Aerobic Fitness and the Diurnal Rhythm of Blood Pressure in Adolescents

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We examined the effects of aerobic fitness and race on the diurnal rhythm of blood pressure of 175 healthy adolescents who performed a cycle ergometer maximal exercise test while oxygen consumption was measured. A median split of maximum oxygen consumption for boys and girls separately classified them as either “more-fit” or “less-fit” subjects. Ambulatory blood pressure recordings were also performed, and the data were analyzed for means while subjects were awake and asleep. Less-fit black boys had higher systolic pressures than more-fit black boys while awake (124 vs. 115 mm Hg; \( p < 0.009 \)) and asleep (117 vs. 108; \( p < 0.001 \)). Less-fit black boys also had higher systolic pressures than less-fit white boys while awake (114; \( p < 0.002 \)) and asleep (105; \( p < 0.001 \)), and they had higher systolic pressures than more-fit white boys while asleep (105; \( p < 0.01 \)). Less-fit black girls had higher systolic pressures than more-fit black girls while awake (116 vs. 109; \( p < 0.004 \)) and asleep (109 vs. 100; \( p < 0.001 \)). Less-fit black girls also had higher diastolic pressures than more-fit black girls while awake (71 vs. 66; \( p < 0.002 \)) and asleep (66 vs. 61; \( p < 0.001 \)). In addition, less-fit black girls had higher systolic pressures than more-fit white girls while asleep (104; \( p < 0.05 \)), higher diastolic pressures than more-fit white girls while awake (68; \( p < 0.05 \)) and asleep (60; \( p < 0.006 \)), and higher diastolic pressures than less-fit white girls while asleep (61; \( p < 0.001 \)). These findings indicate that fitness influences ambulatory blood pressure profiles, particularly in black adolescents. (Hypertension 1990;15:810–814)

Previous studies using ambulatory blood pressure monitoring have demonstrated racial differences in the diurnal rhythm of blood pressure in adolescents and adults. Specifically, black individuals and white individuals have similar levels of blood pressure while awake, but black individuals have higher levels of blood pressure while asleep. Aerobic fitness may be a second factor that influences the diurnal variation of blood pressure. Increased physical activity and aerobic fitness are associated with lower casual blood pressure, as well as a reduced risk for the development of hypertension and coronary heart disease. The purpose of the present study was to examine the effects of aerobic fitness and the interaction between aerobic fitness and race on the diurnal variation of blood pressure in healthy, normotensive adolescents.

Methods

Subjects

A biracial sample of 226 healthy, normotensive children between the ages of 10 and 18 years was recruited as part of an ongoing study evaluating hypertensive risk factors in children. A total of 175 of the 226 children (77%) completed both the cycle ergometer maximal exercise test and the ambulatory blood pressure recording. Parental consent was obtained before testing.

The sample included 80 boys and 95 girls, who were divided into “more-fit” and “less-fit” categories based on a median split of maximum oxygen consumption (\( \text{VO}_2\text{max} \)) performed separately for boys and girls. The more-fit male group was composed of 23 white and 18 black boys with a mean (±SD) age of 14 ±2 years, a mean casual blood pressure of 111/60 ±11/13 mm Hg, and a mean \( \text{VO}_2\text{max} \) of 48 ±5 ml/kg/min. The less-fit male group was composed of 21 white and 18 black boys with a mean age of 13 ±2 years, a mean casual blood pressure of 108/59 ±13/10 mm Hg, and a mean \( \text{VO}_2\text{max} \) of 37 ±4 ml/kg/min. The less-fit boys were heavier than more-fit boys (55 ±15 vs. 63 ±18 kg; \( p < 0.01 \)). The more-fit female group was composed of 19 white and 27 black girls with a
mean age of 13±2 years, a mean casual blood pressure of 99/57±11/3 mm Hg, and a mean \( V_{\text{O}}_{\text{max}} \) of 38±5 ml/kg/min. The less-fit female group was composed of 18 white and 31 black girls with a mean age of 13±2 years, a mean casual blood pressure of 102/65±9/10 mm Hg, and a mean \( V_{\text{O}}_{\text{max}} \) of 27±3 ml/kg/min. Less-fit girls were heavier than more-fit girls (45±9 vs. 62±15 kg; \( p < 0.01 \)). The groups did not differ by parental history of hypertension, alcohol intake, caffeine intake, drug use, or smoking history. Casual measurements were the average of three readings taken in the seated position.

**Voluntary Maximal Exercise Testing**

Maximal exercise testing was performed on an electronically braked cycle ergometer (Ergotest, Jaeger, Rockford, Illinois), as described previously.\(^{16}\) The mask and headgear used for gas analysis were explained and fitted to the subject. The crank length of the ergometer was adjusted for the child’s leg length, and the seat height was adjusted to maintain the same optimal biomechanical knee position for all subjects. Analysis of gas transport was performed from rest through the fifth minute of recovery (Ergopneumotest, Jaeger). Gas analysis was printed every 15 seconds, and \( V_{\text{O}}_{\text{max}} \), which was measured as milliliters per kilogram per minute, was used for analysis.

The continuous, graded maximal exercise test was performed as follows: 1) Predetermined workloads were selected based on gender, body surface area, and race.\(^{16}\) 2) Three-minute stages were designed to produce 33% of maximum during stage one, 67% during stage two, and 100% during stage 3. 3) Children were encouraged during the test to complete at least three stages. 4) Additional stages (increasing workloads of one half of the increment used in previous stages) were used until the child reached voluntary exhaustion. Maximal effort was defined as a respiratory quotient of 1.05 or greater and subjective exhaustion.

**Ambulatory Blood Pressure and Heart Rate Recordings**

The subject was seated, and the ambulatory blood pressure recorder (model 5200, SpaceLabs Inc., Redmond, Washington) was applied and calibrated as described previously.\(^{1}\) The subject was instructed to relax the arm for a blood pressure determination and to provide diary information for each hour the monitor was worn, including the time of sleep and awakening. The child then resumed normal daily activities and returned the following day for the removal of the recorder. The recorder was set to take a reading at 20-minute intervals between the hours of 6:00 AM and midnight and 60-minute intervals between the hours of midnight and 6:00 AM. The following day the child returned to the hospital, and the recorder was removed. A successful recording was one in which less than 25% of the readings during the recording were artifacts and subjects had data for at least 20 hours of the day.

The ambulatory blood pressure data were retrieved from the recorder and entered into a VAX 1170 computer for data editing and analyses as described previously.\(^{1}\) Hourly averages were computed for each individual and coded based on the subject’s diary according to whether the subject was awake or asleep during the hour.

The Statistical Analysis System’s general linear model analysis of variance procedure was used to determine the effects of fitness level, race, and the interactions among the variables. Planned comparisons were performed with \( t \) tests. Separate models were run for awake and asleep readings and for boys and girls.

**Results**

**Boys**

**Systolic blood pressure.** The least-square means for awake and asleep systolic blood pressure for more-fit and less-fit white boys and black boys are shown in Figure 1. The interaction between fitness and race
was significant while awake ($p<0.002$) and asleep ($p<0.01$). More-fit and less-fit white boys did not differ from each other while awake or asleep. Less-fit black boys had higher systolic blood pressures than more-fit black boys while awake ($p<0.009$) and asleep ($p<0.001$). Less-fit black boys also had higher systolic blood pressures than less-fit white boys while awake ($p<0.002$) and asleep ($p<0.001$) and higher systolic blood pressures than more-fit white boys while asleep ($p<0.001$).

Diastolic blood pressure. Fitness and the interaction between fitness and race were not significant for diastolic blood pressure while awake or asleep. Race was not a significant factor during waking hours; however, it was significant while the boys were asleep. Black boys had higher diastolic blood pressures than white boys (66 vs. 60 mm Hg, $p<0.001$).

Girls

Systolic blood pressure. The least-square means for awake and asleep systolic blood pressure for more-fit and less-fit white girls and black girls are shown in Figure 2. Fitness was significant while awake ($p<0.03$) and asleep ($p<0.005$). Planned comparisons showed that less-fit black girls had higher systolic blood pressures than more-fit black girls while awake ($p<0.004$) and asleep ($p<0.001$). Less-fit black girls also had higher systolic blood pressures than more-fit white girls while asleep ($p<0.05$). Less-fit white girls had higher systolic blood pressures than more-fit black girls while awake ($p<0.04$) and asleep ($p<0.04$).

Diastolic blood pressure. The least-square means for awake and asleep diastolic blood pressure for more-fit and less-fit white girls and black girls are shown in Figure 3. Fitness was significant while awake ($p<0.003$). Planned comparisons showed that less-fit black girls had higher awake diastolic blood pressures than more-fit black girls ($p<0.002$) and more-fit white girls ($p<0.05$). Less-fit white girls also had higher diastolic blood pressures while awake than more-fit black girls ($p<0.03$). The interaction between race and fitness was significant for asleep diastolic blood pressure ($p<0.05$). Less-fit black girls had higher diastolic blood pressures while asleep than more-fit black girls ($p<0.001$), less-fit white girls ($p<0.002$), and more-fit white girls ($p<0.006$).

Influence of Body Size on Blood Pressure

A stepwise regression was run to determine the effects of Quetelet index, body surface area, height, and weight on blood pressure while awake and asleep in boys and girls separately. Quetelet index showed the most consistent associations. Separate analysis of
variance models, including Quetelet index, were then run, and the resulting least-square means were compared with the previous means. Inclusion of Quetelet index into the model led to the following modifications: no change in the awake or asleep least-square means of less-fit white boys or girls, a decrease of less-fit black boys by 2 mm Hg while awake and 1 mm Hg while asleep, a decrease in less-fit black girls by 2 mm Hg while awake and an increase by 2 mm Hg while asleep, an increase in more-fit white boys by 1 mm Hg while awake, an increase in more-fit white girls by 1 mm Hg while awake and 2 mm Hg while asleep, an increase of more-fit black boys and girls by 2 mm Hg while awake, and an increase of more-fit black boys and girls by 1 mm Hg while asleep. Similar results were found for diastolic blood pressure.

Discussion

Black Americans between the ages of 18 and 74 have a prevalence of essential hypertension 1.4 times greater than white Americans. Preliminary research suggests that racial differences may, in part, be related to differences in prehypertensive 24-hour ambulatory blood pressure profiles. In a previous study, we demonstrated that the blood pressures of black and white children were similar while the children were awake but that black children had higher blood pressures than white children during sleep. In a second study, Harshfield et al extended these findings to healthy, normotensive black adults without a history of disease. In contrast to previous reports in white children, they reported that black adults did not show a significant decline in blood pressure during sleep. Finally, Murphy et al examined ambulatory blood pressure patterns in black adults and white adults under evaluation for borderline hypertension. The average daytime blood pressure of the black adults and white adults was equivalent, but the black adults had a significantly smaller decline in blood pressure during sleep. In each of these studies, the black individuals displayed either elevated levels of blood pressure throughout the day or the lack of a nocturnal decline in blood pressure. Either of these patterns would result in additional strain on cardiovascular, renal, and central regulatory systems, which could lead to the development of hypertension and associated target organ damage.

The results of the current study suggest that aerobic fitness is a factor that influences ambulatory blood pressure patterns, particularly in black children. In white children, there were no differences in the blood pressures of less-fit and more-fit boys or girls while the children were either awake or asleep. However, in black children, less-fit black children had consistently elevated levels of blood pressure relative to more-fit black children and to less-fit and more-fit white children. Specifically, less-fit black boys had higher awake and asleep systolic blood pressure than more-fit black boys. In addition, less-fit black boys had higher levels of systolic blood pressure than less-fit white boys while awake and asleep and higher systolic blood pressures than more-fit white boys while asleep. A similar pattern was found for girls. Less-fit black girls had higher systolic and diastolic blood pressure than more-fit black girls while awake and asleep. In addition, less-fit black girls had higher systolic blood pressures than more-fit white girls while asleep, higher diastolic blood pressures than more-fit white girls while awake and asleep, and higher diastolic blood pressures than less-fit white girls while asleep. Additional analyses indicated that differences in body size between less-fit and more-fit children did not account for the differences in blood pressure.

The results are in part consistent with previous studies that have demonstrated an inverse relation between physical activity or aerobic fitness and casual blood pressure in children and adolescents. The importance of the study of fitness has been demonstrated by previous studies that have indicated a significant relation between physical activity or fitness and future morbid events.

References


**Key Words**: physical fitness • ethnic differences • blood pressure • adolescents • diurnal patterns • ambulatory blood pressure
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