and only spent 4% of their time, on average, engaged in MVPA, and therefore we are likely underpowered to detect a significant association, although that should not theoretically have an impact on the direction of effect.

We also found slight differences in our results when adjusting for WC instead of adjusting for BMI. Most associations were stronger when controlled for WC rather than BMI. It is possible that greater weight from greater muscle mass, which would be captured by BMI, could have a different effect on blood pressure than greater central adiposity, which would be more accurately captured by WC. While intense exercise that would build muscle mass could have a negative effect on arterial compliance,[48,49] there is also evidence that sarcopenia is associated with increased blood pressure,[76,77] suggesting that perhaps the greater muscle mass captured by BMI in our generally lean sample of men may have an opposite effect compared to WC, which is a more accurate measure of central adiposity.

Body size is a difficult factor to account for in physical activity and blood pressure modeling, because although it is associated with both the exposure and outcome and should be treated as a confounder, it may also be categorized as a mediating factor whose effect should not be overcontrolled.[78] Less physical activity can lead to more fat and greater body size, but greater body size can make physical activity more difficult to accomplish. It is difficult to ascertain the direction of this causal pathway, and important to take results with and without adjustment for body size into consideration.[78]

Our study was limited to older males, so our findings may not be generalizable to younger people or females. Also, while the activity monitor data included METs for each minute of wear time, we did not collect any data on specific types of activities, so we cannot comment on which types of activity, other than steps, may be most beneficial for blood pressure. Another limitation of the SWA software is that skin temperature is used in the algorithm to make calculations, and the monitors have not been validated for warmer climates such as in the Caribbean, although the ambient temperature is monitored by the device.[79] Finally, the most significant limitation to this study is the cross-sectional design, which does not allow for temporal conclusions or assessment of causality. Further studies are required to expand this research to younger individuals and females, and to translate these findings into interventional studies aimed at improving blood pressure and hypertension risk in African ancestry individuals.

The current study adds to the limited body of evidence on the effects of physical activity on blood pressure and hypertension in African ancestry individuals. One strength of the study was the use of validated physical activity monitors for collection of objective data, allowing for more accurate and unbiased ascertainment of each participant's total activity level and intensity. Also, the Tobago Health Study provides a unique sample of older African ancestry men who are less likely to be influenced by Westernized culture, as Tobagonians have lower rates of smoking and alcohol use and tend to walk for transportation more than U.S. residents. Lastly, our analysis also utilized the relatively new isotemporal substitution framework,[74] which was designed to produce results that are easy to understand and apply to public health recommendations.

# 8.0 CONCLUSION

In conclusion, our study found that more time engaged in light physical activity in place of sedentary time was associated with lower blood pressures and odds of prevalent hypertension in older Afro-Caribbean men, independent of age, lifestyle factors, family history of hypertension, and comorbidities. These findings were more pronounced in men who were not on antihypertension medication. Our study adds new evidence to support the idea of increasing physical activity, particularly light physical activity, in blood pressure management. These findings are especially important for Black populations and older populations, who are at greatest risk of hypertension and hypertension complications.[1,4,5,24] Further studies, including interventional studies, are needed to confirm these findings in a broader African ancestry sample, to determine optimal physical activity thresholds and types of activities, and to more fully understand the mechanisms behind these associations in African ancestry populations.

## 8.1 PUBLIC HEALTH SIGNIFICANCE

This study and others like it could have great public health significance by providing evidence for targeted recommendations. We provide evidence that in an older African ancestry population, less sedentary time is associated with better blood pressures and lower odds of prevalent hypertension. The isotemporal substitution modeling framework provides further benefit by producing results that could be used to determine public health recommendations.[74] For example, our results suggest that each 30 minutes of sedentary time that is replaced, daily, by light activity could reduce the odds of prevalent hypertension by 10% in this Tobagonian sample of older men. However, our results are based on cross-sectional data, so temporality cannot be established. However, future interventional studies could further benefit from isotemporal substitution modeling. Making study findings easier to understand and applicable to daily life could be an important way to improve population health, and improving blood pressure around the world is a top public health priority.

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