www.thieme.com

Plasma Steroids are not Associated with Resting and Exercise Blood Pressure

DOI 10.1055/a-0660-0121
Int J Sports Med 2018; 39: 967–971

Publishing House and Copyright:
© 2018 by
Georg Thieme Verlag KG
Rüdigerstraße 14
70469 Stuttgart
ISSN 0172-4622

Thieme

Thieme

Plasma Steroids are not Associated with Resting and Exercise Blood Pressure

Authors
Zihong He[1], Tuomo Rankinen[2], Arthur S. Leon[3], James Skinner[4], André Tchernof[5], Claude Bouchard[2]

Affiliations
1 China Institute of Sport Science, Biology Center, Beijing, China
2 Pennington Biomedical Research Center, Human Genomics Laboratory, Baton Rouge, United States
3 School of Kinesiology, University of Minnesota, Minneapolis, United States
4 Kinesiology, Indiana University, Brevard, United States
5 School of Nutrition, Laval University, Quebec City, Canada

Key words
hypertension, sedentary, endurance exercise, submaximal intensity

accepted 12.07.2018

Bibliography
DOI https://doi.org/10.1055/a-0660-0121
Published online: 5.10.2018
Int J Sports Med 2018; 39: 967–971

ISSN 0172-4622

Correspondence
Dr. Claude Bouchard
Pennington Biomedical Research Center
Human Genomics Laboratory
6400 Perkins Rd
Baton Rouge
70808 United States
Tel.: +1/225/763 2663, Fax: +1/225/763 2525
claude.bouchard@pbrc.edu

ABSTRACT

We investigated the associations between steroid hormones and resting and exercise blood pressure in the sedentary state and in response to an exercise program controlling for sex, body mass, ethnicity, age, oral contraceptives, hormone therapy, smoking and alcohol intake in subjects from the HERITAGE Family Study. In the sedentary state, 267 men (28 % Blacks) and 301 women (37 % Blacks) were available, and 241 men and 254 women completed the exercise program. Fourteen steroid hormones and sex hormone-binding globulin concentrations were assayed in a fasted state. Statistical significance was set at a Bonferroni adjusted $p < 0.0001$. After controlling for the various covariates, only testosterone came close to a significant correlation with exercise systolic blood pressure at 50 W ($r = -0.21$, $P = 0.0006$) in men. No other correlations with resting and exercise blood pressure traits were found at baseline. There were significant changes in blood pressure in response to the exercise program, but none of the correlations with baseline plasma steroids reached statistical significance. Plasma steroids do not correlate with resting and exercise blood pressure in sedentary adults and do not associate with blood pressure changes in response to a 20-week endurance exercise program.

Introduction

Steroid hormones are mainly synthesized from cholesterol in the gonads and adrenal glands, but some are also produced in other tissues such as skeletal muscle [19], adipose tissue, liver and others [10, 11]. Steroid hormones can be grouped into two classes, corticosteroids and sex steroids, resulting in five types of hormones, depending on the receptors to which they bind, namely glucocorticoids, mineralocorticoids, androgens, estrogens, and progestogens. Steroid hormones are generally carried in the blood, bound to specific carrier proteins such as sex hormone-binding globulin (SHBG) [8] or corticosteroid-binding globulin [15].

Mineralocorticoids participate in the regulation of salt and water concentrations and can contribute to retention and hypertension [16]. Mineralocorticoid antagonists are effective blood pressure (BP)-lowering agents in hypertension [2]. Estrogens and androgens have also been implicated in the development of hypertension, with estrogens perceived as protective and androgens detrimental in women but the opposite in men [14]. The effect of post-menopausal hormone therapy (PMHT) on BP remains controversial [18].

Testosterone (TESTO) replacement therapy in men with TESTO deficiency was reported to improve overall health including reduced systolic blood pressure (SBP) and diastolic blood pressure (DBP) [21]. Inverse associations have been observed between blood pressure and TESTO accounting for 19 %–36 % of the variance in SBP and DBP [12]. Endogenous dehydroepiandrosterone sulfate (DHEAS) levels were higher in hypertensive than in normotensive individuals [20], while cortisol (CORT) and CORT: DHEAS ratio were positively associated with hypertension in male subjects [5].

Exercise programs lower average resting BP in adults with normal BP but more so in those with high normal BP or with hypertension, with clinically relevant treatment effects [3, 17]. However, there is little information on the relationships between plasma steroid hormone levels in the physiological range in healthy sedentary individuals with resting and exercise BP at baseline, as well as in response to a standardized exercise program.

The purpose of this study was to investigate the relationships between plasma steroid hormone levels with resting and exercise BP, taking into account the effects of body mass index (BMI), sex, ethnicity, age, menopause status, oral contraceptives (OC), PMHT, smoking and alcohol intake before and in response to a highly controlled, 20-week exercise training program in 568 healthy and previously sedentary subjects from the HERITAGE Family Study.

Materials and Methods

The HERITAGE Family Study cohort has been previously described [4]. Sedentary subjects aged 17 to 65 years took part in a standardized 20-week endurance exercise program. At baseline, subjects completed a questionnaire that included smoking and alcohol consumption habits. For the present study, subjects were classified in the following categories: current-smoker or non-smoker; current-drinker or non-drinker. The study protocol had been previously approved by the institutional review board at each of the four clinical centers of HERITAGE, and it meets the ethical standards of the International Journal of Sports Medicine[9]. Informed written consent was obtained from each subject.

Endurance exercise training program

Each participant trained on a cycle ergometer three times per week for 20 weeks, as detailed elsewhere [4]. Briefly, subjects trained at a heart rate (HR) associated with 55 % of baseline VO_2max for 30 min per session for the first two weeks. The duration and intensity were gradually increased every two weeks, until reaching 50 min and 75 % of the HR associated with baseline VO_2max. This level was maintained for the final six weeks of training. Each exercise session was individually supervised, and adherence to the protocol was strictly enforced.

Blood pressure measurement

Multiple BP measurements were obtained at baseline and after 20 weeks of exercise as detailed elsewhere [4, 24]. Briefly, SBP and DBP and HR measures were taken using the Colin STBP-780 automated BP unit (San Antonio, TX). For the resting BP measurements, participants reported to the laboratory before 11:00 a.m., having refrained from tobacco and caffeine products for at least two hours and having performed no formal exercise in the previous 12 h. A series of four to eight HR and BP measurements were obtained at the same time on each of two separate days, both pre- and post-training. The exercise BP, at 50 W (SBP50W and DBP50W) and at 60 % (SBP60 % and DBP60 %) of the initial VO_2max measurements, was also obtained on two separate days, both pre- and post-training. Identical measurement protocols were used pre- and post-training, with the exception that post-training measurements were obtained at 24 h and then 72 h after the last training bout. We also calculated mean BP (MBP) as follows: MBP = DBP + [0.333 × (SBP-DBP)] and rate pressure product (RPP) as HR × SBP. The response to exercise (Δ) was computed as the difference between mean post-training and baseline values.

Plasma steroid hormone and SHBG concentrations

The hormonal assays have been previously described [6, 22]. Fourteen steroid hormones or their derivatives and SHBG concentrations were assayed: dehydroepiandrosterone (DHEA), DHEAS, androstenedione (DELTA4), TESTO, dihydrotesterone (DHT), androstane 3α17βdiol glucuronide (DIOLG), androsterone glucuronide (ADTG), pregnenolone fatty acid ester (PREGE), progesterone (PROG), estradiol (E2), aldosterone (ALDO), and CORT. Additionally, three ratios were calculated: free androgen index (FAI), E2/TESTO and CORT/DHEAS.

Statistical analysis

The present study is based on sedentary adults from the HERITAGE Family Study who had a complete hormonal and BP profile at baseline and in those who were defined as completers of the HERITAGE standardized exercise training program [24]. The mean of two measurements both in the sedentary state (at baseline) and post exercise program for all hormones and SHBG levels were used. Data from men and women were analyzed separately. Analyses of score distributions revealed no indication of skewness problems (skewness < 3.0) requiring transformation. Paired t-tests were used to compare pre and post exercise program BP variables.

In men, Pearson product-moment correlations were used to quantify the relationships between baseline fasting plasma steroid hormones, SHBG concentration, FAI, E2/TESTO, and CORT/DHEAS ratios with baseline resting and exercise blood pressures (after adjustment for age, ethnicity, BMI, smoking status and alcohol intake) and their responses to the exercise program (after adjustment for age, ethnicity, BMI, smoking status, alcohol status and baseline value). In women, menopause status and OC/PMHT status were added as covariates. There was no indication of non-linearity in the bivariate relationships that could impact the findings of the study. All analyses were performed using the SAS statistical package (SAS Institute, Inc., Cary, NC). Given the number of statistical tests performed, a Bonferroni adjusted level of significance was calculated and set at a p-value threshold of < 0.0001.

Results and Discussion

At baseline, there were 267 men and 301 women with complete data (28 % of males and 37 % of females were Blacks). Data from only the completers [4] of the exercise program were used to investigate the BP responses to regular exercise: 241 men and 254 women (26 % of men and 35 % of women were Blacks) were defined

▶ **Table 1** Partial correlations between baseline plasma steroid hormone levels and baseline exercise blood pressure at submaximal exercise intensities in men (N = 267) and women (N = 301).

	Men						Women			Women		
	SBP50W	**DBP50W**	**MBP50W**	**SBP60%**	**DBP60%**	**MBP60%**	**SBP50W**	**DBP50W**	**MBP50W**	**SBP60%**	**DBP60%**	**MBP60%**
ADTG	0.01	0.03	0.02	0.01	0.04	0.03	0.07	−0.04	0.02	0.14	0.03	0.09
ALDO	−0.02	−0.06	−0.05	0.07	−0.09	−0.01	0.03	0.00	0.02	0.07	0.06	0.07
CORT	0.09	0.02	0.06	0.09	−0.06	0.01	0.05	−0.01	0.02	0.11	0.03	0.08
DELT4	−0.10	−0.07	−0.10	−0.13	−0.13	−0.16	0.03	−0.03	0.00	0.07	−0.04	0.01
DHEA	0.04	−0.04	−0.01	0.00	−0.05	−0.03	0.04	−0.08	−0.02	0.02	−0.13	−0.07
DHEAE	0.06	−0.05	0.00	0.05	−0.01	0.02	0.10	0.00	0.06	0.16	0.02	0.10
DHEAS	0.01	0.01	0.01	0.05	0.09	0.09	0.08	0.02	0.06	0.17	0.01	0.10
DHT	−0.18	−0.08	−0.14	−0.18	−0.12	−0.18	0.07	0.01	0.05	0.08	0.05	0.08
DIOLG	0.06	0.07	0.08	0.09	0.08	0.11	0.08	−0.04	0.02	0.13	0.04	0.10
E2	−0.13	−0.16	−0.16	−0.14	−0.12	−0.16	−0.06	0.06	0.00	0.03	0.04	0.03
OHPROG	−0.05	−0.12	−0.10	0.03	−0.14	−0.07	−0.13	−0.16	−0.17	−0.09	0.08	−0.15
PREGE	0.02	0.03	0.03	0.03	0.03	0.03	0.02	−0.01	0.01	0.04	0.00	0.03
PROG	0.01	0.00	0.01	0.05	−0.01	0.02	−0.06	−0.09	−0.09	−0.00	−0.08	−0.05
SHBG	−0.00	0.01	0.00	−0.09	0.00	−0.05	−0.02	0.00	−0.01	−0.03	−0.01	−0.02
TESTO	**−0.21** **	−0.11	−0.18	−0.19	−0.13	−0.19	0.01	−0.03	−0.02	−0.05	−0.04	−0.05
FAI	−0.17	−0.08	−0.14	−0.10	−0.12	−0.13	0.05	−0.01	0.02	0.07	0.03	0.06
E2/T	−0.04	−0.14	−0.11	−0.07	−0.08	−0.09	−0.07	0.05	−0.01	−0.02	0.08	0.04
CORT/DHEAS	0.12	0.08	0.11	0.06	−0.03	0.02	0.04	0.02	0.03	0.00	0.04	0.03

Age, ethnicity, BMI, smoking status, alcohol intake, oral contraceptives/post-menopausal hormone therapy (in women), and menopause status (in women) were controlled for in the partial correlations; Systolic Blood Pressure: SBP; Diastolic Blood pressure: DBP; MBP = DBP + [0.333 * (SBP-DBP)]. 50 = during cycle exercise in steady state at 50W; 60 = during cycle exercise in steady state at 60% of VO_2max. ** : P = 0.0006; The coefficients were calculated with the mean of two baseline assays for each steroid based on blood samples obtained on two different days under standardized conditions. Likewise, the baseline exercise BP measurements were obtained from two tests performed on two different days; the mean of two valid measurements was calculated for each BP variable.

as HERITAGE completers (▶ **Table S1**). At baseline, there were 78 current smokers (60 % females), 490 non-smokers, 266 alcohol consumers (46 % females), and 302 non-drinkers. Of these, 264 were pre-menopausal and 37 post-menopausal. Among them, 83 pre-menopausal women were on OC and 18 post-menopausal women reported engaging in PMHT. Among the completers of the exercise program, there were 65 current smokers (63 % females), 430 non-smokers, 239 current consumers of alcohol (43 % females), and 256 non-drinkers. There were 221 pre-menopausal and 33 post-menopausal women who completed the exercise program. Among them, 76 were on OC, and 16 were post-menopausal women on PMHT.

Table S1 also shows BP values at baseline and in response to the exercise program under resting and exercise conditions stratified by age, sex and ethnicity. SBP and DBP at 50 W (SBP50W and DBP50W) and DBP at 60 % VO_2max (DBP60 %) were all significantly reduced with the exercise program.

Steroids and BP in the sedentary state

The correlations between steroid hormone concentrations with resting and exercise BP at baseline for men and women are presented in ▶ **Table 1**. Shown are partial correlations, controlling for age, BMI, sex, ethnicity, smoking status, alcohol status, OC/PMHT (in women), and menopause status (in women). Only TESTO was marginally correlated with SBP50W ($P = 0.0006$). No significant correlations were found in the sedentary state (**Table S2**).

Steroids and BP response to exercise training

In response to the exercise program, SBP50W and DBP50W, as well as DBP60 %, changed significantly, but individual differences in response (Δ) were large (see ▶ **Table S1**). In brief, there were no significant correlations between baseline hormonal levels and the responses to the exercise program for SBP and DBP traits in men (**Table S3**) or women (**Table S4**). High BP is one of the leading risk factors for cardiovascular disease [23] and kidney disorders [1]. It has been suggested that plasma sex steroids may influence many factors that control BP [7, 13]. However, our study does not support this view when plasma steroid concentrations are in the physiological range in apparently healthy adults of both sexes as we found that resting and exercise BP in the sedentary state and in response to regular exercise were independent of plasma steroid levels.

Strengths of the study

The present study is characterized by several strong points. It is based on a relatively large sample and critical covariates were available including ethnicity, smoking status, alcohol status, OC/PMHT and menopause status. Two blood samples obtained on consecutive days were used to assay the steroid hormones. Of particular significance, all blood samples were drawn in the early follicular phase of the menstrual cycle for eumenorrheic women. Furthermore, as a large number of significant tests were performed, an alpha threshold of $p < 0.0001$ was used to reduce the risk of false positive results. Additionally, the mean value of all exercise BP traits changed significantly ($p < 0.0001$) and in the expected directions in response to the standardized exercise program.

Conclusion

We conclude that a detailed plasma steroid profile does not associate with resting and exercise blood pressure in sedentary adults and does not correlate with blood pressure changes in response to a 20-week endurance exercise program.

Acknowledgements

The HERITAGE Family Study has been supported over the years by multiple grants from the National Institute for Heart, Lung and Blood Diseases of the National Institutes of Health (HL45670, C. Bouchard and T. Rankinen; HL47323, A.S. Leon; HL47327, J.S. Skinner). CB is partially funded by the John W. Barton Sr. Chair in Genetics and Nutrition. CB is also supported in part by a COBRE center grant from the National Institute of Health (NIH8 1P30GM118430-02). Zihong He is funded by the China Scholarship Council (File No. 201603620001) and China Institute of Sport Science (2015-01, 2016-01). We would like to express our gratitude to Dr. Alain Belanger (retired) and his staff from the Molecular Endocrinology Laboratory of the Laval University Medical Center in Quebec City, Canada, for the assays of the steroids and their dedication to the HERITAGE Family Study. Disclosures AT receives research funding from Johnson & Johnson Medical Companies for studies unrelated to the present paper.

Conflict of Interest

No conflict of interest has been declared by the authors.

References

[1] Appel LJ, Wright JT Jr., Greene T, Agodoa LY, Astor BC, Bakris GL, Cleveland WH, Charleston J, Contreras G, Faulkner ML, Gabbai FB, Gassman JJ, Hebert LA, Jamerson KA, Kopple JD, Kusek JW, Lash JP, Lea JP, Lewis JB, Lipkowitz MS, Massry SG, Miller ER, Norris K, Phillips RA, Pogue VA, Randall OS, Rostand SG, Smogorzewski MJ, Toto RD, Wang X, Group ACR. Intensive blood-pressure control in hypertensive chronic kidney disease. N Engl J Med 2010; 363: 918–929

[2] Bazoukis G, Thomopoulos C, Tsioufis C. Effect of mineralocorticoid antagonists on blood pressure lowering: Overview and meta-analysis of randomized controlled trials in hypertension. J Hypertens 2018; 36: 987–994

[3] Borjesson M, Onerup A, Lundqvist S, Dahlof B. Physical activity and exercise lower blood pressure in individuals with hypertension: Narrative review of 27 RCTs. Br J Sports Med 2016; 50: 356–361

[4] Bouchard C, Leon AS, Rao DC, Skinner JS, Wilmore JH, Gagnon J. The HERITAGE family study. Aims, design, and measurement protocol. Med Sci Sports Exerc 1995; 27: 721–729

[5] Carroll D, Phillips AC, Lord JM, Arlt W, Batty GD. Cortisol, dehydroepiandrosterone sulphate, their ratio and hypertension: evidence of associations in male veterans from the Vietnam Experience Study. J Hum Hypertens 2011; 25: 418–424

[6] Couillard C, Gagnon J, Bergeron J, Leon AS, Rao DC, Skinner JS, Wilmore JH, Despres JP, Bouchard C. Contribution of body fatness and adipose tissue distribution to the age variation in plasma steroid hormone concentrations in men: The HERITAGE Family Study. J Clin Endocrinol Metab 2000; 85: 1026–1031

[7] Dubey RK, Oparil S, Imthurn B, Jackson EK. Sex hormones and hypertension. Cardiovasc Res 2002; 53: 688–708

[8] Hammond GL. Plasma steroid-binding proteins: Primary gatekeepers of steroid hormone action. J Endocrinol 2016; 230: R13–R25

[9] Harriss DJ, Macsween A, Atkinson G. Standards for ethics in sport and exercise science research: 2018 update. Int J Sports Med 2017; 38: 1126–1131

[10] Labrie F. All sex steroids are made intracellularly in peripheral tissues by the mechanisms of intracrinology after menopause. J Steroid Biochem Mol Biol 2015; 145: 133–138

[11] Luu-The V, Labrie F. The intracrine sex steroid biosynthesis pathways. Prog Brain Res 2010; 181: 177–192

[12] Malan NT, Hamer M, Schutte AE, Huisman HW, van Rooyen JM, Schutte R, Mels CM, Steyn HS, Smith W, Fourie CM, Glyn M, Malan L. Low testosterone and hyperkinetic blood pressure responses in a cohort of South African men: The SABPA Study. Clin Exp Hypertens 2013; 35: 228–235

[13] Maranon R, Reckelhoff JF. Sex and gender differences in control of blood pressure. Clin Sci (Lond) 2013; 125: 311–318

[14] Maric-Bilkan C, Manigrasso MB. Sex differences in hypertension: Contribution of the renin-angiotensin system. Gend Med 2012; 9: 287–291

[15] Meyer EJ, Nenke MA, Rankin W, Lewis JG, Torpy DJ. Corticosteroid-binding globulin: A review of basic and clinical advances. Horm Metab Res 2016; 48: 359–371

[16] Mundell L, Lindemann R, Douglas J. Monitoring long-term oral corticosteroids. BMJ Open Qual 2017; 6: e000209

[17] Pescatello LS, Franklin BA, Fagard R, Farquhar WB, Kelley GA, Ray CA. American College of Sports M. American college of sports medicine position stand. Exercise and hypertension. Med Sci Sports Exerc 2004; 36: 533–553

[18] Pimenta E. Hypertension in women. Hypertens Res 2012; 35: 148–152

[19] Sato K, Iemitsu M. Exercise and sex steroid hormones in skeletal muscle. J Steroid Biochem Mol Biol 2015; 145: 200–205

[20] Schunkert H, Hense HW, Andus T, Riegger GA, Straub RH. Relation between dehydroepiandrosterone sulfate and blood pressure levels in a population-based sample. Am J Hypertens 1999; 12: 1140–1143

[21] Traish AM. Testosterone therapy in men with testosterone deficiency: Are the benefits and cardiovascular risks real or imagined? Am J Physiol Regul Integr Comp Physiol 2016; 311: R566–R573

[22] Ukkola O, Gagnon J, Rankinen T, Thompson PA, Hong Y, Leon AS, Rao DC, Skinner JS, Wilmore JH, Bouchard C. Age, body mass index, race and other determinants of steroid hormone variability: The HERITAGE Family Study. Eur J Endocrinol 2001; 145: 1–9

[23] Vasan RS, Larson MG, Leip EP, Evans JC, O'Donnell CJ, Kannel WB, Levy D. Impact of high-normal blood pressure on the risk of cardiovascular disease. N Engl J Med 2001; 345: 1291–1297

[24] Wilmore JH, Stanforth PR, Gagnon J, Rice T, Mandel S, Leon AS, Rao DC, Skinner JS, Bouchard C. Heart rate and blood pressure changes with endurance training: The HERITAGE Family Study. Med Sci Sports Exerc 2001; 33: 107–116

Supplementary Material

▶ **Table S1** Basic characteristics of sedentary males and females.

		Baseline			Training response (%)	
	N	SBP	DBP	N	SBP	DBP
Resting						
Men						
All	267	121 ± 11	69 ± 8	241	−0.33 ± 5.20 (−10.52-9.86)	−0.04 ± 8.21 (−16.13-16.05)
Blacks	76	124 ± 10	73 ± 7	63	−1.53 ± 5.81 (−12.92-9.86)	−0.61 ± 9.59 (−19.41-18.19)
Whites	191	120 ± 10	68 ± 9	178	0.09 ± 4.92 (−9.55-9.73)	0.16 ± 7.68 (−14.89-15.21)
17-29 yrs	126	121 ± 9	66 ± 8	112	−0.61 ± 5.16 (−10.72-9.50)	0.39 ± 9.32 (−17.88-18.67)
30-49 yrs	82	122 ± 10	72 ± 7	76	−0.55 ± 5.23 (−10.80-9.70)	−0.20 ± 8.16 (−16.19-15.79)
50-65 yrs	59	122 ± 14	73 ± 9	53	0.54 ± 5.28 (−9.81-10.89)	−0.74 ± 5.37 (−11.27-9.79)
Women						
All	301	117 ± 12	67 ± 9	254	−0.00 ± 5.76 (−11.29-11.29)	0.50 ± 8.40 (−15.96-16.96)
Blacks	112	123 ± 14	73 ± 9	88	−1.12 ± 5.85 (−12.59-10.35)	−0.11 ± 8.38 (−16.53-16.31)
Whites	189	113 ± 10	64 ± 7	166	0.59 ± 5.64 (−10.46-11.64)	0.82 ± 8.42 (−15.68-17.32)
17-29 yrs	149	113 ± 9	64 ± 8	123	−0.32 ± 4.87 (−9.23-9.87)	0.46 ± 9.64 (−18.43-19.35)
30-49 yrs	106	120 ± 14	71 ± 9	91	0.14 ± 6.17 (−11.95-12.23)	0.40 ± 7.06 (−13.44-14.24)
50-65 yrs	46	121 ± 14	69 ± 7	40	0.67 ± 7.26 (−13.56-14.90)	0.84 ± 7.23 (−13.33-15.01)
Exercise at 50 W						
Men						
All	267	149 ± 18	74 ± 12	241	−4.11 ± 6.99 (−17.8-9.59) ***	−4.62 ± 8.21 (−20.71-11.47) ***
Blacks	76	153 ± 18	80 ± 10	63	−5.01 ± 7.09 (−18.91-8.89) ***	−6.62 ± 7.18 (−20.69-7.45) ***
Whites	191	147 ± 18	72 ± 11	178	−3.79 ± 6.94 (−17.39-9.81) ***	−3.91 ± 8.46 (−20.49-12.67) ***
17-29 yrs	126	142 ± 12	68 ± 9	112	−2.72 ± 6.42 (−15.30-9.86) ***	−3.30 ± 8.61 (−20.18-13.58) ***
30-49 yrs	82	149 ± 17	78 ± 10	76	−4.59 ± 7.11 (−18.53-9.35) ***	−5.45 ± 7.35 (−19.86-8.96) ***
50-65 yrs	59	163 ± 22	81 ± 12	53	−6.36 ± 7.40 (−20.86-8.14) ***	−6.21 ± 8.23 (−22.34-9.92) ***
Women						
All	301	147 ± 21	73 ± 12	254	−5.0 ± 7.18 (19.08-9.06) ***	−5.90 ± 9.64 (−24.79-12.99) ***
Blacks	112	155 ± 21	79 ± 11	88	−6.00 ± 6.75 (−19.23-7.23) ***	−7.22 ± 8.90 (−24.66-10.22) ***
Whites	189	143 ± 20	70 ± 11	166	−4.48 ± 7.36 (−18.91-9.95) ***	−5.19 ± 9.92 (−24.63-14.26) ***
17-29 yrs	149	138 ± 14	67 ± 9	123	−3.97 ± 6.87 (−17.43-9.50) ***	−4.80 ± 10.70(−25.77-16.17) ***
30-49 yrs	106	152 ± 21	79 ± 12	91	−5.09 ± 7.19 (−19.18-9.00) ***	−6.90 ± 8.14 (−22.85-9.05) ***
50-65 yrs	46	166 ± 24	80 ± 8	40	−8.02 ± 7.40 (−22.52-6.48) ***	−6.97 ± 9.19 (−24.98-11.04) ***
Exercise at 60 % VO_2max						
Men	N			N		
All	267	149 ± 18	74 ± 12	241	−0.45 ± 8.06 (−16.25-15.35)	−5.92 ± 9.52 (−24.58-12.74) ***
Blacks	76	178 ± 20	81 ± 11	63	−0.93 ± 8.16 (−16.92-15.06)	−6.80 ± 8.25 (−22.97-9.37) ***
Whites	191	175 ± 18	74 ± 12	178	−0.28 ± 8.05 (−16.06-15.50)	−5.60 ± 9.95 (−25.10-13.90) ***
17-29 yrs	126	173 ± 17	69 ± 10	112	0.64 ± 8.14 (−15.31-16.59)	−4.25 ± 10.47(−24.77-16.27) ***
30-49 yrs	82	177 ± 19	80 ± 10	76	−1.48 ± 8.34 (−17.83-14.87)	−7.03 ± 8.70 (−24.08-10.02) ***
50-65 yrs	59	181 ± 18	84 ± 12	53	−1.27 ± 7.32 (−15.62-13.08)	−7.87 ± 8.00 (−23.55-7.81) ***
Women						
All	301	147 ± 21	76 ± 12	254	0.63 ± 7.54 (−15.41-14.19)	−6.35 ± 9.37 (−24.72-12.02) ***
Blacks	112	157 ± 19	80 ± 11	88	1.29 ± 8.64 (−15.64-18.22)	−8.02 ± 8.34 (−24.37-8.33) ***
Whites	189	153 ± 17	71 ± 11	166	0.28 ± 6.89 (−13.22-13.78)	−5.30 ± 9.77 (−24.45-13.85) ***
17-29 yrs	149	149 ± 15	69 ± 10	123	0.92 ± 6.49 (−11.80-13.64)	−5.79 ± 9.89 (−25.17-13.59) ***
30-49 yrs	106	157 ± 17	80 ± 12	91	1.18 ± 8.41 (−15.30-17.66)	−6.65 ± 8.65 (−23.60-10.30) ***
50-65 yrs	46	164 ± 21	80 ± 8	40	−1.51 ± 8.26 (−17.70-14.68)	−6.71 ± 9.46 (−25.25-11.83) ***

Mean ± SD; BMI: body weight (kg)/height $(m)^2$; *** : P < 0.0001, paired-test between pre-variables and post-variables after training; Training response (%) = [(post-training minus pre-training)/pre-training] x 100; Training response of resting SBP = ([(72 h post-training BP + 24 h post training BP)/2]-baseline) x 100; The baseline and post-training exercise BP measurements were obtained from two tests performed on two different days; the mean of two valid measurements was calculated for each BP variable at baseline as well as the mean of two valid measurements obtained at 24 and 72 h post-training.

▶ **Table S2** Partial correlations between baseline plasma steroid hormone levels and baseline resting blood pressure in men (N = 267) and women (N = 301).

	Men				Women			
	SBP	**DBP**	**MBP**	**RPP**	**SBP**	**DBP**	**MBP**	**RPP**
ADTG	0.04	0.03	0.03	0.14	0.14	0.13	0.14	0.05
ALDO	0.01	−0.09	−0.05	0.04	0.09	0.05	0.07	0.12
CORT	0.14	−0.03	0.04	0.17	0.14	0.01	0.07	0.07
DELT4	0.02	−0.06	−0.03	0.01	0.08	0.09	0.09	0.10
DHEA	0.07	−0.07	−0.01	0.01	0.09	0.05	0.07	0.03
DHEAE	0.03	0.02	0.02	0.03	0.09	0.08	0.09	−0.02
DHEAS	0.12	0.06	0.09	0.13	0.16	0.10	0.14	0.16
DHT	−0.06	−0.07	−0.08	−0.09	0.07	0.07	0.08	0.02
DIOLG	0.09	0.09	0.10	0.17	0.12	0.14	0.14	0.01
E2	−0.01	0.04	0.02	0.00	−0.09	0.06	−0.01	−0.07
OHPROG	0.09	−0.09	−0.02	0.04	−0.10	−0.11	−0.12	−0.02
PREGE	0.07	0.05	0.07	0.03	0.05	0.02	0.03	−0.05
PROG	0.11	−0.01	0.04	0.13	−0.02	−0.05	−0.04	−0.01
SHBG	0.02	−0.08	0.04	−0.10	−0.07	−0.05	−0.06	−0.11
TESTO	−0.01	−0.09	−0.06	−0.03	0.04	0.03	0.04	0.03
FAI	−0.05	−0.02	−0.04	0.11	0.10	0.11	0.11	0.10
E2/T	−0.04	0.05	−0.02	−0.05	−0.07	0.07	0.01	−0.04
CORT/DHEAS	0.05	−0.07	−0.02	0.04	−0.07	−0.08	−0.08	−0.08

Age, ethnicity, BMI, smoking status, alcohol intake and oral contraceptives/post-menopausal hormone therapy (in women), menopause status (in women) were controlled in the partial correlations between baseline plasma steroid hormone levels and baseline resting and exercise blood pressure at submaximal intensity; Systolic Blood Pressure: SBP; Diastolic Blood pressure: DBP; MBP = DBP + [0.333 × (SBP-DBP)];Rate Pressure Product (RPP) = Heart Rate (HR) × SBP

▶ **Table S3** Partial correlations between baseline plasma steroid hormone levels and training response (△) of resting and exercise blood pressure at submaximal exercise intensities in men (N = 241)

	Resting								Submaximal					
	24hSBP	**24hDBP**	**24hMBP**	**24RPP**	**72hSBP**	**72hDBP**	**72hMBP**	**72RPP**	**SBP50W**	**DBP50W**	**MBP50W**	**SBP60 %**	**DBP60 %**	**MBP60 %**
ADTG	0.04	0.07	0.06	0.14	−0.01	−0.03	−0.03	0.01	0.05	−0.00	0.03	0.00	−0.03	−0.01
ALDO	0.10	−0.01	0.04	0.02	0.02	−0.03	−0.01	0.02	0.08	−0.02	0.03	0.05	0.01	0.04
CORT	0.09	0.04	0.07	0.07	−0.06	0.05	0.02	0.03	0.03	0.02	0.02	0.07	−0.10	−0.01
DELT4	0.03	0.04	0.04	0.03	−0.10	−0.01	−0.05	−0.02	−0.06	−0.04	−0.06	−0.01	−0.03	−0.03
DHEA	0.13	0.11	0.14	0.12	−0.06	0.09	0.04	0.15	0.01	0.04	0.03	0.08	0.01	0.06
DHEAE	0.07	0.08	0.09	0.02	0.03	−0.02	−0.00	0.14	0.11	0.07	0.11	0.15	0.07	0.14
DHEAS	−0.08	−0.02	−0.05	−0.06	−0.06	−0.14	−0.14	0.07	0.05	0.01	0.04	0.11	0.01	0.08
DHT	−0.07	−0.04	−0.06	0.09	−0.09	−0.04	-0.07	−0.03	−0.08	−0.05	−0.08	−0.05	−0.04	−0.06
DIOLG	0.00	0.05	0.03	0.09	0.00	0.06	0.04	−0.02	0.10	0.02	0.07	0.01	0.03	0.03
E2	0.06	0.05	0.06	0.07	−0.06	−0.01	−0.04	−0.09	−0.06	−0.03	−0.05	0.03	0.02	0.02
OHPROG	0.01	−0.06	−0.03	0.08	0.02	0.07	0.06	0.00	−0.04	−0.05	−0.06	0.03	−0.04	−0.00
PREGE	−0.05	0.00	−0.02	0.05	−0.03	−0.02	−0.03	0.11	0.10	0.11	0.13	0.13	0.16	0.18
PROG	−0.09	−0.06	−0.08	−0.04	−0.09	−0.02	−0.06	0.14	0.04	−0.05	−0.01	0.10	−0.01	0.06
SHBG	−0.02	0.06	0.04	0.07	0.06	0.13	0.13	−0.08	0.04	−0.03	0.01	0.04	0.05	0.05
TESTO	−0.00	0.00	0.01	0.09	−0.01	0.03	0.02	−0.07	0.01	−0.07	−0.03	−0.04	−0.06	−0.07
FAI	−0.01	−0.08	−0.07	0.02	−0.08	−0.12	−0.13	0.05	−0.01	−0.02	−0.01	−0.07	−0.11	−0.11
E2/T	0.09	0.07	0.08	0.05	−0.00	0.04	0.03	−0.08	−0.09	0.06	−0.01	0.01	0.04	0.03
CORT/DHEAS	0.09	0.07	0.09	0.03	0.07	0.14	0.14	0.03	0.01	−0.01	−0.01	−0.00	−0.06	−0.03

Age, ethnicity, BMI, smoking status, alcohol status, and baseline were controlled for in the partial correlations between baseline plasma steroid hormone levels and training response of resting and exercise blood pressure at submaximal exercise intensities; Systolic Blood Pressure: SBP; Diastolic Blood pressure: DBP; MBP = DBP + [0.333 × (SBP-DBP)]; Rate Pressure Product (RPP) = Heart Rate (HR) × SBP. 50 = during cycle exercise in steady state at 50W; 60 = during cycle exercise in steady state at 60 % of VO_2max; Training response (Δ) = post-training minus pre-training. 24 h = 24 h resting BP after training minus baseline; 72 h = 72 h resting BP after training minus baseline.

▶ **Table S4** Partial correlations between baseline plasma steroid hormone levels and training response (△) of resting and exercise blood pressure at submaximal exercise intensities in women (N = 254).

	Resting								Submaximal					
	24hSBP	**24hDBP**	**24hMBP**	**24RPP**	**72hSBP**	**72hDBP**	**72hMBP**	**72RPP**	**SBP50W**	**DBP50W**	**MBP50W**	**SBP60%**	**DBP60%**	**MBP60%**
ADTG	−0.06	−0.02	−0.04	−0.05	−0.08	−0.07	−0.08	0.05	−0.07	−0.08	−0.09	−0.11	−0.11	−0.14
ALDO	−0.09	−0.11	−0.12	−0.04	0.03	0.04	0.04	0.01	0.03	0.08	0.08	0.06	0.02	0.05
CORT	−0.01	−0.03	−0.02	−0.05	−0.02	−0.08	−0.06	0.01	0.17	0.05	0.11	0.13	0.10	0.13
DELT4	−0.07	−0.01	−0.04	−0.02	−0.03	−0.02	−0.03	0.05	−0.05	0.06	0.01	−0.10	−0.03	−0.07
DHEA	−0.02	−0.02	−0.02	0.05	−0.02	−0.01	−0.01	0.06	−0.04	0.01	−0.01	−0.09	0.00	−0.04
DHEAE	−0.08	−0.05	−0.07	−0.07	−0.05	−0.06	−0.06	0.06	−0.02	−0.04	−0.04	−0.04	−0.07	−0.06
DHEAS	−0.07	−0.09	−0.09	−0.04	−0.03	−0.00	−0.02	0.03	−0.01	0.02	0.00	−0.12	−0.01	−0.06
DHT	−0.04	−0.05	−0.05	−0.02	−0.04	−0.01	−0.02	0.04	−0.05	0.01	−0.02	−0.04	−0.01	−0.03
DIOLG	−0.05	−0.10	−0.09	−0.01	−0.03	−0.09	−0.07	0.01	−0.03	−0.07	−0.06	0.02	−0.07	−0.03
E2	0.15	0.19	0.19	0.04	0.08	0.13	0.12	0.02	−0.03	0.06	0.07	0.01	0.01	0.00
OHPROG	−0.04	−0.00	−0.02	−0.05	−0.09	−0.08	−0.09	0.07	0.06	0.03	0.02	0.00	−0.02	−0.01
PREGE	−0.07	−0.04	−0.06	−0.09	−0.07	−0.08	−0.08	0.03	−0.02	−0.08	−0.07	−0.01	−0.07	−0.05
PROG	−0.11	−0.02	0.06	−0.13	−0.08	−0.06	−0.07	0.03	−0.09	−0.05	−0.08	−0.09	−0.07	−0.09
SHBG	0.12	0.02	−0.06	−0.03	0.06	0.06	0.07	0.00	0.03	−0.04	−0.01	0.01	−0.01	−0.00
TESTO	−0.02	−0.04	−0.04	−0.02	−0.05	−0.08	−0.08	0.05	−0.06	−0.06	−0.07	−0.04	−0.03	−0.04
FAI	−0.11	−0.07	−0.10	−0.00	−0.05	−0.05	−0.06	0.05	−0.11	−0.00	−0.06	−0.12	−0.05	−0.10
E2/T	0.11	0.19	0.17	0.02	0.09	0.14	0.13	−0.01	0.07	0.15	0.14	0.04	0.12	0.09
CORT/DHEAS	0.00	0.02	0.01	−0.06	0.06	0.08	0.08	−0.06	−0.07	−0.08	−0.09	−0.00	−0.03	−0.02

Age, ethnicity, BMI, smoking status, alcohol status, oral contraceptives/post-menopausal hormone therapy, menopause status, and baseline were controlled in the partial correlations between baseline plasma steroid hormone levels and training response of resting and exercise blood pressure at submaximal exercise intensities; Systolic Blood Pressure: SBP; Diastolic Blood pressure: DBP; MBP = DBP + [0.333 × (SBP-DBP)], Rate Pressure Product (RPP) = Heart Rate (HR) × SBP. 50 = during cycle exercise in steady state at 50W; 60 = during cycle exercise in steady state at 60% of VO_2max; Training response (Δ) = post-training minus pre-training. 24 h = 24 h resting BP after training minus baseline; 72 h = 72 h resting BP after training minus baseline.