Preventive Medicine Reports 23 (2021) 101458

Contents lists available at ScienceDirect

Preventive Medicine Reports

journal homepage: www.elsevier.com/locate/pmedr

Association of physical activity with blood pressure in African ancestry men

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ARTICLE INFO

Keywords:
Hypertension
Accelerometry
Isotemporal substitution
Sedentary behavior
Afro-Caribbean

ABSTRACT

This study tested the association of objectively measured physical activity with blood pressure and hypertension in African Caribbean men, an understudied population segment known to be at high-risk for cardiovascular disease (CVD) which has low levels of high-exertion physical activity. Men (N = 310) were from the Tobago Health Study and aged 50–89 years. Systolic (SBP) and diastolic (DBP) blood pressures were measured using an automated device, 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) and consisted of daily time engaged in sedentary behavior (SB), light physical activity (LPA), and moderate to vigorous activity (MVPA), as well as daily step count. Multiple regression analyses using the isotemporal substitution framework were used to test for associations between activity and blood pressures. Models were adjusted in stages for SWA wear time, age, antihypertensive medication use, alcohol consumption, smoking, diabetes, CVD, family history of hypertension, salt intake, and adiposity.

Replacement of SB with LPA was associated with lower SBP adjusted for wear time (β = -0.84, p < 0.05), but attenuated after adjustment for age. Replacement of SB with LPA was associated with lower DBP (β = -0.50) and lower odds of hypertension (OR = 0.88), adjusted for wear time and age (both p < 0.05). All model associations of replacement of SB with LPA were stronger when restricted to men not taking antihypertensive medications, regardless of their hypertension status.

These results support the strategy of increasing light physical activity for blood pressure management in high-risk Afro-Caribbean men.

1. Introduction

Hypertension has rapidly become one of the most common afflictions around the world. (Benjamin et al., 2018) While prevalence rates of hypertension are high among all ethnicities (40% globally World Health Organization. WHO | Raised Blood Pressure., 2018), they are disproportionately higher in African ancestry populations. (Benjamin et al., 2018; World Health Organization, 2011; Zhao et al., 2015) It remains unclear what is driving this difference, though hypotheses range from environmental effects, to lifestyle habits, to genetic factors. (Center for Disease Control, 2009; Cooper et al., 2005; Kao et al., 2008; Kopp et al., 2008; Redmond et al., 2011) Further research within these high-risk populations is needed.

It is well established that physical activity provides a beneficial effect on blood pressure and the development of hypertension. (Börjesson et al., 2016; Hajna et al., 2018; Knaeps et al., 2018; Paffenbarger et al., 1968) New guidelines announced in 2018 by the U.S. Department of Health and Human Services (HHS) and adopted by the American Heart Association are based on emerging evidence that any amount and intensity of physical activity – not just moderate-to-vigorous physical activity (MVPA) – has a wide range of health benefits, including benefits to blood pressure and hypertension risk. (U.S. Department of Health and Human Services, 2018) These guidelines update previous recommendations for weekly activity time, removing requirements for physical activity to be done in bouts of at least 10 min, citing health advantages to even small, intermittent doses of activity. (U.S. Department of Health and Human Services, 2018) However, the benefits of physical activity on blood pressure have not been demonstrated in populations of primarily

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https://doi.org/10.1016/j.pmedr.2021.101458
Received 5 October 2020; Received in revised form 21 April 2021; Accepted 25 April 2021
Available online 16 June 2021

African ancestry, who have the greatest risk of hypertension. (Benjamin et al., 2018; World Health Organization, 2011; Zhao et al., 2015)

The purpose of the current study was to assess the relationship of objectively measured physical activity with blood pressure and the risk of hypertension in Afro-Caribbean men. We hypothesized that greater time spent engaged in physical activity, as compared to time spent sedentary, would be associated with lower systolic blood pressure (SBP), diastolic blood pressure (DBP), and prevalence of hypertension. We hypothesized that these associations would persist even after controlling for age, adiposity, diabetes, personal and family history of cardiovascular disease, lifestyle habits, salt intake, and medication use. In secondary analyses, we tested the associations of other measures of physical activity with blood pressure, including MVPA and step count, a widely used measure of physical activity and alternative measure of activity duration. (U.S. Department of Health and Human Services, 2018)

2. Methods

2.1. 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. (Bunker et al., 2002) To be eligible, men had to be ambulatory, noninstitutionalized, and not terminally ill. Recruitment for the study was accomplished by flyers, public service announcements, 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. (Tilves et al., 2016) Participants from the Tobago Health Study are of homogenous African ancestry with low European admixture (<6%) and due to the origin of the study for prostate cancer screening, include only men. (Miljkovic-Gacic et al., 2005) Between 2014 and 2016, 856 men participated in a follow-up clinic examination, representing 85.6% of contacted survivors. About halfway through this examination, we added armband-based accelerometry to objectively measure physical activity. We collected valid accelerometry and blood pressure data in 310 men. 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.

2.2. 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. (Barone Gibbs et al., 2017) 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. (Barone Gibbs et al., 2017) The calculations come from proprietary algorithms that are not publicly available in the SenseWear software created by BodyMedia. However, these algorithms 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). (Johannsen et al., 2010) However, step count data from the SWA may not be as accurate as other wearable devices, (Wahl et al., 2017) therefore, we present information on both activity and step data in this study. Data from the SWA were considered to be usable if the participant wore the armband for 10 waking hours of a given day and for a minimum of 4 days. Sleep versus awake status was determined by the SWA. Activity intensity levels in the current study were defined as sedentary behavior (SB, <1.5 metabolic equivalents (METs)), light physical activity (LPA, ≥1.5 METs and < 3.0 METs), and moderate to vigorous physical activity (MVPA, ≥3.0 METs).

2.3. Blood pressure measurements

Blood pressure readings were taken three times at the study examination while the participant was sitting and after 10 min of rest using an automated oscillometric blood pressure device (HEM705CP; Omron Healthcare, Inc, Vernon Hills, IL). The average of the 2nd and 3rd readings was used to determine mean SBP and DBP. Antihypertensive medication use was ascertained by self-report, as well as through classification of all the participants' current medications, which they brought to the study examination. While recently updated guidelines from the American College of Cardiology (ACC) (Whelton et al., 2017) call for lower thresholds for the definition of hypertension, we used the definition of hypertension that was used at the time of data collection as the clinical diagnosis of hypertension may have influenced lifestyle habits and choices. Therefore, for this study we defined hypertension as SBP ≥ 140 mmHg, DBP ≥ 90 mmHg, or current use of antihypertensive medication. In sensitivity analyses, we investigated whether associations held when using the newer blood pressure guidelines, (Whelton et al., 2017) defining hypertension as SBP ≥ 130, DBP ≥ 80, or current use of antihypertensive medication.

2.4. Other Tobago data sources

Standing height and waist circumference (WC) were measured twice using a wall-mounted stadiometer (Perspective Enterprises, Portage, MI, USA) and flexible tape (Country Technology Inc., Gary Mills, WI, USA), respectively, and averaged to the nearest 0.1 cm. Weight was measured to the nearest 0.1 kg using a balance beam scale (Seca Corp., Chino, CA, USA). Body mass index (BMI) was calculated as the ratio of weight to height in meters 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>100 cigarettes, but were not currently smoking. Regular alcohol consumption was defined as drinking an average of 4 or more drinks per week over the previous 12 months. Fasting serum glucose was measured using an enzymatic procedure, and diabetes was defined as fasting serum glucose levels ≥ 126 mg/dl and/or use of antidiabetic medication. Other prevalent comorbidities including cardiovascular disease and family history of hypertension were self-reported. Diet was assessed using a food-frequency questionnaire tailored to the Tobago diet that calculated daily intake of specific nutrients, including sodium (mg/day).

Participants were 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) ([22]). For this analysis, we used information on medications for hypertension, diabetes and lipid management.

2.5. Statistical analysis

We examined the distribution of each physical activity variable for normality and outliers, and transformed the data as necessary. We tested for differences in population characteristics by 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. Therefore, to study the effects of time spent in different intensity levels of activity, we used the isotemporal substitution framework, an analytic technique that estimates the effect of substituting one activity level for another. (Mekary et al., 2009) For the current analysis, we were interested in the association of three levels of activity intensity on blood pressure and hypertension: SB, LPA, and MVPA, the effects of which were standardized to 30 min per day for each for ease of interpretation.

Linear and logistic regressions were used in conjunction with the isotemporal substitution framework to assess the associations of substituting 30-minutes of each intensity level of activity for other intensity levels with blood pressure and prevalent hypertension. Additionally, we tested the association of daily step count – a commonly used alternative measure of the overall volume of physical activity (U.S. Department of Health and Human Services, 2018) – with blood pressure and prevalent hypertension using linear and logistic regression analysis (without the isotemporal substitution framework.) Initial models only adjusted for SWA wear time (considered the minimally adjusted model), and additional covariates were added in sequence. Age was added first, followed by use of antihypertensive medication for linear models of continuous blood pressure. Next, the fully adjusted model added adjustment for pre-identified covariates of interest, including alcohol consumption, smoking status, family history of hypertension, personal history of CVD, diabetes, and salt intake. Finally, WC (or BMI in sensitivity analyses) was added separately to the full model to assess the confounding and possibly mediating effects of adiposity. This step-by-step model building method was defined *a priori* in order to interpret the individual covariate effects of our singular research question. As such, this does not constitute multiple testing, but rather an expanded presentation of the effects. Therefore, we used an alpha of 0.05 for all analyses. The associations of physical activity with continuous blood pressures were further assessed in the subset of men who were not using antihypertensive medication. For each 30-minute replacement of SB with LPA, we have 80% power to detect a difference of 0.90 mmHg SBP and 0.47 mmHg DBP in our sample of 310 men. All analyses were performed using SAS version 9.3 (SAS Institute, Cary, NC, USA).

3. Results

Baseline characteristics of the men are presented in Table 1, stratified by antihypertensive use. As expected, men using antihypertensives were older, weighed more, had a larger WC and higher BMI, were more likely to have a positive family history of hypertension, and more likely to be diabetic than men not using antihypertensives even after adjustment for age (all $p < 0.05$). Users were also generally less active than non-users, with 1700 fewer average daily steps ($p = 0.0003$) and ~ 10% more sedentary time ($p < 0.0001$). SWA wear time was not significantly different between hypertensive and normotensive men ($p = 0.59$).

Associations between physical activity and blood pressures are presented in Table 2. Replacing 30 min 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 attenuated ($p = 0.076$). In addition, greater daily step count was associated with lower SBP, but only in the minimally adjusted model ($p = 0.013$). Associations between replacement of SB with LPA or steps with SBP were attenuated after adjustment for antihypertensive use, and changed little after adjustment for additional potential confounders including WC. Replacing SB or LPA with MVPA was not associated with SBP in any model.

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

Because associations were attenuated by inclusion of antihypertensive medication in the models, we also tested the association of physical activity with SBP and DBP restricted to men who were not using antihypertensive medication (Table 3). In this subset, the association of replacing 30 min 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 (all $p < 0.05$). For example, in fully adjusted models, replacing 30 min 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 replacing SB or LPA with MVPA were associated with SBP or DBP in any model in this subset of men not using antihypertensive medication. The associations of SB replacement with LPA and SBP and DBP from fully adjusted models are visualized in Fig. 1.A. Results for these associations were not significant in men using antihypertensive medications (Supplemental Table 1).

Finally, the associations between activity and odds of prevalent hypertension in all men are presented in Table 4. Each 30-minute replacement of daily SB with LPA was associated with ~ 10% lower odds of prevalent hypertension, even after full adjustment for potential confounders ($p = 0.002$). Greater daily step count was associated with lower odds of prevalent hypertension, and this association was also significant after full adjustment ($p = 0.040$). However, these associations were attenuated after additional adjustment for WC. Replacing SB or LPA with MVPA was not associated with odds of prevalent hypertension in any model. The association of SB replacement with LPA and the probability of hypertension is visualized in Fig. 1.B. Sensitivity analyses showed similar results for all models including adjustment for BMI instead of WC (Supplemental Tables 2-4). Sensitivity analyses investigating the same associations using the 2017 ACC definition of hypertension showed similar results (Supplemental Table 5).

Table 1
Baseline Characteristics, Stratified by Antihypertensive Use (AHTX).

	Overall(N = 310)	Not using AHTX(N = 180)	Using AHTX(N = 130)	p-value
Age	62.8 ± 8.1	61.1 ± 7.0	65.2 ± 8.9	<0.0001
Weight (kg)	86.3 ± 16.3	83.3 ± 15.7	90.4 ± 16.3	<0.0001
BMI (kg/m^2)	28.1 ± 4.8	27.1 ± 4.7	29.6 ± 4.7	<0.0001
Waist Circumference (cm)	99.3 ± 12.9	96.0 ± 11.9	104.0 ± 12.8	<0.0001
Systolic Blood Pressure (mmHg)	143.2 ± 23.4	136.1 ± 19.6	153.0 ± 24.8	<0.0001
Diastolic Blood Pressure (mmHg)	80.4 ± 12.2	76.5 ± 10.4	85.9 ± 12.4	<0.0001
Alcohol Consumption (% ≥4 drinks per week)	12.9%	14.4%	10.8%	0.7140
Smoking Status (%)				
Current	9.7%	9.4%	10.0%	0.6899
Former	21.6%	21.7%	21.5%	0.7485
Family History of Hypertension (%)	59.2%	47.2%	76.0%	<0.0001
Personal History of CVD (%)	5.8%	2.8%	10.0%	0.0239
Diabetes (%)	22.2%	12.3%	35.9%	<0.0001
Salt Intake (mg/day)	2306 ± 934	2230.7 ± 950.7	2411.8 ± 903.8	0.0461
Physical Activity				
Steps / day	5405 ± 3015	6134.3 ± 3013.4	4396.6 ± 2722.1	0.0003
% Sedentary Time	67.5 ± 15.9	63.3 ± 16.0	73.3 ± 13.9	<0.0001
% Light Activity	27.0 ± 12.5	29.9 ± 12.5	23.0 ± 11.6	0.0003
% MVPA Time	4.0 [1.6, 8.1]	2.9 [1.2, 6.9]	1.4 [0.3, 3.9]	0.0004
Daily Wear Time (hr)	16.6 ± 1.4	16.5 ± 1.4	16.6 ± 1.4	0.5923

P-values adjusted for age.
Characteristics expressed as Mean ± SD, Median [IQR], or percentage.

4. Discussion

We found that among older, Afro-Caribbean Tobagonian men, greater duration of LPA in place of SB was associated with lower blood pressure and odds of prevalent hypertension. These associations were attenuated ($P = 0.076$) when controlling for antihypertensive use,

Table 2
Associations of Objectively Measured Daily Physical Activity on Blood Pressure.

	30 Min LPA replacing SB	30 Min MVPA replacing SB	30 Min MVPA replacing LPA	Steps (per 1000)
Systolic Blood Pressure				
Model 1: minimal	**−0.84 (0.37)** [†]	−0.71 (1.19)	0.11 (1.07)	**−1.10 (0.44)** [†]
Model 2: model 1 + age	−0.67 (0.37)	−0.72 (1.18)	0.27 (1.07)	−0.64 (0.48)
Model 3: model 2 + HTN meds	−0.42 (0.36)	−0.29 (1.13)	0.71 (1.02)	−0.05 (0.47)
Model 4: full adjustment	−0.38 (0.36)	−0.21 (1.13)	0.69 (1.02)	−0.03 (0.48)
Model 5: full + WC	−0.36 (0.40)	−0.17 (1.15)	0.69 (1.03)	0.01 (0.49)
Diastolic Blood Pressure				
Model 1: minimal	**−0.41 (0.19)** [†]	−0.83 (0.62)	−0.12 (0.56)	**−0.46 (0.23)** [†]
Model 2: model 1 + age	**−0.50 (0.19)** [†]	−0.83 (0.62)	−0.21 (0.56)	**−0.63 (0.25)** [†]
Model 3: model 2 + HTN meds	−0.34 (0.18)	−0.56 (0.57)	0.07 (0.52)	−0.26 (0.24)
Model 4: full adjustment	−0.35 (0.18)	−0.62 (0.57)	0.07 (0.52)	−0.21 (0.25)
Model 5: full + WC	−0.28 (0.21)	−0.55 (0.58)	0.03 (0.52)	−0.14 (0.25)

Effects are presented as beta (standard error), bold text indicates $p < 0.05$
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)
[†] **p < 0.05**

Table 3
Associations of Objectively Measured Daily Physical Activity on Blood Pressure, in Participants not using Antihypertensive Medication (N = 180).

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

Effects are presented as beta (standard error), bold text indicates $p < 0.05$
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)
[†] **p < 0.05**
[‡] **p < 0.01**

cardiovascular risk factors, and adiposity, though robust within men that were not currently using antihypertensive medication. Conversely, replacing SB or LPA with MVPA showed no beneficial association with blood pressure measures or odds of hypertension in these men. Within the isotemporal framework, our estimates suggest that if this sample of African Caribbean men were to exist by doing 30 min more LPA in place of SB, population mean SBP and DBP would each be ~ 1 mmHg lower and there would be ~ 10% less prevalent hypertension in this sample overall. While our main analyses used the past definition for hypertension diagnosis that was in place at the time of data collection, sensitivity analyses using guidelines updated in 2017 by the ACC showed similar and even slightly stronger associations between lesser SB and decreased odds of hypertension.

These findings are consistent with many other studies (Börjesson et al., 2016; Paffenbarger et al., 1968; Boyer and Kasch, 1970; Jennings et al., 1991; Mark and Janssen, 2008; Shephard, 2001) that found associations between increasing total active time, rather than specifically high intensity activity, and lower blood pressure. Reducing sedentary time has been shown to be an important lifestyle modification in reducing blood pressure and the risk of hypertension. (Shephard, 2001) Step count, an alternate measure of activity duration, (U.S. Department of Health and Human Services, 2018) was not significantly associated with blood pressure after adjustment for medication use in our study, but it was significantly associated with lower odds of hypertension in fully adjusted models. Our study and others (Jennings et al., 1991; Shephard, 2001; Hamer et al., 2017; Swindell et al., 2018) have found that replacing SB with LPA is associated with lower blood pressure, which may be a more feasible and sustainable strategy for behavior modification guidelines than increasing MVPA.

There are multiple mechanisms that may underlie this association. Shear stress caused by exercise invokes a homeostatic response in the blood vessels, increasing the levels of nitric oxide (NO) and NO_2, which improve endothelial function and decrease blood pressure. (Green et al., 2004) Also, increased movement and exercise improves peripheral circulation, which also leads to lower blood pressure. (Laughlin et al) It has also been shown that sedentary behavior itself negatively affects blood pressure by reducing conduit vessel flow and increasing vasoactive mediators. (Dempsey et al., 2018) However, more studies are needed to demonstrate these mechanisms in diverse populations, particularly those of African ancestry, which are at the highest risk of hypertension.

The association of LPA with lower blood pressure was strongest in the subset of men who were not using antihypertensive medication and remained significant after full adjustment for potential confounders, including adiposity. Men not on antihypertensive medication were healthier, about 4 years younger, and had 16 mmHg lower SBP and 10 mmHg lower DBP than those on medication, with mean SBP and DBP of 136 and 77 mmHg, respectively. These analyses demonstrate the confounding effect of antihypertensive medication on studies of blood pressure. Overall, our findings highlight the importance of physical activity on blood pressure maintenance in men at risk for hypertension and/or in the early stages of hypertensive disease (i.e., prior to initiation of antihypertensive use), which is in line with current guidance to begin with lifestyle changes as a first step in minimizing hypertensive burden. (Whelton et al., 2017)

All models included adjustment for adiposity as the last step since obesity may confound or potentially mediate the effects of activity on hypertension. In our primary analyses, we used WC, a measure of central adiposity, instead of BMI, which can be influenced by muscle mass. However, in sensitivity analyses adjusting for BMI instead of WC, associations were of similar direction and effect sizes (Supplemental Tables 2-4). Increased lean body mass is a 'health index' and increased

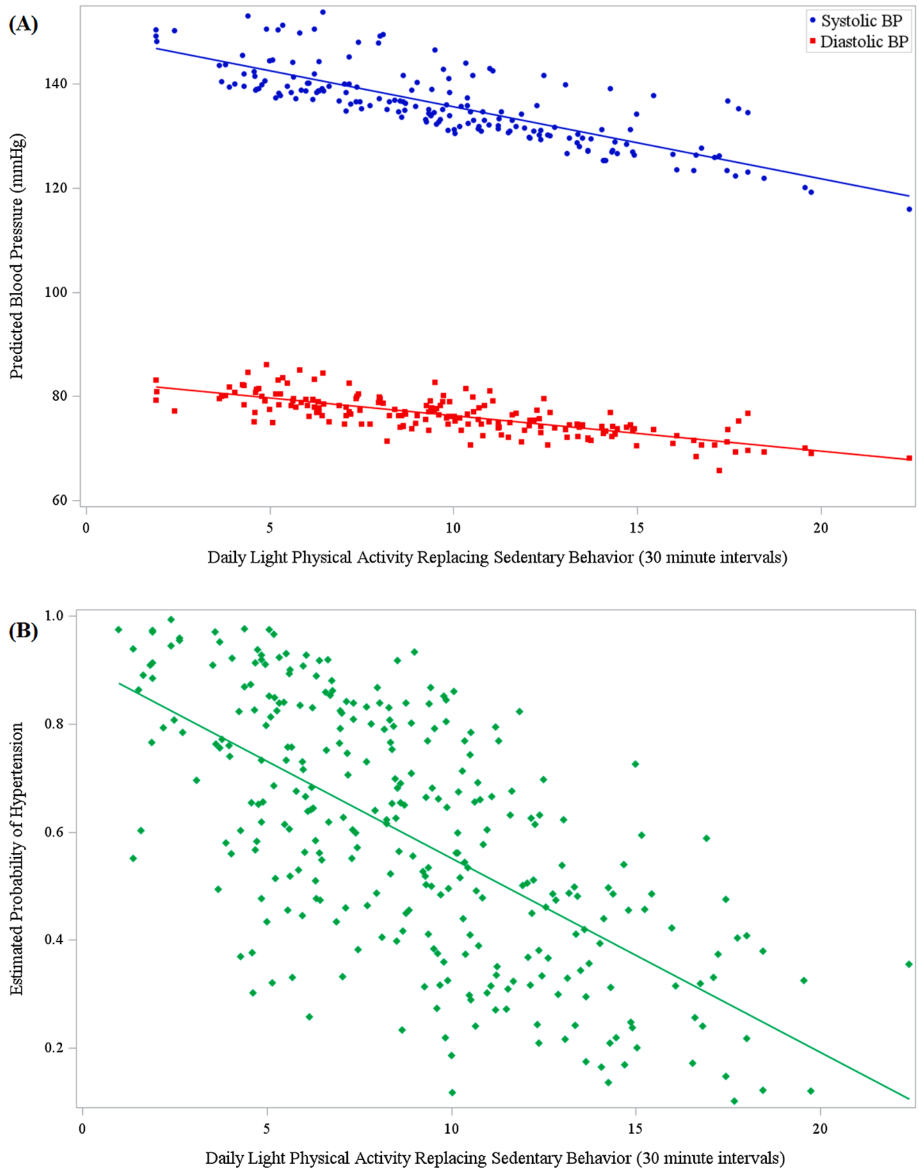

Fig. 1. Predicted Values of Blood Pressure and Estimated Probability of Hypertension per 30 min of LPA in place of SB. (A) shows the predicted values and line of best fit of systolic and diastolic blood pressure using Model 3 covariate adjustment from Table 3, in our sample of 180 men untreated for hypertension. (B) shows the estimated probability and line of best fit of prevalent hypertension using Model 3 covariate adjustment from Table 4, in our full sample of 310 men.

body fat is associated with cardiovascular complications, (Antonopoulos et al., 2016) and since BMI does not distinguish between the two, the association on blood pressure may be confounded. (Antonopoulos et al., 2016) As such, we believe the models shown adjusting for WC are the better representation of the negative effects of central adiposity on blood pressures. The addition of WC to the models did not significantly attenuate results for blood pressures in men not using antihypertensive medication (Table 3) and only slightly attenuated the effect estimate for prevalent hypertension in the whole study (Table 4). Therefore, we do not believe that adiposity plays a large confounding role in these associations, especially in men who are at risk for hypertension and/or early on in hypertensive disease progression (i.e., those not yet on antihypertensive medications).

Our study found no significant association between blood pressure and time spent in MVPA. This is not surprising given findings that higher intensity activity provides no additional benefits on blood pressure (Shephard, 2001; Hamer et al., 2017) and the recently updated 2018 physical activity guidelines (U.S. Department of Health and Human Services, 2018) remove the recommendation for bouted MVPA. Our findings for replacing LPA with MVPA trended towards being associated with increased SBP, DBP, and odds of hypertension. However, it is important to note that our population only spent an average of 4% of their time engaged in MVPA. Therefore, we do not have adequate statistical power to test this association and these results should not be over-interpreted.

Our study has several potential limitations. Our population sample was limited to older African ancestry males, and findings may not be generalizable to younger men or females. 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 control. Importantly, we used a definition of SB that is based only on intensity and does not measure posture and this may have affected results (Gibbs et al., 2015). Finally, this study is cross-sectional and cannot provide temporal conclusions or an assessment of causality.

The current study also has notable strengths. Our research adds to the limited body of evidence on the relationship between physical activity and hypertension in African ancestry individuals. The use of

Table 4
Associations of Objectively Measured Daily Physical Activity on Odds of Prevalent Hypertension.

	30 Min LPA replacing SB	30 Min MVPA replacing SB	30 Min MVPA replacing LPA	Steps (per 1000)
Model 1: minimal	**0.87**[‡] **(0.81–0.93)**	0.93 (0.80–1.07)	1.07 (0.89–1.29)	**0.85**[‡] **(0.79–0.93)**
Model 2: model 1 + age	**0.88**[‡] **(0.82–0.95)**	0.96 (0.82–1.12)	1.09 (0.90–1.32)	**0.89**[†] **(0.82–0.97)**
Model 3: full adjustment	**0.89**[‡] **(0.82–0.96)**	1.00 (0.86–1.18)	1.13 (0.93–1.39)	**0.90**[†] **(0.82–1.00)**
Model 4: full + WC	0.93 (0.85–1.01)	1.03 (0.88–1.22)	1.12 (0.91–1.37)	0.93 (0.84–1.03)

Effects are presented as Odds Ratio (95% Confidence Interval), bold text indicates $p < 0.05$
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).
[†] **p < 0.05**
[‡] **p < 0.01**

validated accelerometers for collection of objective physical activity data provided a more accurate and unbiased assessment of each participant's total activity level and intensity. Our relatively large population cohort carefully measured blood pressure and other potential covariates in a unique sample of older African ancestry men with low European genetic admixture (Miljkovic-Gacic et al., 2005). Our analysis also utilized the isotemporal substitution framework (Mekary et al., 2009), which produces results that are easy to understand and can be applicable for public health recommendations. Nevertheless, further studies are required to expand this research to females and to translate findings into interventional studies aimed at improving blood pressure and lowering hypertension risk, including incorporating the updated 2017 ACC hypertension guidelines, (Whelton et al., 2017) in high-risk population segments.

In conclusion, our study found that replacing sedentary time with light physical activity was associated with lower blood pressure and odds of hypertension in older Afro-Caribbean men. These findings were more pronounced and independent of other cardiovascular risk factors in men who were not on antihypertension medication. Our study supports the strategy of increasing light physical activity in blood pressure management and hypertension prevention. These findings are especially important for African ancestry and older populations, who are at greatest risk of hypertension and hypertensive complications.(Benjamin et al., 2018; World Health Organization, 2011; Zhao et al., 2015; Pinto, 2007) Further studies, including interventional studies, are needed to confirm these findings in a larger population 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.

CRediT authorship contribution statement

Ryan K. Cvejkus: Conceptualization, Software, Formal analysis, Data curation, Writing - original draft. **Iva Miljkovic:** Resources, Supervision, Project administration, Funding acquisition. **Bethany Barone Gibbs:** Methodology, Writing - review & editing, Supervision. **Joseph M. Zmuda:** Project administration, Funding acquisition. **Victor W. Wheeler:** Resources, Project administration. **Allison L. Kuipers:** Conceptualization, Methodology, Supervision, Funding acquisition, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Funding: This work was supported by grants R01-DK097084 (PI: Miljkovic) from the National Institute of Diabetes and Digestive and Kidney Diseases, K01-HL125658 (PI: Kuipers) from the National Heart, Lung and Blood Institute, and R01-AR049747 from the National Institute of Arthritis and Musculoskeletal and Skin Diseases (PI: Zmuda).

Other Contributors: The authors would like to thank Drs. Clareann Bunker, Lewis Kuller, and Alan Patrick for launching the Tobago Health Study (THS) in 1997, Dr. Jane Cauley for providing the SenseWear monitors for our study, and all Tobago Health Study Office nurses, staff, and participants who made this research possible.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2021.101458.

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