

## Ethnic and Gender Differences in Ambulatory Blood Pressure Trajectories

### Results From a 15-Year Longitudinal Study in Youth and Young Adults

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**Background**—Cross-sectional studies demonstrated ethnic and gender differences in ambulatory blood pressure patterns, but little is known about the longitudinal development of these differences.

**Methods and Results**—Twenty-four-hour ambulatory blood pressure was measured up to 12 times (5 times on average) over a 15-year period in 312 African Americans (AAs) and 351 European Americans aged 7 to 30 years. Multivariate individual growth curves across age were created for daytime and nighttime blood pressure jointly. For both daytime and nighttime systolic blood pressure (SBP), AAs and males had higher levels ( $P<0.001$ ) than European Americans and females. Males also showed a greater increase with age ( $P<0.001$ ) than females. For nighttime SBP, a faster increase of SBP with age ( $P<0.01$ ) in AAs was additionally observed. The ethnic difference in nighttime SBP levels and its increase with age were significantly larger than in daytime SBP. For daytime and nighttime diastolic blood pressure, AAs had higher levels than European Americans ( $P<0.001$ ), and this difference was significantly larger at night. From late adolescence onward, males showed a greater increase in diastolic blood pressure with age than females. Ethnic and gender differences persisted after adjustment for height, body mass index, socioeconomic status, and stress-related coping styles. Family history of essential hypertension explained ethnic differences in daytime SBP.

**Conclusions**—We observed significant ethnic and gender differences in longitudinal trajectories of ambulatory blood pressure in youth and young adults. The blunted nocturnal decline and its exacerbation with age in AAs corroborate and extend findings of cross-sectional studies. (*Circulation*. 2006;114:2780-2787.)

**Key Words:** blood pressure ■ follow-up studies ■ pediatrics ■ population ■ sex ■ ethnic groups

Ambulatory blood pressure (ABP) monitoring offers advantages over casual blood pressure (BP) readings, including the ability to track BP at night and to study circadian BP patterns.<sup>1</sup> There is increasing evidence from prospective studies that nighttime BP may be superior to casual or daytime BP as a predictor of cardiac morbidity and mortality.<sup>2,3</sup> Furthermore, studies reported that individuals with a blunted nocturnal decline in BP, referred to as nondippers, display the highest risk, because this pattern exposes these individuals to a greater cardiovascular load each day.<sup>4,5</sup>

#### Editorial p 2757 Clinical Perspective p 2787

Adult hypertension often has its origin in childhood,<sup>6</sup> and the early identification of children at risk would aid prevention efforts. Hence, an increased understanding of the development of ABP patterns from childhood into adulthood in

different demographic groups is important. Cross-sectional studies in both adult and pediatric populations<sup>7,8</sup> have shown a higher nighttime BP and/or a blunted nocturnal decline in black Americans (AAs) and males compared with European Americans (EAs) and females, respectively. It is presently unclear, however, at which age differences in ABP patterns first appear and how they subsequently change over time. Furthermore, the moderating effects of between-subject differences in growth, adiposity, socioeconomic status (SES), stress-related coping styles, and genetic susceptibility to essential hypertension (EH) have been reported in cross-sectional studies,<sup>9–14</sup> but their effects on the change of ABP patterns with age are unknown. In the present longitudinal study of 312 AAs and 351 EAs who were followed up as often as 12 times over a 15-year period, we measured ABP from childhood into early adulthood. Using multivariate growth-curve modeling, we examined and contrasted the ethnic and gender differences in the trajectories of daytime and nighttime BP and further determined the degree to which

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these differences could be explained by measures of growth, adiposity, SES, coping styles, and genetic susceptibility to EH.

## Methods

### Subjects

The participants ( $n=663$ ; 47.1% AAs, 50.8% females) were from an ongoing longitudinal study evaluating the development of cardiovascular risk factors in youth and young adults.<sup>15</sup> The data encompass a 15-year period (1989 to 2004) in which 12 assessments were conducted. Recruitment and evaluation of participants began in 1989 and have been described in detail elsewhere.<sup>16,17</sup> Briefly, participants were identified with family health history questionnaires obtained from a county-wide (Richmond County, Georgia) public school screening of children in kindergarten through grade 8 whose families were interested in health research. Of 13 850 family health histories, 65.5% had complete information, and among these, 58.9% of the children were classified as having a positive family history (FH) of EH (defined as EH in 1 or both biological parents), whereas 41.1% were classified as having a negative FH of EH. A random sample was selected who were stratified by ethnicity, gender, and FH classification. Participants who met the following criteria were recruited: (1) aged 7 to 16 years in 1989; (2) AA or EA; (3) normotensive for age and gender based on BP screening; and (4) apparently healthy based on parental reports of the child's medical history. A high participation rate was obtained, with 96.3% of those contacted agreeing to participate. Participants were classified as AAs if (1) both parents reported being of African heritage, (2) the parents and the child were born and raised in the United States, and (3) parents considered themselves and their child to be African American, black, or Afro-American. Participants were classified as EAs if (1) both parents reported that they were of European ancestry, (2) the parents and the child were born and raised in the United States, and (3) they considered themselves and their child to be European American, white, or Caucasian. The annualized attrition rate has been <4% per year, which has been primarily due to participants moving out of the region. There have been no significant differences in age, ethnicity, and sex distributions between dropouts and the participants who remained in the study.<sup>15</sup>

The data set is complicated because not all participants had the same number of visits, with participants recruited into the study at different ages and different years. However, 67% of participants had  $\geq 4$  visits, which makes this data set very informative for the study of ABP patterns over time. The age range during all the visits was 7 to 30 years. During the study, 11 participants began to take antihypertensive medication, and the data obtained during this period were excluded from analyses.

The Institutional Review Board at the Medical College of Georgia gave approval for the study. The fact that 141 of the total 663 participants were siblings may have affected the significance of observed effects; when siblings were excluded from the analyses, however, the results were virtually unchanged, so results for the entire sample are reported here.

### Measurements

On each laboratory visit, height and weight were measured as described elsewhere.<sup>15</sup> Body mass index (BMI) was calculated as a measure of general adiposity.

SES was indexed by parental education level, Hollingshead Four Factor Social Status Index,<sup>18</sup> and marital status. Because parental education level remained highly stable across the years of the present study, its value, as measured at the midpoint of the study, was considered representative of the entire study period. Parental education level was measured in years on a 7-point scale that ranged from less than high school to postgraduate education and was subsequently divided into 3 categories: low (<12 years), medium ( $\geq 12$  and <16 years), and high ( $\geq 16$  years). Hollingshead index was calculated for each visit on the basis of parental education level, employment status, and occupation, with a higher value indicating a

higher SES.<sup>18</sup> Marital status was assessed on each visit and was divided into single-parent households (single, divorced, widowed, or separated) versus 2-parent households (married).<sup>15</sup>

The stress-related coping styles of anger expression (ie, anger in and anger out) and John Henryism were evaluated with the Spielberger Anger Expression Scale<sup>19</sup> and John Henryism Active Coping Scale,<sup>20</sup> respectively. For both scales, a  $z$ -score transformation was applied to each laboratory visit. These were subsequently averaged across visits to yield 1 anger expression score and 1 John Henryism score taken to represent all 12 visits.

FH of EH was used as a proxy for genetic susceptibility. A positive FH of EH was defined as the occurrence of EH in 1 or both biological parents at any visit. Diagnosis of EH was verified by the individual's physician or medical records.<sup>21</sup>

### ABP Recordings

Our procedures for ABP recordings have been described in detail previously.<sup>9</sup> Briefly, an ABP monitor was fitted to the nondominant arm (model 90207, SpaceLabs, Redmond, Wash). Measures were obtained every 20 minutes during the daytime (8 AM to 10 PM) and every 30 minutes during the nighttime (12 midnight to 6 AM). Transitional periods from 6 AM to 8 AM and 10 PM to midnight were not included in the analyses. Adequacy of recordings were based on acceptable readings with previously established criteria<sup>9</sup> for  $\geq 14$  readings over the 14 hours designated as daytime and  $\geq 6$  readings over the 6 hours designated as the nighttime, as suggested by the European Society of Hypertension Working Group on Blood Pressure Monitoring.<sup>1</sup>

### Statistical Analyses

The main purpose of the present analyses was to examine and contrast the effects of ethnicity and gender on the development of daytime and nighttime BP from childhood to adulthood. We further investigated whether the effects could be explained by measures of growth, adiposity, SES, coping styles, and genetic susceptibility to EH.

### Growth-Curve Modeling

All analyses in the present study were conducted by use of individual growth-curve modeling within a multilevel, multivariate framework. The multilevel framework is a technique particularly suited for longitudinal data analysis,<sup>15</sup> because such data can be considered clustered or hierarchical since repeated observations are nested within subjects. A multivariate model is one in which there are 2 or more response variables for each observation, for example, daytime and nighttime systolic BP (SBP) in the present study. Multivariate response data can conveniently be incorporated into a multilevel model by creating an extra low level that defines the multivariate structure. Daytime and nighttime BP (level 1) are nested within each visit, and visits (level 2) are nested within subjects (level 3). This multivariate growth-curve model fits 2 curves for each subject, 1 for daytime BP and 1 for nighttime BP. These curves (daytime and nighttime BP development with age) are characterized by their intercept (or level) and slope (rate of change). Addition of independent variables to the model, such as ethnicity and gender, is aimed at explaining between-subject variation (in level and slope) of the growth curves.<sup>22</sup>

The multivariate analysis has 2 advantages over univariate growth-curve modeling, which analyzes different dependent variables in separate models. First, differences between the coefficients for different responses can be tested directly. For example, it can be examined whether ethnicity and gender relate to daytime BP in the same way as they relate to nighttime BP. Second, joint estimation can be much more efficient when there are many missing responses. Separate univariate analyses must ignore all individuals with missing values on the chosen response variable, whereas a multivariate procedure can use the responses that are present for these individuals to provide information in the estimation of those that are missing.<sup>22</sup>

TABLE 1. General Characteristics of Participants' First Visit

	EA Males	EA Females	AA Males	AA Females
Demographics				
n	184	167	142	170
Age, y	14.2±3.3	14.3±3.3	14.5±3.3	14.4±3.5
Subjects with ≥4 visits, %	64.7	67.7	65.5	70.6
ABP measures				
Daytime SBP, mm Hg	119.7±8.8	115.7±7.4	121.7±9.6	117.7±8.2
Nighttime SBP, mm Hg	107.7±9.2	104.0±7.6	111.0±10.3	106.8±8.4
Daytime DBP, mm Hg	71.0±6.4	70.9±6.4	72.5±6.9	72.5±6.4
Nighttime DBP, mm Hg	58.1±6.8	57.4±5.4	60.3±7.3	60.5±7.2
Daytime HR, bpm	82.7±11.6	87.3±10.1	81.3±11.7	89.5±8.4
Nighttime HR, bpm	67.5±10.9	71.6±10.1	68.5±10.6	75.5±10.1
Anthropometric measures				
Height, cm	162.2±16.6	157.5±10.6	162.8±13.7	158.7±10.6
BMI, kg/m <sup>2</sup>	21.7±4.7	22.5±5.5	23.2±6.3	24.8±7.7
SES				
Father's education level, y	13.9±2.5	13.8±2.2	12.6±2.4	12.9±2.1
Mother's education level, y	13.6±2.1	13.7±2.1	13.5±1.9	13.3±1.8
Hollingshead index	44.1±12.6	43.5±13.3	36.9±13.9	36.4±13.7
Single-parent household, %	15.8	17.8	38.7	42.7
Stress-related coping styles				
Anger in	14.8±2.8	15.3±3.0	16.0±2.8	16.1±3.0
Anger out	15.8±2.8	15.5±2.9	15.3±2.9	15.0±3.1
John Henryism	47.3±5.3	47.8±5.8	48.6±5.4	49.4±4.4
Genetic susceptibility measure				
FH of EH, %	63.3	65.8	86.1	89.4

HR indicates heart rate. Values are mean±SD unless otherwise indicated.

## Analytical Strategy and Software

MLwiN software<sup>22</sup> was used to construct the multivariate multilevel model. A 3-level model was calibrated with subjects at level 3 (between-subject level), repeated measurements (or visits) at level 2 (within-subject level), and the response, which is either the daytime or nighttime BP, at level 1. Level 2 variation is within-subject, and level 3 is between-subject variation. There is no level 1 variation because level 1 exists solely to define the multivariate structure.

We first specified the unconditional growth model, in which fixed and random linear, quadratic, and cubic trends were fitted by the addition of, respectively, age, age<sup>2</sup>, and age<sup>3</sup> to the intercept-only model. Age was expressed as a deviation from its mean of 17 years. Ethnicity and gender were then added to the unconditional growth model to test the effects on daytime and nighttime BP intercept and on the rate of change, the latter modeled as interaction with age, age<sup>2</sup>, and age<sup>3</sup>. The interaction between ethnicity and sex was also tested.

In the next step, height, BMI, heart rate, SES, coping styles, and FH of EH were separately added to the model to estimate the effect of these variables on the development of ABP pattern with age. Height, BMI, and heart rate were centered at 168 cm, 24.0 kg/m<sup>2</sup>, and 77 bpm, respectively. The interactions of these variables with ethnicity and gender were also tested. In the final step, all variables that had significant effects on the ABP pattern in the previous models were entered simultaneously in a full model to obtain estimates of ethnicity and gender effects adjusted for individual differences in growth, adiposity, heart rate, genetic susceptibility, SES, and coping styles.

A likelihood ratio test was used to determine the significance of the fixed and random effects that were added to the model in each of the analyses steps. This test yields the deviance of the model, which is defined as  $-2 \times \log$  likelihood. The deviance difference (between

2 models) is asymptotically  $\chi^2$  distributed, with the number of degrees of freedom equal to the difference in number of estimated parameters between the 2 models. To judge the significance of parameters in the full model, each parameter was removed from the model, and a likelihood ratio test was used to examine whether its effect was significant in this full model.<sup>15</sup> Differences between coefficients of fixed parameters for daytime and nighttime BP were compared with F tests based on the Kenward-Roger method.<sup>22</sup>

The authors had full access to the data and take full responsibility for the integrity of the data. All authors have read and agree to the manuscript as written.

## Results

Descriptive characteristics by ethnicity and gender at participants' first evaluation are shown in Table 1.

### Daytime and Nighttime SBP Growth Curves

Results of growth-curve modeling for daytime and nighttime SBP are presented in Table 2. The unconditional growth model with fixed and random linear effects (age) and a fixed quadratic effect (age<sup>2</sup>) provided the best fit.

Ethnicity and gender had significant effects on both daytime and nighttime SBP level, indicating higher levels for AAs and males than for EAs and females, respectively (Table 2, model 1). Gender also showed a significant interaction with age and age<sup>2</sup>, which reflects that a linear increase in adolescence and a nonlinear leveling off in early adulthood with age were only displayed in males (Figure 1). For

**TABLE 2. Results of Growth-Curve Modeling of Variables With Regard to Daytime and Nighttime SBP**

(Model) Variables	$\beta$		<i>P</i>			Explained Variance Within Subjects, %		Explained Variance Between Subjects, %	
	Day	Night	Day	Night	Day-Night*	Day	Night	Day	Night
(1) Age+ethnicity+gender model	...	...	...	...	...	14.4	11.8	27.7	37.8
Age	0.74	0.81	<0.001	<0.001	NS	...	...	...	...
Age <sup>2</sup>	-0.08	-0.07	<0.001	<0.001	NS	...	...	...	...
Gender	-7.31	-7.05	<0.001	<0.001	NS	...	...	...	...
Gender×age	-0.64	-0.74	<0.001	<0.001	NS	...	...	...	...
Gender×age <sup>2</sup>	0.06	0.07	<0.001	<0.001	NS	...	...	...	...
Ethnicity	1.47	4.03	<0.01	<0.001	<0.001	...	...	...	...
Ethnicity×age	0.00	0.22	NS	<0.05	<0.05	...	...	...	...
(2) Height model: model 1+height+(height×gender)	...	...	...	...	...	14.7	11.8	29.7	39.0
Height	0.19	0.13	<0.001	<0.001	NS	...	...	...	...
Height×gender	-0.12	-0.15	<0.05	<0.05	NS	...	...	...	...
(3) BMI model: model 1+ BMI	...	...	...	...	...	15.2	12.2	27.8	39.1
BMI	0.19	0.26	<0.001	<0.001	<0.05	...	...	...	...
(4) HR model: model 1+HR	...	...	...	...	...	22.6	22.7	26.7	33.8
HR	0.30	0.32	<0.001	<0.001	NS	...	...	...	...
(5) Age+ethnicity+gender model†	...	...	...	...	...	15.2	12.1	30.2	39.3
(6) Coping model: model 5+John Henryism	...	...	...	...	...	15.2	12.1	30.8	39.8
John Henryism	0.79	0.69	<0.05	<0.05	NS	...	...	...	...
(7) Age+ethnicity+gender model‡	...	...	...	...	...	14.4	11.9	27.8	37.8
(8) Genetic model: model 7+(FH of EH)	...	...	...	...	...	14.5	11.9	30.0	40.0
FH of EH	2.71	2.71	<0.001	<0.001	NS	...	...	...	...
(9) Age+ethnicity+gender model§	...	...	...	...	...	15.2	12.1	30.2	39.3
(10) Full model: model 9+height+(height×gender)+BMI+HR+JH+(FH of EH)	...	...	...	...	...	24.7	22.8	33.2	39.2

HR indicates heart rate; JH, John Henryism; coding of ethnicity: 0 for EAs and 1 for AAs; coding of gender: 0 for males and 1 for females.

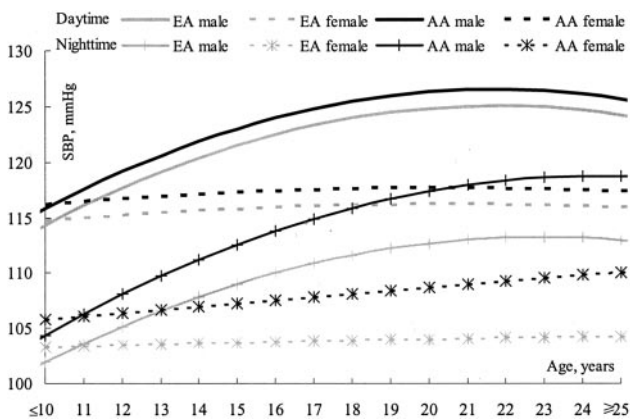
\*Test whether predictor had the same effect on daytime and nighttime BP.

†Smaller sample size involving 606 subjects and 2967 measurements (cases missing on JH excluded).

‡Smaller sample size involving 656 subjects and 3084 measurements (cases missing on FH of EH excluded).

§Smaller sample size involving 604 subjects and 2955 measurements (cases missing on JH or FH of EH excluded).

nighttime SBP, a significant interaction between ethnicity and age was additionally discovered (Table 2, model 1). As shown in Figure 1, AA males and females displayed a stronger linear increase in nighttime SBP with age than did



**Figure 1.** The increase of daytime and nighttime SBP with age by ethnicity and gender.

EAs. The gender effect was the same for daytime and nighttime SBP. In contrast, ethnicity had a significantly larger effect on nighttime SBP intercept ( $P<0.001$ ) and on the rate of change ( $P<0.05$ ) than on daytime SBP. This means that at age 17 years, the ethnic difference was 1.5 mm Hg during the daytime and 4 mm Hg during the nighttime, whereas the more rapid linear increase of nighttime SBP with age compared with EAs was not observed for the daytime SBP.

As shown in Table 2 (models 2, 3, 4, and 6), height, BMI, heart rate, and John Henryism coping style had significant effects on both daytime and nighttime SBP levels; that is, SBP increased with increasing height, adiposity, heart rate, and John Henryism score. Height also showed an interaction with gender, which indicates that females had lower SBP levels than males of similar height. After we controlled for anthropometric measures, heart rate, and coping styles, the gender and ethnic effects on daytime and nighttime SBP remained significant.

FH of EH had a significant effect on both daytime and nighttime SBP levels, which indicates that participants genetically predisposed to EH had higher SBP levels (model 8).



**TABLE 3. Results of Growth-Curve Modeling of Variables on Daytime and Nighttime DBP**

(Model) Variables	$\beta$		<i>P</i>			Explained Variance Within Subjects, %		Explained Variance Between Subjects, %	
	Day	Night	Day	Night	Day-Night*	Day	Night	Day	Night
(1) Age+ethnicity+gender model	...	...	...	...	...	9.9	9.2	11.2	27.7
Age	0.21	0.39	<0.001	<0.001	<0.01	...	...	...	...
Age <sup>2</sup>	0.03	0.05	<0.001	<0.001	NS	...	...	...	...
Gender	-0.32	-0.37	NS	NS	NS	...	...	...	...
Gender×age	-0.14	-0.16	NS	<0.05	NS	...	...	...	...
Gender×age <sup>2</sup>	-0.02	-0.03	NS	<0.05	NS	...	...	...	...
Ethnicity	1.16	3.02	<0.05	<0.001	<0.001	...	...	...	...
(2) Height model: model 1+height	...	...	...	...	...	10.0	9.7	10.5	26.5
Height	-0.05	-0.09	<0.05	<0.001	NS	...	...	...	...
(3) BMI model: model 1+BMI+(BMI×age)	...	...	...	...	...	9.6	9.1	16.2	29.1
BMI	-0.15	-0.08	<0.001	<0.01	<0.05	...	...	...	...
BMI×age	0.01	0.02	<0.05	<0.05	NS	...	...	...	...
(4) HR model: model 1+HR	...	...	...	...	...	27.3	20.1	21.7	29.2
HR	0.31	0.27	<0.001	<0.001	<0.05	...	...	...	...
(5) Age+ethnicity+gender model†	...	...	...	...	...	9.8	9.2	11.2	27.5
(6) Genetic model: model 5+(FH of EH)	...	...	...	...	...	9.9	9.2	12.6	30.0
FH of EH	1.46	1.62	<0.01	<0.001	NS	...	...	...	...
(7) Full model: model 5+BMI+(BMI×age)+(FH of EH)+HR	...	...	...	...	...	27.2	20.3	28.1	34.7

HR indicates heart rate; coding of ethnicity: 0 for EAs and 1 for AAs; coding of gender: 0 for males and 1 for females.

\*Test whether predictor had the same effect on daytime and nighttime BP.

†Smaller sample size involving 656 subjects and 3084 measurements (cases missing data on FH of EH excluded).

After we controlled for FH of EH, the ethnic difference disappeared for daytime SBP ( $\beta=0.86$ ,  $P=NS$ ) and decreased for nighttime SBP levels ( $\beta=3.39$ ,  $P<0.001$ ). With regard to SES measures, neither parental education level, Hollingshead index, nor marital status had a significant effect on daytime and nighttime SBP. Inclusion of height, BMI, heart rate, John Henryism coping style, and FH of EH in the full model did not explain the ethnic effect on the nighttime SBP intercept or slope.

### Daytime and Nighttime Diastolic BP Growth Curves

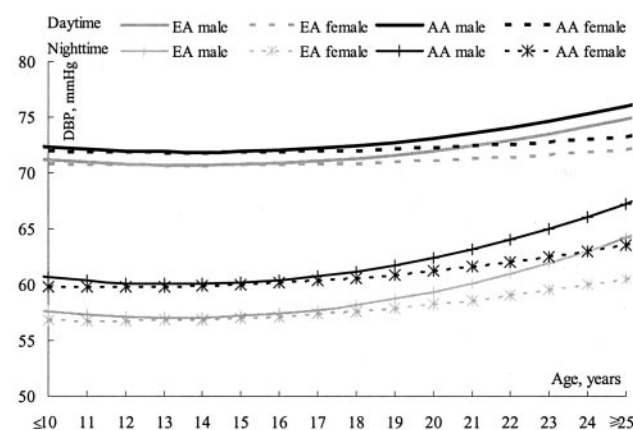
Results of growth-curve modeling for daytime and nighttime diastolic BP (DBP) are presented in Table 3. The unconditional growth model with fixed and random linear effects (age) and a fixed quadratic effect (age<sup>2</sup>) provided the best fit.

For both day and night DBP, ethnicity had a significant effect on DBP level, with higher levels for AAs than EAs (Table 3, model 1); however, this ethnic effect was significantly larger at night ( $P<0.001$ ). At age 17 years, the ethnic difference was  $\approx 1$  mm Hg during the daytime and 3 mm Hg during the nighttime. For nighttime DBP, gender showed a significant interaction with age, demonstrating that males showed significantly greater increases in nighttime DBP with age than females, beginning in late adolescence (Figure 2). A similar trend was observed for daytime DBP, although the interaction of gender with age and age<sup>2</sup> did not reach significance (Figure 2).

As shown in Table 3 (models 2, 3, and 4), height and BMI had significant negative effects on both daytime and night-

time average DBP levels, which suggested that DBP level decreased with increasing height and adiposity. On the other hand, for both daytime and nighttime DBP, BMI showed a significant interaction with age, which indicates that more obese participants showed a stronger linear increase with DBP. Heart rate had a significant positive effect on both daytime and nighttime DBP levels (model 4). After we controlled for anthropometric measures and heart rate, effects of gender and ethnicity on daytime and nighttime DBP remained significant.

FH of EH had a significant effect on both daytime and nighttime DBP levels, with higher DBP levels in participants



**Figure 2.** The increase of daytime and nighttime DBP with age by ethnicity and gender.

genetically predisposed to EH. Neither the SES measures nor the stress-related coping styles had significant effects on daytime or nighttime DBP. In the full model in which the effects of BMI, heart rate, and FH of EH were included, the ethnic effect on daytime and nighttime DBP remained significant.

### Discussion

The present study is the first to characterize ethnic differences in ABP trajectories from childhood to early adulthood. We observed that AAs experienced higher levels of SBP and DBP both at night and during the day than EAs from early adolescence onward. Moreover, the ethnic differences were significantly greater at night than during the day. For example, at age 17 years, the ethnic difference was 1.5 and 1 mm Hg during the daytime and 4 and 3 mm Hg during the nighttime for SBP and DBP, respectively. Similar findings have been reported by Profant and Dimsdale,<sup>7</sup> who performed a meta-analysis on 18 cross-sectional studies involving 2852 participants to identify the overall effect of ethnicity on diurnal BP patterns. In addition, we demonstrated that AAs exhibited a faster increase of nighttime SBP with age than EAs. Given that AAs and EAs show the same increase in daytime SBP, these results indicate that the nocturnal decline in SBP was not only less pronounced but also continued to decrease with age in AAs compared with EAs. For example, the present results suggest that in AAs, the nocturnal decline in SBP decreases from 10 to 6 mm Hg between 17 and 27 years, whereas it remains at 12 mm Hg for EAs. It is also of great interest to discover at about which age ethnic differences in ABP patterns first appear. Our longitudinal design with repeated measures is among the few studies that permit this type of analysis. By recentering age at different values, we discovered that AAs already display a significantly higher nighttime BP and less pronounced nocturnal decline at age 10 years (data not shown). Although the age range of the present study was 7 to 30 years, the majority of the evaluations were conducted in participants aged between 10 and 25 years (95% of all measurements). Thus, we cannot exclude the possibility that an ethnic difference in nocturnal decline might already exist before the age of 10.

A unique and important feature of the present study is the analytic strategy we employed. We used multivariate, multi-level growth-curve modeling, which not only enabled us to investigate determinants of ABP growth curves but also made it possible to study determinants of the diurnal BP patterns simultaneously without having to resort to derived measures of dipping. Although day-night BP dip (calculated as the absolute or relative absence of nocturnal decline) is a widely used measure of diurnal BP patterns, previous studies<sup>23,24</sup> have shown much lower reliability for day-night BP dip than for daytime or nighttime BP, probably because it contains potential measurement error of both the daytime and nighttime measures.

This is also the first study to characterize gender differences in ABP trajectories. Consistent with previous cross-sectional studies<sup>10,25,26</sup> on the age and gender distribution of ABP values in children, males showed significantly higher average daytime and nighttime SBP levels and a greater rise

in SBP over time than females. Also in line with previous studies<sup>25,26</sup> that did not observe a gender difference in either daytime or nighttime DBP in children up to 18 years old, we observed that a faster rise of DBP with age in males only began in late adolescence. In contrast to the ethnic difference in diurnal patterns, however, the nocturnal decline in BP was the same in males and females, because gender did not show different effects on either the levels or slopes of daytime and nighttime BP.

A secondary purpose of the present study was to determine whether ethnic and gender differences in ABP could be explained by differences in growth, adiposity, SES, stress-related coping styles, and genetic susceptibility to EH. In line with previous findings,<sup>9,10,26</sup> both daytime and nighttime SBP increased with increasing height and adiposity. Height and adiposity showed negative effects on daytime and nighttime DBP levels, however. The fact that previous studies<sup>10,26</sup> in youth observed that DBP did not increase with height and the fact that the partial effect of height on DBP became negative only after inclusion of age and age<sup>2</sup> in the present study suggests that the negative effect of height on DBP might be due to an overadjustment of age (correlation between age and height before age 18 years was 0.66). Furthermore, the effect of height on DBP was weak, because it barely explained any additional variance in DBP. Although the negative effect of BMI on DBP is contrary to findings in adults, it is not uncommon in children. Both our previous study<sup>15</sup> on casual DBP using the same cohort and the study by Stettler et al<sup>27</sup> on a large, representative sample of US adolescents observed the negative association between BMI and DBP levels. In addition, we also observed a faster increase in DBP with age in more obese participants, which appears to reconcile the opposite findings of the effect of BMI on DBP in youth and adults. The present findings confirm previous research that a strong behavioral disposition to actively handle psychosocial stress may be associated with higher BP. The majority of previous studies on John Henryism found it associated with BP, particularly in lower SES AAs.<sup>20,28</sup> The present results expand these findings across ethnicity and SES and show this active coping style has a small but consistent effect on both daytime and nighttime SBP levels from childhood through young adulthood. In contrast with the findings by Stepnowsky et al,<sup>11</sup> we did not observe any significant effect of SES on ABP patterns; however, findings in that study were based on small sample size ( $n=78$ ) and a direct measure of dipping.

In the present study, we used FH of EH as a proxy for genetic predisposition. Individuals with a positive FH of EH had higher SBP and DBP for both daytime and nighttime measures. After we controlled for FH of EH, the significant ethnic difference in daytime SBP was no longer significant, and the difference for nighttime SBP decreased. However, given the fact that the heritability of BP commonly exceeds 50%,<sup>29,30</sup> the large effect of FH of EH on ethnic difference is not unexpected. We must be cautious in interpreting this finding, because FH of EH is only a crude measure of genetic susceptibility, and it also partly reflects familiar environment. Furthermore, given that the lifetime risk of EH is close to 90%, individuals who initially have a negative FH of EH may

become positive over time as their parents develop EH during the course of the study. For this reason, we excluded available information on EH in the grandparents from the definition of FH of EH and only used information on the parents. In the present study, 98% of parents were younger than 60 years of age at the last visit. The relatively young age of these parents should have provided sufficient discriminatory power to differentiate between families with a positive and negative FH of EH.

We also must be cautious in the interpretation of ethnic differences. Self-reported ethnicity is neither purely biological nor measured with precision. It represents a mixture of genetic, social, economic, behavioral, psychological, and other environmental factors. Despite this, use of self-reported ethnicity has been advocated in biomedical and genetic research. It is a useful tool to establish ethnic variation, after which explanatory disease mechanisms can be identified in follow-up research. Methods able to distinguish genetic from environmental aspects of ethnicity, along with development of excellent measures of social factors and behavior, will advance the understanding of these underlying factors in cardiovascular risk development and may enable our society to more effectively remedy ethnic health disparities.<sup>31</sup>

The blunted nocturnal decline that began at 10 years of age and its exacerbation with age in AAs were the most important findings of the present study. The increased cardiovascular load may contribute to the much higher prevalence of cardiovascular morbidity and mortality in AAs compared with EAs. Although the basis for the differential nocturnal decline between AAs and EAs is not currently known, the fact that blacks outside of the United States experience the same nocturnal decline as whites<sup>32</sup> and that FH of EH can only account in part for the ethnic difference seen here and elsewhere suggest that the ethnic difference in ABP patterns is the result of a gene-environment interaction. We have hypothesized that pressure remains elevated at night in an attempt to excrete the daily sodium load.<sup>33</sup> Consistent with this hypothesis, we observed that AAs experience more stress-induced sodium retention than EAs.<sup>34</sup> Long-term stress and high salt intake, both of which occur more frequently in AAs, in combination with genetic variants involved in sodium excretion and retention may explain this discrepancy. Further work will be needed to determine the specific risk factors, both genetic and environmental, that potentially interplay to mediate the ethnic differences in ABP patterns over time.

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### Disclosures

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### CLINICAL PERSPECTIVE

Measures of blood pressure (BP) derived from ambulatory BP monitoring may be better predictors of cardiac morbidity and mortality than casual BP. Cross-sectional studies have shown a higher nighttime BP and/or a blunted nocturnal decline in African Americans (AAs) compared with European Americans. In the present longitudinal study of 312 AA and 351 European American youth and young adults who had ambulatory BP measured up to 12 times (5 times on average) over a 15-year period, we discovered that AAs already display a significantly higher nighttime BP and a less pronounced nocturnal decline at the age of 10 years. Moreover, we demonstrated that the nocturnal decline in systolic BP was not only less pronounced but also continued to decrease with age in AAs compared with European Americans. The increased cardiovascular load may contribute to the much higher prevalence of cardiovascular morbidity and mortality in AAs. The results also provide confirmatory information on the clinical significance of the difference. Because adult hypertension often has its origin in childhood, increased understanding of the development of ambulatory BP patterns from childhood into adulthood in different demographic groups will aid prevention efforts.