The Association Between Exercise and Hypertension

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Introduction:

In the United States, nearly half of the population have experienced hypertension, adding up to over 116 million cases (Centers for Disease Control and Prevention, 2021). This is a remarkably huge increase compared to the number in 1989, which was only about 20 million cases. Hypertension can cause many serious cardiovascular diseases without any symptoms at the initial stage, such as stroke and coronary heart disease. For this reason, scientists have put significant efforts into hypertension's pharmacologic therapy during the past decades. More than that, they also try to find other non-pharmacological ways to decrease systolic and diastolic blood pressure (BP) among the hypertensive patients. Regular exercise has been found to be pretty useful in this field.

This report will mainly focus on the relationship between exercise and hypertension. Additionally, there will also be conclusions on other potential factors such as patients and their socio-demographic characteristics, smoking habits, alcohol consumption, BMI, etc. Three original medical research papers have been chosen in advance, all from reliable academic journals. The first two reports, *Effect of exercise training in 60- to 69-year-old persons with essential hypertension* and *How much exercise is required to reduce blood pressure in essential hypertensives: a dose–response study* are randomized controlled trial (RCT) medical studies and *Prevalence and correlates of hypertension: a cross-sectional study among rural populations in sub-Saharan Africa* is a cross-sectional study. We will analyze each paper's study design, including the methods they used to collect data, individual analysis and its results. Lastly, we will conclude the report with a synthesis, and find out whether or not there is a significant relationship between different levels of exercise and hypertension.

Study I:

In this study, *Effect of exercise training in 60- to 69-year-old persons with essential hypertension*, thirty-three 60- to 69-years-old hypertensive patients were chosen as study subjects after the approval of the Human Studies Committee of the Washington University School of Medicine. The strictly initial screening were conducted during the selection, all patients were given 4 BP evaluations 1 week apart to ensure they had the persistently elevated BP. Any individual who had larger than 20.2 mV of ST-segment depression during the exercise, or developed symptoms other than fatigue was excluded from the study.

This study was designed in the Randomized Controlled Trial form, and the aim was to determine the relationship between the endurance exercise training and blood pressure(BP), and to compare the effects between the low-intensity and moderate-intensity training programs. Hence, after the screening and selection of study subjects, thirty-three patients were randomized to either control group or treatment groups, which are 9-month low-intensity or moderate-intensity training groups respectively.

Patients in the 9-month low-intensity exercise group were required to do a one-hour walk at home three times per week at 50% VO2 max. Study personnel supervised patients for the first month and after that, participants would return forms every 2 weeks to indicate their exercise time and heart rate. Three of fourteen patients in the low-intensity group did not complete the program — one for orthopedic problems and others for non-medical problems.

For patients in the 9-month moderate-intensity training group, they would go for walking first and then gradually began to do fast walking, jogging, cycle ergometry and treadmill walking. The training intensity would also gradually increase to 70-85% VO2 max for 45 to 60 minutes 3 times per week during this period. It is worth noting that subjects in this group would be supervised throughout the experiment and no one dropped from the study in this group.

Data on body weight, body composition, VO2 max, BP variation, plasma renin activity, urinary creatinine, Na+ concentrations and 24-hour excretion rates are collected as outcome for analysis (seen in appendix).

Analyzing the data about body weight and composition, it is noticeable that there was a significant decrease of body weight in the moderate-intensity training group, but none in other groups. VO2 max experienced increments in both training groups, but no change was observed in the control group. For BP measurements, the initial BP values for all three groups were on the same level, and after the 9-month endurance training, there was an obvious decline in the diastolic BP and mean BP in the training groups. One interesting phenomenon was systolic BP did not change a lot compared with the control group in the moderate-intensity group, but for the low-intensity training group, it changed a lot.

The changes in plasma renin activity, urinary creatinine, Na+ concentrations and 24-hour excretion rates were not significant compared with the control group.

This study found out that when the training program was conducted for 3 month, the effect of reduction in BP among the low-intensity group was equal or greater than the moderate-intensity group. And after completing the whole training session, which was a duration of 9-month, we could observe that the low-intensity training group could bring more systolic BP reductions. Hagberg et al pointed out in the paper that the reason why this would happen may be systolic BP was somehow inversely correlated to the exercise intensity ($r=-0.40$).

This study can give huge epidemiologic implications in the essential hypertension area considering the older men and women's capabilities to do the high-intensity training activities. This study definitely provides an alternative way for older hypensives besides the traditional drug therapy, especially when you look at the year the paper was published, which was 1989.

However, the limitation for this study was obvious. The sample size for this RCT was small, which was only 33 subjects total. This could make all the outcomes not significant enough to do the statistical analysis. As also, the low-intensity training patients were only supervised by the study personnel for one month, and then submitted the self-declaration for the rest 8-month. This would cause measurement bias when the patients could not correctly and precisely record their activities. More importantly, the participants may not complete the required exercise every day without supervision.

Study II:

The second study "*How Much Exercise Is Required to Reduce Blood Pressure in Essential Hypertensives: A Dose-Response Study*" is a Randomized Controlled Trial study. In this study, the main objective is to investigate whether a dose-response relationship exists between regular aerobic exercise and blood pressure (BP) for essential hypertensive patients. To conduct this study, 207 untreated healthy subjects identified with essential hypertension were selected and divided into a control group and an exercise group. After an 8-week-long exercise intervention on the exercise group, the test data were evaluated by using ANOVA and there is no loss of follow-up in this study. Overall, this study concludes that there is no apparent relationship between the frequency of exercise per week and the reduction of BP in essential hypertensive subjects; however, the cumulative time of exercise per week significantly impacts BP among essential hypertensive subjects. Also, it is worth noticing that one interesting conclusion in this study is that even a 30~60 min/week of exercise would be enough for essential hypertensive patients to decrease their systolic and diastolic BP.

Since this study is part of the Risk Factor Intervention Trial in Japan, the subjects of this study were selected from the 1425 participants in the trial. Among these 1425 participants, 450 of them had stage 1 or 2 hypertension. Then by considering the exclusion criteria such as antihypertensive drug use, cardiovascular disease status, consistency of dietary habits, and active lifestyle habits, this study finally confirmed 207 untreated healthy essential hypertension subjects among those 450 hypertension patients as the study sample of this study. The 207 subjects were initially divided into two groups: a control group (39 subjects) and an exercise group (168 subjects); then the exercise group was further divided into four groups based on their weekly exercise time and frequency during the 8-week exercise training after completing the study. Therefore, in this study, the exposure is whether the subject joined the 8-week exercise training, and the outcome is the subjects' reduction in BP.

Before the exercise intervention, some baseline data were measured. This study uses consistent measurement equipment and reference tables to measure the subjects' basic physical and dietary conditions. The measurements were conducted under the supervision of medical staff in 22 fitness clubs, and the detailed results are summarised in appendix study II table 1. In the measurement, the arterial BP at rest was measured twice, at two-week intervals, using an automatic oscillometric BP monitor (BP-203RVII, Colin, Aichi, Japan); the average of the two values was recorded as the baseline value. The BMI was calculated using the formula BMI = body mass (kg)/height (m^2), and the body mass was calibrated using a physical balance scale. The total intake of caloric and salt were referenced to the standard tables of food composition (Science & Technology Agency of Japan). The amount of maximal aerobic capacity was referred to as the maximal oxygen consumption measured on a cycle ergometer.

After all baseline data were collected, the subjects were asked to conduct an 8-week exercise intervention. During the intervention, the subjects in the control group did not change their sedentary status. That is, maintaining their regular physical activity intensity. This is estimated through well-validated pedometers (Yamax Digiwalker, Tokyo, Japan). For the exercise group, the subjects proceeded with an 8-week exercise training that includes a warm-up, aerobic exercise, and conditioning exercise in their nearest fitness club and guided by professional trainers. The physical activity intensity was personally customized for subjects according to their maximal oxygen consumption, and the training progress was detailed and recorded that included all of the exercise duration and type of exercise. After the intervention, the collected data of the exercise group were divided into four groups (30 to 60 min/wk, 61 to 90 min/wk, 91 to 120 min/wk, and >120 min/wk) according to the subjects' weekly exercise duration and frequency (details in appendix study II Figure 1 and Figure 2).

In the analyses step, from table 1 and figure 1&2 in the appendix, we can see that in the control group, there is almost no deviation in both systolic and diastolic BP; however, in all four exercise groups, both systolic and diastolic BP at rest significantly decreases. From the figure1, the amount of deduction of systolic BP increases as the weekly exercise duration increases; however, for diastolic BP, only the 61~90min/wk group had the highest reduction. Moreover, the reduction of both BP in the 91`120min/wk group and >120min/wk group are similar. This concludes that a 30~60 min exercise per week may be the most suitable amount for those essential hypertensive patients to reduce their BP. From the figure2, there is no distinct relationship between the exercise frequency per week and the deduction of BP in all four exercise groups. Overall, the study found that, for those subjects in the control group, they can easily get a significant deduction in BP by taking a small amount of exercise every week; that is, to reduce the BP for essential hypertensive population, maybe fewer amounts of exercise than the society consensus is enough. Therefore, the result is helpful for clinical staff to give regular aerobic physical activity as a reasonable treatment for those essential hypertensive patients.

The strength of this study is that as of the publish day of this study (2003 August), it is the second dose-response intervention study in studying the relationship between the amount of regular exercise and reduction on BP among essential hypertensive patients. By comparing with the first study on this topic, this study gives clearer classification on exercise duration and frequency which eliminates the bias on the previous study. Moreover, the result of this study is not only consistent with but also can provide mechanistic insight into the results of studies on how physical activities can reduce the risk of coronary disease.

However, limitations do exist in the study design. The division of exercise groups was done after the study instead of randomization in the initial stage. Therefore, systematic bias may exist. Moreover, although the four sub-groups of the exercise group were defined after the study, those subjects in control group and exercise groups were still not blinded and cannot be blinded in this study. Therefore, the subjects in exercise may have positive psychological hints in their mind during the exercise training.

Study III:

In recent times, non-communicable diseases such as cardiovascular diseases will be the major causes of morbidity and mortality in developing places such as Sub-Saharan Africa (SSA), accounting for almost four times as many deaths as from communicable diseases. Although cardiovascular cases such as hypertension (HTN) is well-documented, some of the few studies in the SSA have inconsistent findings. Hence in this cross-sectional study, *Prevalence and correlates of hypertension: a cross-sectional study among rural populations in sub-Saharan Africa*, we want to evaluate the prevalence of HTN and assess correlations involving three poorer, rural villages in east and southeast Africa. This would help identify potential risk factors and guide prevention strategies, and help inform needs for public health interventions around the SSA.

Subjects included adults in 300 households of each of the villages Mwandama in Malawi, Mayange in Rwanda and Mbola in Tanzania. They were selected using a stratified random sampling procedure that took into account the wealth status and gender of each household head, using the information collected in the baseline demographic and socioeconomic surveys. This ensures an accurate representation of the study population. Overall, among 1485 eligible adults (18+) agreed to participate in the study, with the average age being 41.4 years, with 48% of them being males and 52% females. All information obtained from the surveys were kept confidential and all the research team members received institutional review board training.

Assessment of exposure in this study were collected by enumerators who received a 3-day training and certification by master trainers, in the form of questionnaires. The data that was collected included information on the study participants' socio-demographic characteristics, smoking habits, work-related vigorous physical activity, alcohol intake, TV/Radio ownership and dietary habits (meat, fish, fruits/vegetables, carbohydrates amd fat). Additionally, BMI, was also calculated as weight in kilograms over heigh in meters squared. Our outcome athropometric and blood pressure measurements were conducted by health-care professional who received training using validated field protocols, using an automated measuring device OMRON 907 (OMRON, Hoofdorrp, The Netherlands). The cuff size was chosen based on mid-upper arm circumference measures, and blood pressure was measured in a sitting position after the participant rested for at least 5 min. In total, 3 measurements were taken with intervals of 3 minutes between each measurement. The average systolic and diastolic blood pressure measurements (SBP and DBP) and the Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure criteria (JNC 7 criteria) were used to define HTN status.

For the results, about 22% of the study participants had HTN, which was comparable to the age-standarized rate of 22.8% in table 1. Male participants had a higher HTN prevalence with 24% compared to female at 20%. Those with HTN had mostly Stage 1 (70%). Additionally, 44% of the study participants (49% males and 40% females) had pre-HTN. There were also traditional risk factors that were associated with HTN in this population (Table 3), including old age (P-value for trend <0.001), and higher BMI (P-value for trend=0.07). Vigorous work-related physical activity and television ownership were also associated with the prevalence of HTN (OR 0.66; 95% CI 0.47–0.93 for physical activity and OR 2.99; 95%CI 1.26–7.19 for television ownership). In addition, smoking status, alcohol intake, and radio owership were found to be not in association with HTN prevalence. As for dietary intake patterns (Table 4), the study found that higher frequencies of eating high-fat foods and meat were associated with greater odds of HTN (P-value for trend for high-fat foods and meat 0.02 and 0.07). Participants in the highest quartile of frequency of eating high-fat foods had two times the odds of HTN compared to participants in the first quartile (OR 2.08; 95%CI 1.10–3.92). Participants in the the top three quartiles for frequency of consumption of meat had approximately twofold higher odds of HTN compared with participants in the lowest quartile (P-values range from 0.03 to 0.06). Meanwhile, higher frequency of fruits/vegetables consumption was associated with lesser odds of HTN (P-value as a continuous variable=0.02 and P-value for trend in quartile regression models=0.10). Participants in the highest quartile for frequency of consuming fruit/vegetables had 54% lower odds of HTN (OR 0.47; 95%CI 0.22–1.00). Consumption of fish, high-carbohydrate foods and dairy products were not associated with prevalence of HTN in this population. Associations with dietary habit and HTN persisted after taking in consideration for potential confounding variables (age, sex, BMI, work-related vigorous activity and television ownership). Upon evaluating associations of risk factors with components of blood pressure measurements (Table 5), it was found that age, BMI and television ownership were positively associated with SBP, DBP and MABP (P-values <0.05). On the other hand, work-related vigorous physical activity was inversely associated with SBP, DBP and MABP (all P-values <0.05). Gender was only associated with SBP, whereby males had about 4 mm Hg higher SBP compared with females (P-value <0.05). Among dietary patterns, higher frequency of fruit/vegetables was associated with lower SBP, DBP and MABP (P-value <0.05).

Overall, both HTN and pre-HTN were highly prevalent in rural SSA, with male participants having higher prevalence compared with female participants. Old age, high BMI, television ownership consumption of meat/high-fat foods and less work-related vigorous physical activity were associated with higher prevalence of HTN and high blood pressure measures, while frequent intake of fruit and vegetables were associated with lower HTN prevalence and low blood pressure. These findings proved to have several strengths, as the study was conducted in stites in rural Africa, which helped represent remote and impoverished areas of SSA with chronically undernourished populations, as they are often underrepresented in other studies. To minimize measurement errors and bias, training was conducted for data collectors, and the same automated devices and standardized protocols were utilized to collect data from every participant. The participants were also selected in a systematic manner to achieve a proper representation of the SSA rural population.

However, there are a few limitations in this cross-sectional study. First of all, blood pressure was measured among participants at one point in time, which may lead to misclassification of HTN status. Dietary frequencies of fruits and vegetables are also higher than previous reports in other populations, as there could be measurement bias in how questions are interpreted by the responders. The questionnaires may not have been the best measurement tool, as the measurements may be crude. There could also be residual confounding by unmeasured variables and misclassification of measured confounders. Lastly, the study evaluated three villages in SSA, which may not apply to other parts of rural Africa, as populations could potentially have different disease and risk factor distributions.

Synthesis:

Based on the previous three studies, we can conclude that physical activity and exercise has an inverse relationship with blood pressure, and helps control hypertension/high blood pressure, as more frequent exercise levels indicate a lower HTN prevalence. The best exercise duration per week for those essential hypertensive patients to reduce their blood pressure is about 30~60 minutes, this amount is in general coincident with the guidelines of recommendation of physical activity that an adult should have more than 30 minutes of moderate physical activity per week. We also found that dietary habits also affect blood pressure, as frequent consumption of fruit and vegetables lowers blood pressure and HTN prevalence as well. To prove our main point even further, we found out that high BMI, television ownership are also associated with higher HTN. This makes the exercising a potential confounder, as higher levels of physical activity is associated with BMI. On the other hand, owning a television in the household may lead to less exercise, and hence relates to the increase of blood pressure as well. Therefore overall, there is strong evidence that higher levels of exercise will lead to lower blood pressure, and hence there is less likelihood of being diagnosed with hypertension.

Reference

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Appendix

Study I:

TABLE I Training Data for the Two Exercise Training Groups

Training Group	Weeks of Training	Sessions/ Week	Training Intensity (%$\dot{V}O_2$ max)	Session Duration (min)	Kilocalories Expended/ Week*
Moderate-intensity	37 ± 5	2.5 ± 0.5	73 ± 7	51 ± 7	1,043 ± 377
Low-intensity	37 ± 3	3.1 ± 0.9†	53 ± 5‡	51 ± 6	782 ± 266

All values are expressed as mean ± standard deviation.
* Estimated from $\dot{V}O_2$ max and training intensity and duration; † $p < 0.05$ for the comparison between the 2 groups; ‡ $p < 0.01$.

TABLE II Body Weight and Body Composition of the Three Groups

Variable	Moderate-Intensity Training Group	Low-Intensity Training Group	Control Group
Weight (kg)			
Initial	79.3 ± 10.8	69.2 ± 18.3	71.0 ± 15.5
3-month	78.7 ± 10.1	70.5 ± 19.8	—
Final	76.8 ± 9.5*	68.7 ± 18.8	70.5 ± 14.8
Percent body fat			
Initial	21 ± 7	25 ± 8	22 ± 6
Final	21 ± 8	24 ± 8	21 ± 7

All values are mean ± standard deviation.
* $p < 0.05$ for difference from initial value compared with that of both other groups.

TABLE III Hemodynamics at Rest for the Three Groups During the Study

Variable	Moderate-Intensity Training Group	Low-Intensity Training Group	Control Group
SBP			
Initial	160 ± 21	158 ± 18	152 ± 9
Final	154 ± 16	151 ± 7	151 ± 11
DBP			
Initial	100 ± 10	90 ± 10	90 ± 7
Final	91 ± 7*	87 ± 7	89 ± 4
Mean BP			
Initial	120 ± 13	113 ± 11	110 ± 7
Final	112 ± 9*	108 ± 9*	110 ± 6
CO			
Initial	4.5 ± 1.0	4.2 ± 1.0	4.7 ± 0.8
Final	4.7 ± 0.8	3.7 ± 0.9*	5.4 ± 1.8
HR			
Initial	73 ± 6	87 ± 9	75 ± 6
Final	65 ± 9†	74 ± 10†	76 ± 5
SV			
Initial	62 ± 16	49 ± 10	63 ± 13
Final	74 ± 19	51 ± 14	71 ± 25
TPR			
Initial	2,223 ± 546	2,263 ± 658	1,957 ± 417
Final	1,944 ± 325‡	2,516 ± 844	1,805 ± 623

All values are mean ± standard deviation. The BP data are those measured during the hemodynamic assessment testing session.

* $p < 0.05$ for the difference from the initial value compared with that of the control group; † $p < 0.01$; ‡ $p < 0.05$ for the difference from the initial value compared with that of the low-intensity exercise training group.

BP = blood pressure (mm Hg); CO = cardiac output (liters/min); DBP = diastolic blood pressure (mm Hg); HR = heart rate (beats/min); SBP = systolic blood pressure (mm Hg); SV = stroke volume (ml); TPR = total peripheral resistance (dynes s cm^{-5}).

TABLE IV Pressor Hormone Levels at Rest and During Submaximal Exercise in the Three Groups

Variable	Moderate-Intensity Training Group	Low-Intensity Training Group	Control Group
Plasma renin activity (ng/ml/hr)			
Initial	2.0 ± 1.3	1.6 ± 1.1	1.4 ± 0.6
Final	1.1 ± 0.9*	0.7 ± 0.4*	0.6 ± 0.5*
Plasma norepinephrine (pg/ml)			
Supine			
Initial	349 ± 198	405 ± 127	421 ± 183
Final	292 ± 161†	389 ± 171†	705 ± 511
Standing			
Initial	601 ± 282	755 ± 202	756 ± 261
Final	536 ± 137†	621 ± 260†	959 ± 479
Submaximal exercise			
Initial	915 ± 339	1,358 ± 530	1,269 ± 403
Final			
Same absolute	823 ± 407†	859 ± 182‡	1,723 ± 1,101
Same relative	1,064 ± 288	2,078 ± 1,831	1,723 ± 1,101
Plasma epinephrine (pg/ml)			
Supine			
Initial	15 ± 6	39 ± 36	53 ± 49
Final	25 ± 10	40 ± 42	152 ± 180
Standing			
Initial	19 ± 7	31 ± 28	49 ± 41
Final	27 ± 14	40 ± 41	86 ± 61
Submaximal exercise			
Initial	32 ± 18	103 ± 90	85 ± 47
Final			
Same absolute	51 ± 39	52 ± 26	133 ± 172
Same relative	64 ± 46	141 ± 153	133 ± 172
Plasma insulin (μU/ml)			
Initial	13 ± 6	15 ± 18	8 ± 2
Final	8 ± 2*	12 ± 10	9 ± 3

All values are mean ± standard deviation.

* $p < 0.01$ for comparison versus initial value in that group; † change from initial to final was significantly different from that in the control group at $p < 0.05$; ‡ $p < 0.01$.

Same absolute = exercise intensity was the same in terms of treadmill speed and grade before and after training. Same relative = patients were exercising at the same percentage of their $\dot{V}O_2$ max before and after training.

TABLE V Blood Volumes and Urinalysis Data for the Three Groups

Variable	Moderate-Intensity Training Group	Low-Intensity Training Group	Control Group
Hematocrit (%)			
Initial	42 ± 3	39 ± 3	38 ± 2
Final	42 ± 3	38 ± 4	39 ± 2
Total plasma vol (ml)			
Initial	2,971 ± 474	2,473 ± 635	2,940 ± 501
Final	3,051 ± 514	2,642 ± 640	3,046 ± 439
Plasma vol (ml/kg)			
Initial	36.2 ± 6.2	35.6 ± 4.2	38.2 ± 3.5
Final	38.7 ± 6.3	36.8 ± 3.3	41.2 ± 5.4
Total blood vol (ml)			
Initial	5,182 ± 931	4,021 ± 931	4,761 ± 873
Final	5,232 ± 954	4,229 ± 963	4,954 ± 738
Urinary Na (mM)			
Initial	70 ± 37	49 ± 34	58 ± 26
Final	64 ± 21	46 ± 26	50 ± 17
24-hour Na excretion (mmol)			
Initial	148 ± 62	117 ± 47	174 ± 74
Final	115 ± 37	104 ± 36	146 ± 56

All values are mean ± standard deviation.

There were no significant differences in either of the exercise training groups in the changes from the initial to the final value for any variables compared with that of the control group.

Na = sodium; vol = volume.

Study II:

Table 1. Changes in selected subject characteristics in groups classified by total weekly amount of exercise

	Control (n = 39)	30–60 min/wk (n = 55)	61–90 min/wk (n = 54)	91–120 min/wk (n = 21)	>120 min/wk (n = 38)	Sig.
Sex (male/female)	28/11	37/18	38/16	13/8	28/10	
Exercise time (min/wk)	0.0 ± 0.0	44.7 ± 8.6	75.1 ± 8.3	103.7 ± 8.9	165.4 ± 27.5	<.001
Age (y)	49.6 ± 7.4	48.6 ± 7.7	50.3 ± 6.7	52.1 ± 6.9	51.0 ± 7.4	.30
Height (cm)	162.8 ± 8.6	162.5 ± 9.6	160.6 ± 7.3	159.8 ± 9.8	161.8 ± 8.6	.57
Body weight (kg)						
Before	69.4 ± 7.9	67.1 ± 12.0	66.3 ± 10.3	64.0 ± 10.5	64.6 ± 10.3	.20
After	68.8 ± 7.8	66.6 ± 12.2	65.7 ± 10.1*	63.4 ± 10.0	64.0 ± 9.8*	
Body mass index (kg/m^2)						
Before	26.2 ± 2.7	25.3 ± 3.0	25.6 ± 2.9	24.9 ± 2.1	24.6 ± 2.7	.13
After	26.0 ± 2.7	25.1 ± 2.9*	25.4 ± 2.8*	24.7 ± 1.8	24.4 ± 2.5*	
Total caloric intake (kcal/day)						
Before	1930 ± 520	2181 ± 611	2095 ± 409	2085 ± 625	2005 ± 581	.20
After	1977 ± 624	1971 ± 456*	1865 ± 315*	1945 ± 545	1959 ± 463	
Salt intake (g/day)						
Before	11.9 ± 3.4	11.9 ± 3.2	12.4 ± 3.2	12.8 ± 6.1	13.1 ± 3.3	.50
After	11.5 ± 3.3	11.1 ± 3.7	11.7 ± 3.2	12.6 ± 4.3	11.5 ± 3.4	

All values are means ± SD.

* $P < .01$ *v* before; Sig. = probability of differences in baseline values among groups.

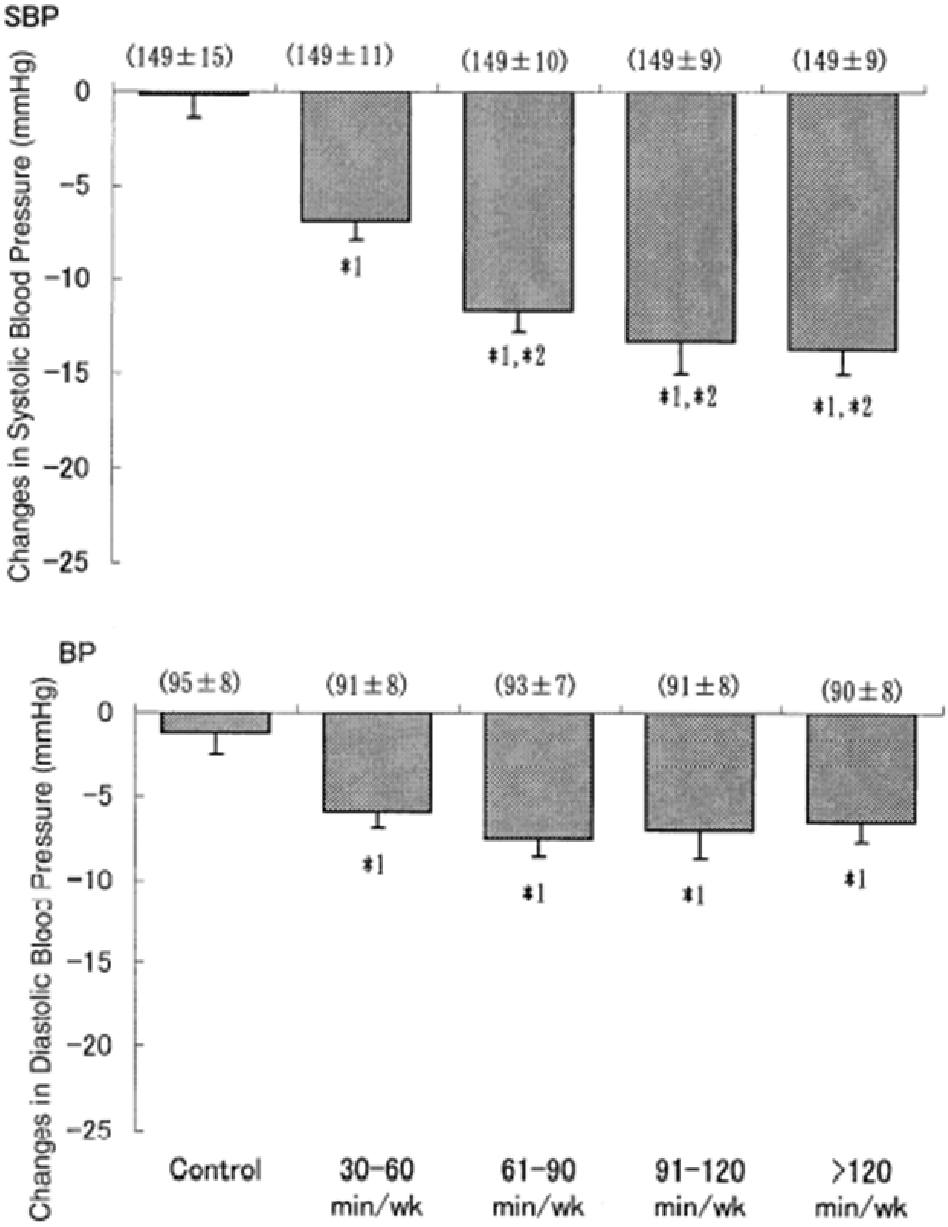

FIG. 1. Changes in resting systolic (SBP) and diastolic (DBP) blood pressure with exercise training intervention of different exercise duration. Baseline (preintervention) resting BP values are shown in parenthesis. The changes were adjusted for baseline BP, and changes in body mass and energy and salt intake. *1 < .01 *v* sedentary control; *2 < .01 *v* 30 to 60 min/wk group.

Figure 2.

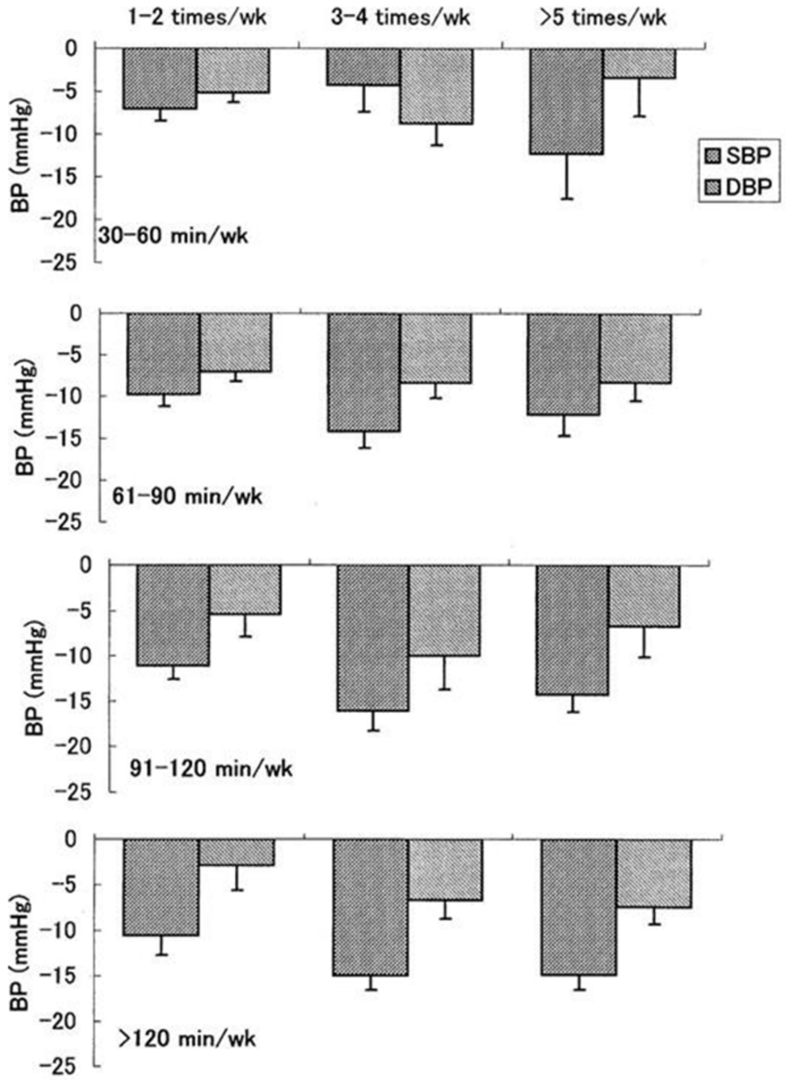
1-2 times/wk
3-4 times/wk
>5 times/wk
SBP
DBP
BP (mmHg)
30-60 min/wk
61-90 min/wk
91-120 min/wk
>120 min/wk
0
-5
-10
-15
-20
-25

Table 1 Population characteristics of the three African villages

From: Prevalence and correlates of hypertension: a cross-sectional study among rural populations in sub-Saharan Africa

Characteristics	***Mwandama (Malawi)*** **N=*408***	***Mayange (Rwanda)*** **N=*535***	***Mbola (Tanzania)*** **N=*542***	***All participants*** **N=*1485***
Age, years[a]	38.4 (16.1)	42.2 (17.3)	42.8 (17.4)	41.4 (17.1)
Male sex	163 (40)	216 (40)	328(61)	707 (48)
Current smokers	59 (14)	86 (16)	101 (19)	246 (17)
Alcohol intake[b]	22 (8)	28 (16)	1 (1)	51 (8)
Physical activity[c]	275 (67)	190 (36)	519 (97)	984 (67)
Television owners	18 (5)	9 (2)	6 (1)	33 (2)
Radio owners	269 (66)	313 (59)	285 (53)	867 (59)
BMI (kg m^{-2})[a]	21.5 (3.6)	21.3 (4.5)	21.2 (3.4)	21.3 (3.9)
Pulse, per minute	78.5 (13.3)	79.0 (12.8)	78.4 (14.9)	78.6 (13.7)
SBP (mm Hg)[a]	128.5 (20.9)	123.5 (16.6)	130.6 (18.5)	127.5 (18.8)
DBP (mm Hg)[a]	76.9 (12.1)	73.3 (10.1)	77.6 (11.9)	75.9 (11.5)

Abbreviations: BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure.

[a]Mean (s.d.), otherwise number (%).

[b]Alcohol intake$\geqslant$3 drinks per week.

[c]History of work-related vigorous physical activity (yes/no grouping).

Table 2 Prevalence of hypertension (HTN) and pre-hypertension in the three African villages

From: Prevalence and correlates of hypertension: a cross-sectional study among rural populations in sub-Saharan Africa

Hypertension status [a]	*Mwandama (Malawi)*			*Mayange (Rwanda)*			*Mbola (Tanzania)*			*All participants*		
	Male	*Female*	*Both*	*Male*	*Female*	*Both*	*Male*	*Female*	*Both*	*Male*	*Female*	*Both*
Number	163	243	406	216	319	535	328	213	542	707	704	1485
Normal blood pressure	49 (30)	97 (40)	146 (36)	75 (35)	143 (45)	220 (41)	70 (21)	72 (34)	145 (27)	194 (27)	312 (40)	507 (34)
Pre-HTN	73 (45)	92 (38)	166 (41)	107 (50)	122 (38)	229 (43)	163 (50)	88 (42)	252 (46)	343 (49)	302 (39)	647 (44)
HTN	40 (25)	53 (22)	94 (23)	34 (16)	52 (16)	86 (16)	93 (28)	52 (24)	145 (27)	167 (24)	157 (20)	325 (22)
Stage I HTN	26 (16)	31 (13)	57 (14)	28 (13)	42 (13)	70 (13)	66 (20)	34 (16)	99 (18)	119 (17)	107 (15)	226 (15)
Stage II HTN	14 (9)	22 (9)	37 (9)	6 (3)	10 (3)	16 (3)	27 (8)	18 (8)	46 (9)	47 (7)	50 (7)	98 (7)
Standardized HTN[b]	—	—	27.3	—	—	16.8	—	—	26.8	—	—	22.8

Abbreviations: DBP, diastolic blood pressure; SBP, systolic blood pressure.

Classification—normal blood pressure: SBP <120 mm Hg and DBP <80 mm Hg; pre-hypertension: SBP 120–139 mm Hg and/or DBP 80–89 mm Hg; Stage I hypertension: SBP140–159 mm Hg and/or DBP 90–99 mm Hg; Stage II hypertension: SBP ⩾160 mm Hg and/or DBP ⩾100 mm Hg.

[a]Number (%).

[b]Age standardized hypertension prevalence (%) according to WHO age distribution (Ahmad *et al.*[18]).

Table 3 Associations of selected risk factors with prevalence of hypertension

From: Prevalence and correlates of hypertension: a cross-sectional study among rural populations in sub-Saharan Africa

Characteristics	Hypertensive N (%)	Model 1 (unadjusted)		Model 2 (adjusted)		Model 3 (adjusted)	
		Odds ratio (95% CI)	P-value	Odds ratio (95% CI)	P-value	Odds ratio (95% CI)	P-value
Age, years [a]							
Continuous		**1.03 (1.03–1.04)**	**<0.001**	**1.03 (1.02–1.04)**	**<0.001**	**1.03 (1.02–1.04)**	**<0.001**
18–39	114 (14.8)	Reference	—	Reference	—	Reference	—
40–59	101 (23.2)	**1.73 (1.28–2.33)**	**<0.001**	**1.77 (1.27–2.46)**	**0.001**	**1.82 (1.28–2.59)**	**0.001**
60–79	89 (40.8)	**3.96 (2.83–5.54)**	**<0.001**	**4.00 (2.77–5.77)**	**<0.001**	**4.45 (3.01–6.58)**	**<0.001**
80+	21 (36.8)	**3.35 (1.89–5.94)**	**<0.001**	**3.00 (1.48–6.10)**	**0.002**	**2.34 (1.04–5.27)**	**0.039**
		P-value for trend	**<0.001**	*P*-value for trend	**<0.001**	*P*-value for trend	**<0.001**
Sex							
Females	157 (20.4)	Reference	—	Reference	—	Reference	—
Males	167 (23.7)	1.22 (0.95–1.56)	0.120	1.15 (0.87–1.53)	0.324	1.14 (0.84–1.54)	0.406
BMI (kg m^{-2})							
Continuous		1.02 (0.99–1.05)	0.190	1.03 (1.00–1.07)	0.062	1.03 (1.00–1.07)	0.078
<18	46 (22.7)	Reference	—	Reference	—	Reference	—
18–25	222 (20.6)	0.88 (0.62–1.27)	0.503	1.17 (0.77–1.79)	0.454	1.17 (0.75–1.80)	0.493
>25	57 (28.9)	1.39 (0.89–2.18)	0.152	**1.71 (1.01–2.88)**	**0.044**	1.64 (0.95–2.85)	0.075
		P-value for trend	0.137	*P*-value for trend	**0.042**	*P*-value for trend	0.073
Smoking status							
Non-smokers	259 (21.0)	Reference	—	Reference	—	Reference	—
Smokers	66 (26.8)	**1.38 (1.01–1.89)**	**0.045**	1.04 (0.72–1.50)	0.851	1.20 (0.81–1.77)	0.359
Alcohol intake							
Continuous		0.98 (0.53–1.78)	0.935	0.88 (0.46–1.69)	0.707	0.98 (0.50–1.89)	0.941
<3 drinks per week	129 (21.0)	Reference	—	Reference	—	Reference	—
⩾3 drinks per week	9 (17.7)	0.65 (0.28–1.49)	0.308	0.61 (0.26–1.45)	0.262	0.72 (0.30–1.75)	0.471
Radio ownership							
Do not own	136 (22.6)	Reference	—	Reference	—	Reference	—
Own	185 (21.4)	0.93 (0.73–1.20)	0.595	1.14 (0.84–1.52)	0.412	1.06 (0.78–1.45)	0.697
Television ownership							
Do not own	291 (21.1)	Reference	—	Reference	—	Reference	—
Own	11 (33.3)	1.87 (0.90–3.91)	0.094	**2.97 (1.32–6.71)**	**0.009**	**2.99 (1.26–7.19)**	**0.013**
Physical activity [b]							
Non-vigorous	94 (19.1)	Reference	—	Reference	—	Reference	—
Vigorous	229 (23.4)	0.77 (0.59–1.01)	0.060	**0.70 (0.51–0.95)**	**0.023**	**0.66 (0.47–0.93)**	**0.016**

Abbreviation: BMI, body mass index.

Bolded values are those which are significant findings ($P<0.05$).

[a]Adjusted in Model 2: as appropriate for age, sex, village and sampling variables. Model 3: as appropriate for age, sex, village, sampling variables, BMI, television ownership and work-related vigorous physical activity.

[b]Work-related vigorous physical activity.

Table 4 Food groups and risk of hypertension (HTN) in the three African villages

From: Prevalence and correlates of hypertension: a cross-sectional study among rural populations in sub-Saharan Africa

Food category	*Frequency* [a]	*N*	*HTN N (%)*	*Model 1* [b]		*Model 2* [b]		*Model 3* [b]	
				Odds ratio (95%CI)	*P-value*	*Odds ratio (95%CI)*	*P-value*	*Odds ratio (95%CI)*	*P-value*
Fruits/vegetables									
Continuous[c]	10.74 (7.03, 14.57)	665	138 (20.8)	**0.75 (0.57–1.00)**	**0.050**	0.83 (0.59–1.17)	0.285	**0.25 (0.08–0.77)**	**0.015**
Quartile 1	4.53 (3.12, 5.66)	165	41 (24.9)	Reference	—	Reference	—	Reference	—
Quartile 2	9.20 (8.22, 10.03)	170	34 (20.0)	0.76 (0.45–1.27)	0.288	0.82 (0.47–1.44)	0.489	0.64 (0.35–1.18)	0.153
Quartile 3	12.42 (11.44,13.16)	165	34 (20.6)	0.78 (0.47–1.32)	0.358	1.02 (0.55–1.88)	0.948	0.77 (0.40–1.49)	0.436
Quartile 4	19.50 (16.39, 22.31)	165	29 (17.6)	0.64 (0.38–1.100	0.108	0.77 (0.41–1.41)	0.381	0.47 (0.22–1.00)	0.051
				P-value for trend	0.134	*P*-value for trend	0.523	*P*-value for trend	0.096
Fish									
Continuous[c]	0.07 (0.03, 0.32)	665	138 (20.8)	1.16 (0.97–1.39)	0.105	1.16 (0.97–1.47)	0.091	1.67 (0.91–3.07)	0.095
Quartile 1	0.00 (0.00, 0.00)	163	38 (23.3)	Reference	—	Reference	—	Reference	—
Quartile 2	0.07 (0.03, 0.07)	173	29 (16.8)	0.66 (0.39–1.14)	0.135	0.86 (0.48–1.53)	0.600	0.84 (0.46–1.54)	0.568
Quartile 3	0.21 (0.14, 0.29)	160	37 (23.1)	0.99 (0.59–1.66)	0.968	1.48 (0.78–2.79)	0.231	1.24 (0.63–2.46)	0.534
Quartile 4	0.86 (0.35, 1.14)	169	34 (30.1)	0.83 (0.49–1.40)	0.480	1.46 (0.75–2.86)	0.267	1.21 (0.54–2.67)	0.645
				P-value for trend	0.829	*P*-value for trend	0.173	*P*-value for trend	0.554
Meat									
Continuous[c]	0.07 (0, 0.17)	665	138 (20.8)	0.91 (0.72–1.15)	0.432	0.96 (0.75–1.21)	0.708	0.78 (0.43–1.42)	0.413
Quartile 1	0.00 (0.00, 0.00)	174	34 (19.5)	Reference	—	Reference	—	Reference	—
Quartile 2	0.07 (0.03, 0.07)	187	42 (22.5)	1.19 (0.72–1.98)	0.497	1.55 (0.89–2.70)	0.124	**1.85 (1.01–3.40)**	**0.048**
Quartile 3	0.13 (0.10, 0.14)	156	34 (31.8)	1.15 (0.67–1.96)	0.613	**1.90 (1.04–3.48)**	**0.037**	**2.18 (1.08–4.39)**	**0.029**
Quartile 4	0.31 (0.21, 0.42)	148	28 (18.9)	0.96 (0.55–1.68)	0.888	1.61 (0.86–3.00)	0.137	2.06 (0.96–4.41)	0.062
				P-value for trend	0.883	*P*-value for trend	0.101	*P*-value for trend	0.066
Carbohydrates									
Continuous[c]	4.2 (2.91, 6.07)	665	138 (20.8)	0.98 (0.76–1.26)	0.873	1.14 (0.86–1.51)	0.351	2.48 (0.46–13.32)	0.291
Quartile 1	2.17 (1.39, 2.59)	170	31 (18.2)	Reference	—	Reference	—	Reference	—
Quartile 2	3.52 (3.22, 3.84)	164	41 (25.0)	1.49 (0.88–2.53)	0.134	1.54 (0.88–2.72)	0.133	1.37 (0.74–2.54)	0.317
Quartile 3	5.00 (4.47, 5.60)	167	32 (19.2)	1.06 (0.61–1.84)	0.827	1.33 (0.74–2.38)	0.341	1.15 (0.58–2.26)	0.695
Quartile 4	7.52 (6.64, 9.10)	164	34 (20.7)	1.17 (0.68–2.02)	0.565	1.60 (0.87–2.92)	0.128	1.34 (0.59–3.03)	0.485
				P-value for trend	0.894	*P*-value for trend	0.194	*P*-value for trend	0.630
Dairy									
Continuous[c]	0.07 (0, 0.86)	665	138 (20.8)	1.22 (0.99–1.37)	0.065	1.11 (0.87–1.41)	0.419	1.20 (0.80–1.80)	0.383
Quartile 1	0.00 (0.00, 0.00)	417	91 (21.8)	Reference	—	Reference	—	Reference	—
Quartiles 2/3	0.07 (0.03, 0.07)	93	17 (18.3)	0.80 (0.45–1.42)	0.450	0.89 (0.48–1.66)	0.723	0.87 (0.45–1.67)	0.667
Quartile 4	0.35 (0.29, 1.14)	155	30 (19.4)	0.86 (0.54–1.36)	0.521	0.83 (0.48–1.42)	0.485	0.59 (0.32–1.10)	0.097
				P-value for trend	0.450	*P*-value for trend	0.474	*P*-value for trend	0.104
High-fat									
Continuous[c]	0.35 (0.07, 1.29)	665	138 (20.8)	1.17 (0.99–1.37)	0.067	1.17 (0.98–1.41)	0.088	1.49 (0.87–2.56)	0.146
Quartile 1	0.00 (0.00, 0.03)	176	33 (18.8)	Reference	—	Reference	—	Reference	—
Quartile 2	0.29 (0.14, 0.29)	162	26 (16.1)	0.83 (0.47–1.46)	0.514	0.97 (0.53–1.77)	0.916	0.99 (0.52–1.88)	0.979
Quartile 3	0.97 (0.86, 1.00)	158	32 (20.3)	1.10 (0.64–1.89)	0.729	1.34 (0.74–2.40)	0.332	1.37 (0.73–2.58)	0.325
Quartile 4	2.00 (2.00, 2.07)	169	47 (27.8)	**1.67 (1.01–2.77)**	**0.047**	**1.96 (1.10–3.48)**	**0.022**	**2.08 (1.10–3.92)**	**0.024**
				P-value for trend	**0.026**	*P*-value for trend	**0.015**	*P*-value for trend	**0.016**

Abbreviation: BMI, body mass index.

Statistically significant values ($P<0.05$) have been bolded.

[a]Median daily intake (25,75%iles).

[b]Adjustments for Model 1: none. Model 2: age, sex and village, sampling variables. Model 3: Model 2 variables, BMI, television ownership, work-related vigorous physical activity and other food group consumption.

[c]Log-converted frequency of daily dietary intake as a continuous variable.

Table 5 Associations of SBP, DBP and MABP with selected risk factors

From: Prevalence and correlates of hypertension: a cross-sectional study among rural populations in sub-Saharan Africa

Risk factors	*SBP*		*DBP*		*MABP*	
	β estimates±s.e.	*P-value*	*β estimates±s.e.*	*P-value*	*β estimates±s.e.*	*P-value*
Selected risk factors [a]						
Age, years	**0.28±0.03**	**<0.001**	**0.08±0.02**	**<0.001**	**0.15±0.02**	**<0.001**
Male sex	**4.23±1.05**	**<0.001**	−0.59±0.68	0.389	0.95±0.74	0.200
BMI (kg m^{-1a})	**0.58±0.13**	**<0.001**	**0.19±0.09**	**0.027**	**0.34±0.09**	**<0.001**
Physical activity (yes/no)	**−3.61±1.11**	**0.001**	**−2.30±0.72**	**0.001**	**−2.68±0.78**	**0.001**
TV ownership (yes/no)	**8.13±3.52**	**0.022**	**8.08±2.28**	**<0.001**	**8.09±2.49**	**0.001**
Dietary factors [b]						
Fruits/vegetables	**−6.13±2.80**	**0.031**	**−3.94±1.96**	**0.047**	**−4.67±2.11**	**0.029**
Fish	0.72±1.61	0.656	0.13±1.13	0.911	0.32±1.21	0.789
Meat	−0.51±1.56	0.746	−0.71±1.09	0.515	−0.64±1.18	0.585
Carbohydrates	2.29± 4.43	0.607	1.15±3.10	0.712	1.53±3.34	0.648
Dairy	1.36±1.10	0.220	−0.88±0.77	0.258	−0.13±0.83	0.874
Fat	−0.10±1.23	0.435	1.13±0.86	0.191	0.72±0.92	0.438

Abbreviations: BMI, body mass index; DBP, diastolic blood pressure; MABP, mean arterial blood pressure; SBP, systolic blood pressure; TV, television.

Statistically significant values (P<0.05) have been bolded.

[a]β estimates (s.e.) of models evaluating associations of SBP, DBP and MABP with risk factors adjusted for age, sex, village, sampling variables, BMI, TV ownership and work-related vigorous physical activity among ~1400 study participants.

[b]β estimates (s.e.) of models evaluating associations of SBP, DBP and MABP with dietary factors (log-converted frequency of daily dietary intake as continuous variables) adjusted for age, sex, village, sampling variables, BMI, TV ownership, work-related vigorous physical activity and other dietary intakes (as appropriate) among ~600 study participants.