Associations between household and neighbourhood socioeconomic status and systolic blood pressure among urban South African adolescents

Abbreviated title: Blood pressure, socioeconomic status, South Africa

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Summary

Factors resulting in high risk for cardiovascular disease have been well studied in high income countries, but have been less well researched in low/middle income countries. This is despite robust theoretical evidence of environmental transitions in such countries which could result in biological adaptations that lead to increased hypertension and cardiovascular disease risk. Data from the Birth to Twenty bone health sub-sample (n= 358, 47% female) were used to model associations between household socio-economic status (SES) in infancy, household/neighborhood SES at 16 years, and systolic blood pressure (multivariate linear regression) and risk for systolic pre-hypertension (binary logistic regression). Bivariate analyses revealed household/neighbourhood SES measures that were significantly associated with increased systolic blood pressure. These significant associations included improved household sanitation in infancy/16 years, caregiver owning the house in infancy, and being in a higher tertile (higher SES) of indices measuring school problems/environment or neighbourhood services/problems/crime at 16 years of age. Multivariate analyses adjusted for sex, maternal age, birthweight, parity, smoking, term birth, height/body mass index at 16 years. In adjusted analyses, only one SES variable remained significant for females; those in the middle tertile of the crime prevention index had higher systolic blood pressure ($\beta = 3.52$, $SE = 1.61$) compared to the highest tertile (i.e. Those with the highest crime prevention). In adjusted analyses, no SES variables were significantly associated with the systolic blood pressure of boys, or with the risk of systolic pre-hypertension in either sex. The lack of association between SES and systolic blood pressure/systolic pre-hypertension at age 16 years is consistent with other studies showing an equalisation of adolescent health inequalities. Further testing of the association between SES and systolic blood pressure would be recommended in adulthood to see whether the lack of association persists.

Key words: Household socioeconomic status, neighbourhood socioeconomic status, pre-hypertension, South Africa, adolescents.

Introduction

Annually there are approximately 17 million cardiovascular disease deaths (WHO, 2002), with high blood pressure contributing to this mortality (Kearney*,* *et al.*, 2005). Factors resulting in high risk for cardiovascular diseases have been well studied in high income countries, but have been less well researched in low/middle income countries. This is despite robust theoretical evidence of environmental transitions in these countries which could result in biological adaptations that increase cardiovascular disease risk (Adair and Prentice, 2004). Given the different social, economic and cultural contexts of transitioning societies compared to high income countries, it is important to better understand how such environments influence cardiovascular disease risk.

This research uses the principles of embodiment which recognize that humans are both social and biological beings. Embodiment refers to how human beings "incorporate, biologically, the world in which we live, including our societal and ecological circumstances" (Krieger, 2005:351). In Glass and McAtee's (2006:1653) model, which fosters these principles of embodiment to study behaviour and disease, time from conception to death runs along a horizontal axis representing the life-course. In the model a vertical axis exists that incorporates the different levels of social organisation that influence health (e.g. family, school, neighbourhood, state, geopolitical systems) as well as the biological levels that embody the impact of the social environments (eg multi-organ system, cellular, molecular, and genomic substrate levels). The model helps to show that health outcomes are influenced over time by human actions and behaviours as individuals move through different social and physical environments and embody these at varying biological levels at different stages of the life-course (Glass and McAtee, 2006). This paper will particularly focus on considering the SES environment at two levels (household and neighbourhood) and at two points in the life-course (infancy and age 16 years). The paper uses data from Birth to Twenty (Bt20), a 1990 born Johannesburg-Soweto South African birth cohort, to study associations between the socio-economic environment and blood pressure outcomes in adolescents.

The South African context provides a unique transitioning environment to study associations between socio-economic status (SES) and blood pressure. The Bt20 cohort was born in the year that Nelson Mandela was released from prison. The four decades preceding this had seen the introduction of legislation endorsing apartheid in South Africa. Apartheid legislation split the population into four ‘population groups’ that were labelled African or Black, Mixed race or Coloured, Asian or Indian, and White. The combined impact of apartheid and the economic sanctions placed on the South African government because of apartheid legislation by the international community resulted in vast inequality between the population groups by the mid 1980s (Cameron, 2003). Health expenditure for Whites in the mid 1980s by the government was five times that spent on the Black population per capita and the infant mortality rate was also five times higher in the Black group. At the same time literacy was less than 50% in the Black population compared to 99% in the White group (Cameron, 2003). Since 1990 South Africa's Human Development Index has remained quite stable changing from 0.601 in 1990 to 0.597 in 2010, resulting in a drop in 7 places in global rankings but maintaining a classification in the medium development level of the global table. South Africa is one of the more developed countries in sub-Saharan Africa, with only Botswana, Namibia, and Gabon having higher rankings on the Human Development Index in 2010 (UNDP, 2011). Risk for chronic disease in South Africa is higher than most other sub-Saharan African countries because of its relatively higher economic development, which has fuelled its more rapid transition. For instance WHO (2011) data show that it ranks second in sub-Saharan Africa for its male (6^{th} in Africa) and female (3^{rd} in Africa) adult (aged 15+ years) prevalence of overweight (68.5% females and 41.3% males with a BMI > 25) (WHO, 2011). South Africa therefore represents a middle income nation that has been undergoing significant political and social change with a high prevalence of risk factors for cardiovascular disease such as overweight. Understanding the associations between SES and risk for cardiovascular disease within this context will build upon the already established evidence base relating to these associations in high income settings.

The evidence base from high income settings shows that socio-economic status (SES) is known to be associated with adult cardiovascular disease and high blood pressure. A review of adult studies found that lower SES was associated with higher blood pressure in most high income country studies, although consistent associations were not observed in low/middle income countries (Colhoun*, et al.*, 1998). The majority of childhood/adolescent studies, including most low/middle income country studies that were published after the review of Colhoun et al. (1998) have also not found SES associated differences in blood pressure (Miranda*, et al.*, 2009; Adair*, et al.*, 2009). Only two published studies in low/middle income countries have shown an association in children/adolescents, such that low SES is correlated with increased blood pressure ((Akinkugbe*, et al.*, 1999; Longo-Mbenza*, et al.*, 2007)). Longo-Mbenza et al (2007), however, failed to take account of height, a critically important variable in analyses of blood pressure in children/adolescents, and Akinkugbe et al (1999) did not use appropriate age and sex adjusted standards for assessing blood pressure (US Department of Health and Human Services and National Institutes of Health Heart Blood and Lung Institute, 2005). Focusing on adolescent cardiovascular risk factors in low/middle income country contexts is important in order to understand critical life-course associations between SES and blood pressure because there is some suggestion from high income countries that inequalities might equalise during the adolescent period (West, 1997).

Biological changes in metabolic, endocrine, and/or immune parameters early in life due to poor environmental conditions have been proposed to be responsible for links between the environment and later health outcomes (Lucas, 1991). Biologists often refer to these physiological changes as adaptations (Ellison, 2005; Kuzawa, 2005). Potential adaptations that lead to increased blood pressure include alterations in kidney structure and function, epigenetic mechanisms such as those that might be induced by short telomeres, endocrine mechanisms such as IGF1's role in the growth of vascular smooth muscle cells, and variation in body composition (Adair and Dahly, 2005). It has been proposed that early life adaptations may be based on predictions that arise not only from the mother's own environmental experiences but also those of preceding generations (Kuzawa, 2005). For the Bt20 participants the end of apartheid has meant that the cohort have been born into a rapidly changing social environment. If adaptations such as the ones proposed by Kuzawa do occur they could be more problematic in the type of environment that the Bt20 cohort were born into, because of the rapidly changing environment. This could result in predictions based on the maternal environment being inappropriate for the cohort participants' growth and development (Kuzawa, 2005).

In relation to blood pressure, there is a clear need for research to consider the potentially changing role of SES in its association with blood pressure across ages (Calhoun, 1998). A number of studies have taken a life-course approach to studying health effects of SES; in high income countries a literature review identified gaps in the literature to be a lack of prospectively collected childhood SES data collected at key developmental stages or a lack of SES data collected on more than two occasions, and a lack of studies reporting results for non Whites (Pollitt*, et al.*, 2005).

The association between blood pressure and individual/household SES has been more researched than neighbourhood SES. Households with similar

SES can have different health outcomes when living in contrasting areas (Macintyre and Ellaway, 2000). In reviews, Pickett and Pearl (2001) and Riva et al. (2007) found that contextual (i.e. neighbourhood) effects existed in most studies. The majority of recent evidence from high income settings highlights significant associations between deprivation in neighbourhoods and risk factors for coronary artery disease such as high blood pressure (Diez-Roux, *et al.*, 2008; Mujahid, *et al.*, 2008). Neighbourhood SES could be linked to blood pressure through its known influence on health behaviours like physical activity or availability of healthy foods (Duncan, *et al.*, 2005). It could also influence blood pressure through psycho-social pathways as poor environments could result in elevated psychosocial stress leading to an abnormal neuroendocrine secretory pattern (Galea, *et al.*, 2005). For the Bt20 cohort apartheid legislation limited the neighbourhoods that population groups could reside in around the time of the cohort's birth, although the removal of this legislation very quickly led to children experiencing different environments. For example between birth and 14 years 56 % of the Black cohort children had moved their address at least once (Ginsburg, *et al.*, 2009). This means that by the time the children of the cohort were entering their adolescent years they were residing in very diverse neighbourhoods, with the potential to influence health in different ways.

Using Glass and McAtee's (2006) model, we have identified two gaps in the literature in relation to understanding the association between SES and blood pressure outcomes in adolescents from low/middle income countries; 1) The lack of use of a life-course perspective to assessing inequalities (the horizontal axis of Glass and McAtee's model) and 2) A focus only on household inequalities without placing them within the wider social context (the vertical axis of Glass and McAtee's model). Thus the present paper aims to study associations between household SES in infancy, household SES at 16 years, neighborhood SES at 16 years, and systolic blood pressure as well as systolic pre-hypertension in a sample of Black 16 year old urban South Africans.

Methods

Participants

The participants in this study were participants in the Bone Health sub-cohort of the Bt20 study, which has been described in detail elsewhere (Richter*, et al.*, 2004; Richter*, et al.*, 2007). At ages 9/10 years, a random sub-sample from the cohort (n=429) were enrolled into a longitudinal study assessing factors influencing bone health. Bone Health participants had more detailed health assessments than the Bt20 cohort. The bone health participants were predominantly Black participants (n=376) as a consequence of the demographics of the South African population. Only Black participants are included in this analysis because of the small sample size of the White ethnic group and its homogeneity within the high SES group. Those Black participants with data on weight, height, and systolic blood pressure that were measured at 16 years of age were included in current analyses (n= 358, 47% female).

Ethical approval was granted by the ethics committees of the University of the Witwatersrand, South Africa for primary data collection and Loughborough University, UK for secondary data analyses. The primary caregiver gave written informed consent for their adolescent to participate in each assessment and the adolescent provided written assent at 16 years.

Socio-economic status measures

During infancy and at 16 years, caregivers were asked to assess household SES using a questionnaire based on standard measures used by the Demographic and Health Surveys (see www.measuredhs.com). The Bt20 SES questionnaire was piloted with 30 non-cohort caregivers to ensure understanding of concepts, an optimal layout, and to test translation. Measures included caregiver's education, private medical insurance coverage, home ownership, housing type, water/toilet facilities, marital status, and consumer durable ownership.

At 16 years of age, neighbourhood SES was assessed using a culturally relevant questionnaire, which was specifically developed in the Bt20 cohort using focus group discussions and in-depth interviews (Sheppard*, et al.*, 2010). Questions related to economic and social aspects of neighbourhoods, as well as the school environment were included. The adolescents answered the neighbourhood/school SES questions. We used the concept of a “sociologically meaningful” (Bond Huie, 2001) definition of neighbourhood and adopted the findings of our earlier qualitative study to define a neighbourhood covering an area within approximately 20 minutes walk (i.e. 2 kilometres) from home in any direction (Sheppard et al., 2010). Convenient administrative boundaries were not used to define neighbourhoods as others have suggested that such boundaries do not necessarily associate with actual areas defining the causal variables linking neighbourhood social environments to health (Pickett and Pearl, 2001).

Anthropometric measures

Birth weight, weight, and height at 16 years were assessed using standard techniques (Lohman*, et al.*, 1991). Low birth weight was defined as a birth weight less than 2.5kg. Body mass index (BMI) was calculated as weight (Kg)/height $(m)^2$. Adolescents were classified as normal weight, overweight, or obese using Cole et al.’s (2000) international age specific cut off points.

Blood pressure measures

Blood pressure was measured three times using a digital device (Omron M6; Omron, Kyoto, Japan) at 16 years of age. Appropriate cuff sizes were used, and participants were measured seated and resting with a break of several minutes between measurements. The first measurement was discarded and the second and third averaged. An average systolic blood pressure at or above the National Heart Blood Lung Institute's (US Department of Health and Human Services and National Institutes of Health Heart Blood and Lung Institute, 2005) 90^{th} sex, age, and height standardized percentile was used to define systolic pre-hypertension . Systolic pre-hypertension, and not stage 1 hypertension, was included in the current analyses because few adolescents in this sample had stage 1 hypertension.

Other variables used in the analyses

Individuals born before 37 weeks gestation were classified as preterm and after 41 weeks as post term. Mother's marital status and age were self reported during infancy. Adolescent's parity and smoking status (current, previous, or never) were self reported in a questionnaire.

Statistical analyses

Linear regression was used where the continuous systolic blood pressure variable was the outcome and logistic regression for the dichotomous systolic pre-hypertension outcome. Because systolic blood pressure is known to vary by sex and height, all analyses where systolic blood pressure was the outcome were stratified by sex and adjusted for height. Where data were missing for a particular variable they were coded into a separate category to maximise the sample size for analysis. Using this approach, with alpha set at 0.05 and power at 0.80, the sample size analysed has the statistical power to detect medium to large effect sizes, but would not be adequate to detect small effect sizes (Cohen, 1992). Initial unadjusted regression analyses explored relationships between each SES measure and each blood pressure outcome (controlling for height for systolic blood pressure). Subsequently multivariate regression analyses were adjusted for all variables that had shown a relationship with systolic blood pressure or systolic pre-hypertension in the initial analyses with a p-value <0.1.

Regression models were built in steps; 1) infancy SES variables from the initial analysis (P<0.1) entered, 2) added year 16 household/ neighbourhood SES variables with a p-value < 0.1 from the initial analysis, and 3) added other infancy and year 16 variables with a p-value < 0.1 in unadjusted analyses. This approach allows for any mediating effect of the year 16 SES variables on the association between the infancy SES variables and the systolic blood pressure outcomes as well as any mediating effects of the other infancy and 16 year measures on the association between the SES measures and systolic blood pressure to be investigated.

Over 100 questions were asked relating to neighbourhood SES. To enable a more parsimonious analysis of these measures and to avoid potential problems of multicolinearity, principal components analysis (PCA) was used to extract indices that grouped similar neighbourhood SES variables together. A theory based approach was used to develop nine neighbourhood indices and PCA confirmed the appropriateness of grouping these variables together. In each case the first component scores were extracted and the statistical assumption that all Eigenvalues be greater than 1 was met. Standardised Cronbach Alpha scores were calculated as a measure of reliability and the percentage of the variation in the variables explained by the PCA index calculated. Three indices measured neighbourhood economics; 1) economic index, 2) need for more services/facilities index, and 3) problem index. Two indices measured neighbourhood social aspects; 1) crime prevention index and 2) social support/happiness index. In addition there were two variables (How safe do you feel in the neighbourhood and How much crime is there in the neighbourhood?) that did not load well onto any indices and were therefore retained as individual variables. There were also two school neighbourhood indices identified; 1) School environment index and 2) School problems index. In addition to the seven neighbourhood SES indices, household SES questionnaire data were used to construct two indices that measured ownership of consumer durables, the first during infancy and the second at 16 years. Regression factor scores were extracted for each index and tertiles were created. In all cases the highest tertile or group represented the highest level of SES (reference category).

All analyses were conducted using SPSS 16.0 (Chicago, Illinois).

Results

Descriptive statistics

The prevalence of systolic pre-hypertension at age 16 years in this sample of Black South African adolescents was approximately 11%, with a mean (SD) for systolic blood pressure of 110.4 mm Hg (9.4) and 116.3 mm Hg (10.4) for girls and boys respectively (Table 1). Boys were significantly heavier than girls at birth (two sided $p<0.05$), but at 16 years of age girls were approximately three times more likely to be overweight/ obese compared to boys ($\chi^2 = 24.02$, $p < 0.001$).

Household and neighbourhood SES indices

The distribution of the tertiles of household assets at birth and 16 years show the dynamic nature of relative SES between birth and age 16 years in the cohort (Figure 1). For example, of the households classified as low SES at birth using this asset index, just over 50% were classified as medium or high at age 16 years.

The constructs included in each of the neighbourhood indices are shown in Table 2. Cronbach Alpha values for the indices varied from 0.56 to 0.98 with between 27 and 91% of the variation explained by the various PCA indices. These values are higher than those observed for neighbourhood indices reported with UK data (Cronbach Alpha scores between 0.48 and 0.98, with two scores lower than this range considered to be too low for internal reliability in the UK study) (Cummins*, et al.*, 2005).

Systolic blood pressure

Initial linear regression models of systolic blood pressure at 16 years controlling for height showed that for males infancy variables that resulted in significantly higher systolic blood pressure (other than the missing data category) were being born post term, living in a private rental property compared to owning, and having a mixture of inside/outside or outside only water/toilet facilities (Table 3). Birth weight was significantly negatively associated with systolic blood pressure for boys. For females the only one of these infancy variables that was shown to be significantly associated with increased systolic blood pressure was being born post term. In addition for females having a mother who was aged 20-29 years at the time of birth was associated with significantly reduced systolic blood pressure (Table 3). At 16 years for males, living in a neighbourhood with not much crime relative to a lot of crime was associated with lower systolic blood pressure and those in the middle tertile of the neighbourhood problem index had significantly higher systolic blood pressure than those in the highest tertile (Table 4). Furthermore, for males being taller and having a higher BMI or being obese were also associated with higher systolic blood pressure. When compared to males, the females had a broader range of SES measures that were found to be significantly associated with systolic blood pressure adjusting only for height in initial regression models at age 16 years. Being in the middle tertile of the neighbourhood need for more services index was associated with having lower systolic blood pressure compared to those in the highest tertile. Those in the lowest tertile of the neighbourhood crime index, school environment index, the school problems index or the household consumer durable index were predicted to have increased systolic blood pressure compared to those in the highest tertile of these indices (Table 4). Similar to the male findings, females with a higher BMI or who were obese were associated with higher systolic blood pressure, although unlike the male findings being taller was not significantly associated with increased systolic blood pressure in the females (Table 4).

For males, none of the infancy or year 16 SES variables were significant in their association with systolic blood pressure after being entered simultaneously into regression models (Table 5). Lower birth weight and increased height were significantly associated with increased systolic blood pressure in the adjusted model, which accounted for 13.1% of the variance in systolic blood pressure for males (Table 5). Neither of these variables was significant in the female models of systolic blood pressure. For females the only significant variables in the fully adjusted models showed that those in the middle tertile of the index of crime prevention showed significantly higher systolic blood pressure compared to those in the highest tertile. Furthermore, obese girls and those born post term were also associated with significantly higher systolic blood pressure. The fully adjusted model for females explained 23.2% of the variation in systolic blood pressure (Table 5).

Systolic pre-hypertension

The only infancy variable that was significantly associated with reduced risk of systolic pre-hypertension in the initial model (other than the missing data category) was maternal age 25-29 years compared to a maternal age of 35 plus years. Increased risk of systolic pre-hypertension was observed in those who were born post term, and had outside only access to water/toilet facilities and shared use of water and toilet facilities (Table 3). In initial models for year 16 SES variables, shared use of indoor running cold water or shared use of an outdoor flush toilet compared to sole use were significantly associated with increased risk of systolic pre-hypertension (Table 4). In step one of the multiple regression, all of the significant infancy variables from the initial models, apart from shared use of water and toilet facilities, retained significance and direction of association (Table 6). In step two, the only infancy variable to retain significance was having a mother aged 25-29 years. None of the year 16 SES variables were significant when entered simultaneously in step two. Step three did not change the significance of the other variables, although those born post term were also found to have higher systolic pre-hypertension risk than those born term.

Discussion

Within the context of Glass and McAtee's (2006) framework this paper has provided evidence that enhances understanding of associations between two of their identified levels of hierarchy of SES measurement (household and neighbourhood) with systolic blood pressure measures in a middle income context. Furthermore, the paper has considered the stage of the life-course at which the Bt20 household SES measures were assessed (infancy and age 16 years). Glass and McAtee also acknowledge the importance of considering the life-course stage at which environmental differences are embodied in their model. These associations have been studied within the context of a cohort of South African adolescents born on the dawn of democracy in South Africa after a prolonged period of legislation enforcing apartheid. Despite the legacies of apartheid, South Africa is one of the most advanced countries for economic, social and epidemiological transition in the sub-Saharan African region. Results are discussed within the context of the two levels of hierarchy studied (household and neighbourhood), as well as an overall consideration of the relative contribution of the different life-course measurement time points of birth and age 16 years for the systolic blood pressure outcomes considered.

Infancy SES measures

Despite the broad range of infancy assessed household SES measures tested, none remained significant in adjusted analyses. This finding of a lack of association is not unique to this study (Lawlor, *et al.*, 2002). Where an SES association was observed in the unadjusted analyses, it followed the pattern previously described in the literature of a negative association between SES measured in infancy and disease risk (Pollitt, *et al.*, 2005).

Most of the significant infancy SES variables in unadjusted analyses relate to early life measures of water and sanitation facilities. Whilst these measures are probably a proxy for an overall measure of the SES environment, it is also feasible that aspects of the SES environment specific to water and sanitation are more important for systolic blood pressure in early life than other SES measures. Poor sanitation facilities might result in a high risk environment for infections with a faecal-oral route of transmission (e.g. diarrhoea). High diarrhoea prevalence in infancy could result in repeated exposure to dehydration, which may ‘program’ the body for increased water and salt retention to cope with a risky dehydration environment, leading to hypertension risk (Davey Smith*, et al.*, 2006; Lawlor*, et al.*, 2006). This hypothesis might be better tested in other countries in sub-Saharan Africa with higher prevalence of diarrhoea and malnutrition early in infancy because such countries would provide higher prevalence levels of repeated severe diarrhoea episodes. Most studies investigating this association between diarrhoea episodes/sanitation and blood pressure have taken place using high/middle income country cohorts in the UK, Brazil, and Peru and have not provided evidence for this association (Batty*, et al.*, 2007; Pearce*, et al.*, 2008; Batty*, et al.*, 2009; Miranda*, et al.*, 2009). The fact that Bt20 data show some evidence in unadjusted analyses in a middle income country context to potentially support this hypothesis, suggests that further testing in low income environments with higher prevalence of diarrhoea is warranted.

Age 16 Years household SES measures

Similar to the findings for the infancy SES variables, none of the year 16 SES measures were significant in adjusted analyses. In previous child/adolescent developing country studies in adjusted analyses where height, age and sex were accounted for no association between SES and blood pressure was shown, which concurs with what has been observed here (Adair*, et al.*, 2009; Miranda*, et al.*, 2009).

There are not many other studies that have simultaneously assessed the association between household and neighbourhood SES measures and blood pressure in adolescents. Chen and Paterson (2006) studied these associations in a US sample of 315 14-19 year olds and observed little association between measures of household SES and systolic blood pressure before controlling for neighbourhood SES measures. Only one measure out of four tested showed an inverse association with systolic blood pressure and this was family savings (R^2=0.02) (Chen and Paterson, 2006). This compares with an R^2=0.08 in the current study for females in a model that included only water and toilet facilities at age 16 years and height. Our findings are also similar to those in a sample of 212 US 14-16 year olds undertaken by McCrath et al. (2006) who considered the association between household education/occupation levels and systolic blood pressure and observed no significant effect. A limitation of comparing the findings of this study with both of these preceding studies is that neither of these papers controlled for height, which could alter their findings. Nevertheless, the combined results of these studies suggest that household SES measures do not show a strong association with systolic blood pressure in adolescents aged 14-19 years. Our results, along with the weak associations presented in previous adolescent studies, provide support for West's (1997) hypothesis of equalising of health inequalities in adolescence.

Age 16 years neighbourhood SES measures

This study aimed to understand the relationship between neighbourhood SES and systolic blood pressure in a transitioning country to add to the evidence base already built in high income countries. In adult studies in high income countries the association between neighbourhood SES and cardiovascular disease risk factors has been observed in the majority of studies, with those in higher SES neighbourhoods having less risk for cardiovascular disease (Diez Roux et al., 2008). Findings of this study in 16 year old children show that in adjusted analyses only one measure of neighbourhood SES was significant in its association with systolic blood pressure for females only. Those in the middle tertile of the index of crime prevention showed higher systolic blood pressure than those in the highest tertile. This association was however not significant for those in the low tertile of the index, although the association was in the same direction. The lack of association in the lower tertile could be related to the relatively smaller sample size in this group amongst females in the sample compared to the middle tertile, which would reduce the statistical power available to detect differences. Similar studies that have assessed the association between neighbourhood SES, household SES, and systolic blood pressure in high income countries in adolescents have observed contrasting findings regarding the significance of associations. Chen and Paterson (2006) revealed no significant association between systolic blood pressure and neighbourhood measures of SES (education levels, employment, income and housing values) in unadjusted analyses. McGrath et al. (2006) observed an association between a neighbourhood measure of income at or below the poverty line in both adjusted and unadjusted analyses with systolic blood pressure. No association was observed with other neighbourhood measures (racial composition and low levels of high school education). The differences in results across the adolescent studies of the association between household/neighbourhood SES and systolic blood pressure could be partly explained by the different measures of neighbourhood SES used, different ages within adolescence examined, and the different methods adopted to define neighbourhoods. Whilst all three studies had similar objectives, comparisons between the findings are complicated because of these differences. These problems are common to comparisons of findings across neighbourhood level studies (Bond Huie, 2001; Messer, 2007; Mujahid*, et al.*, 2007).

Most adult studies of SES and blood pressure have shown BMI to mediate the association (Colhoun*, et al.*, 1998). This mediation did not occur with the neighbourhood crime measure in this study. This may be because the significant associations observed with this SES measure could work through different mechanisms besides BMI. Although a lack of neighbourhood crime prevention could make healthy lifestyle behaviours (e.g. physical activity) more difficult, it is also plausible that the influence of such neighbourhoods on blood pressure could be mediated through stress, for example through increased cortisol secretion, which increases risk of higher blood pressure (Kapuku*, et al.*, 2002)..

The contribution of the birth and age 16 environment to age 16 systolic blood pressure

When considering the time (life-course) axis of Glass and McAtee's (2006) framework, the infancy measures had a slightly higher overall contribution to the variation in systolic blood pressure outcomes for males (Adj. R^2 = 0.07) compared to the age 16 SES measures (Adj R^2 change = 0.02). For females, the contribution of the SES measures at age 16 to the proportion of variance explained in systolic blood pressure was greater (Adj R^2 change = 0.05) than the proportion of variation explained by the infancy SES measures (Adj R^2 = 0.01), suggesting a sex difference in the relative importance of the SES measures taken at different ages. However, for both males and females the overall variation in systolic blood pressure explained by any of the SES measures regardless of the point on the horizontal time axis at which they were measured is small. This shows little evidence to support physiological changes related to adolescent systolic blood pressure having taken place as a result of environmental insults early in life in this middle income context, even during this time of social change in South Africa. However, it would be dangerous to make strong conclusions at this stage in relation to early life influences on later risk for adult disease as this adolescent sample have relatively healthy systolic blood pressure and this may change as the cohort transition to adulthood.

Limitations

When modelling neighbourhood health effects it is common for researchers to use a multilevel approach to control for the clustering of SES characteristics within neighbourhoods (Pickett and Pearl, 2001). However, the definition of neighbourhood used here (within 20 minutes of home) meant that no two households exactly shared a neighbourhood, although they will share some aspect of their neighbourhood with other participants. Not being able to correct for this partial lack of independence could lead to slightly biased standard error estimates. This study also lacks neighbourhood SES measures before age 16 years of age, which means that we are only able to study neighbourhood SES in adolescence and take a cross sectional approach to studying associations with systolic blood pressure. Cross sectional approaches make it difficult to assess whether associations between health outcomes and neighbourhood factors are due to the context of the neighbourhood or its composition (Kawachi and Subramanian, 2007; Do and Finch, 2008). This problem can be overcome by using a longitudinal approach that controls for pre neighbourhood exposure baseline characteristics (Do and Finch, 2008). As Bt20 begins to build a longitudinal approach to assessing the neighbourhood future research will be able to incorporate such analyses. A limitation of using data from a longitudinal study is that participants often have some level of missing data. In order to maximise the sample size available for the analyses presented here some participants had missing data on some of the predictor variables. These individuals were classified as a separate missing group where relevant. The number of missing cases is small but in a number of cases this resulted in statistically significant associations being displayed between the missing group and blood pressure outcomes, indicating that the missing group were not missing at random. If these missing cases were selectively from a particular SES group this might have changed the conclusions that we made regarding the strength of association between the SES measures and the systolic blood pressure outcomes. A final limitation of the study is the relatively small sample size, which has the power to detect medium to large effect sizes, but not small effect sizes. We can therefore only conclude with a reasonable level of certainty about associations that have a medium to large effect size on systolic blood pressure. Despite this final limitation these findings confirm those observed in other adolescent studies in high and middle income settings, which did analyse data from larger samples.

Conclusions

Returning to the framework that Glass and McAtee (2006) propose where time (Stage of life-course) is on the horizontal axis and hierarchies of influence on the outcome (e.g. household and neighbourhood) are on the vertical-axis, we have shown that SES measures at any of these levels on the vertical axis account for a very small amount of the variation in systolic blood pressure in these urban South African 16 year olds. Time had little influence on the size of the effect of the SES measures on systolic blood pressure. Our findings are similar to those of other studies of the association between SES and systolic blood pressure in high income environments that have found weaker associations in adolescent populations compared to the stronger associations that have been observed in adults. We have extended the test of the evidence in relation to systolic blood pressure/pre-hypertension beyond previous studies in two ways; 1) by focussing on adolescent household and neighbourhood SES environments in a middle income country and 2) by using SES data from two points in the early life course (birth and age 16 years) to give a longitudinal test of the association between SES measures and systolic blood pressure. Despite the extension of the findings of previous work, there remain a number of untested components of Glass and McAtee's (2006) model that future studies could address. Firstly, we have only tested these associations to age 16, where risk for increased systolic blood pressure is low in this South African cohort. Future work should extend the test of these longitudinal associations later into the life-course in middle countries. Secondly, we have considered these associations in South Africa which is advanced in its social, economic and epidemiological transition compared ot other sub-Saharan African countries and provides a unique social setting because of the apartheid legacy that this cohort were born into. Further testing of these associations is needed in other sub-Saharan African countries and other low income environments. Finally, this paper has not studied evidence for the biological factors that embody social and environmental experiences of humans and this evidence is clearly needed in low and middle income countries to add to the growing evidence base on this topic in high income countries.

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References

Adair, L. & Dahly, D. (2005) Developmental Determinants of Blood Pressure in Adults*. Annual Review of Nutrition* 25, 407-434.

Adair, L. S., Martorell, R., Stein, A. D., Hallal, P. C., Sachdev, H. S., Prabhakaran, D., Wills, A. K., Norris, S. A., Dahly, D. L., Lee, N. R. & Victora, C. G. (2009) Size at birth, weight gain in infancy and childhood, and adult blood pressure in 5 low- and middle-income-country cohorts: when does weight gain matter?*. The American Journal of Clinical Nutrition* DOI: 10.3945/ajcn.2008.27139 89, 1383-1392.

Adair, L. S. & Prentice, A. (2004) A Critical Evaluation of the Fetal Origins Hypothesis and Its Implications for Developing Countries*. The Journal of nutrition* 134, 191-193.

Akinkugbe, F. M., Akinwolere, A. O. & Kayode, C. M. (1999) Blood pressure patterns in Nigerian adolescents*. West African journal of medicine* 18, 196-202.

Batty, G. D., Horta, B. L., Smith, G. D., Barros, F. C. & Victora, C. (2009) Early life diarrhoea and later blood pressure in a developing country: the 1982 Pelotas (Brazil) birth cohort study*. Journal of epidemiology and community health* DOI: 10.1136/jech.2008.077818 63, 163-165.

Batty, G. D., Smith, G. D., Fall, C. H., Sayer, A. A., Dennison, E., Cooper, C. & Gale, C. R. (2007) Association of diarrhoea in childhood with blood pressure and coronary heart disease in older age: analyses of two UK cohort studies*. International journal of epidemiology* DOI: 10.1093/ije/dym178 36, 1349-1355.

Bond Huie, S. A. (2001) The Concept of Neighbourhood in Health and Mortality Research*. Sociological Spectrum* 21, 341-358.

Cameron, N. (2003) Physical growth in a transitional economy: the aftermath of South African apartheid. *Economics and human biology* 1, 29-42.

Chen, E. & Paterson, L. Q. (2006) Neighborhood, Family and Subjective Socioeconomic Status: How Do They Relate to Adolescent Health?*. Health Psychology* 25, 704-714.

Cohen, J. (1992) A power primer*. Psychological bulletin* 112, 155-159.

Cole, T. J., Bellizzi, M. C., Flegal, K. M. & Dietz, W. H. (2000) Establishing a standard definition for child overweight and obesity worldwide: international survey*. BMJ (Clinical research ed.)* 320, 1240-1243.

Colhoun, H. M., Hemingway, H. & Poulter, N. R. (1998) Socio-economic status and blood pressure: an overview analysis*. Journal of human hypertension* 12, 91-110.

Cummins, S., Macintyre, S., Davidson, S. & Ellaway, A. (2005) Measuring neighbourhood social and material context: generation and interpretation of ecological data from routine and non-routine sources*. Health and Place* 11, 249-260.

Davey Smith, G., Leary, S., Ness, S. & ALSPAC Study Team. (2006) Could dehydration in infancy lead to high blood pressure? *Journal of epidemiology and community health* DOI: 10.1136/jech.2005.040006 60, 142-143.

Diez-Roux, A. V., Kershaw, K. & Lisabeth, L. (2008) Neighborhoods and Cardiovascular Risk: Beyond Individual-Level Risk Factors*. Current Cardiovascular Risk Reports* 2, 175-180.

Do, D. P. & Finch, B. K. (2008) The Link between Neighbourhood Poverty and Health: Context or Composition? *American Journal of Epidemiology* 168, 611-619.

Duncan, M. J., Spence, J. C. & Mummery, W. K. (2005) Perceived environment and physical activity: a meta-analysis of selected environmental characteristics*. The international journal of behavioral nutrition and physical activity* DOI: 10.1186/1479-5868-2-11 2, 11.

Ellison, P. T. (2005) Evolutionary Perspectives on the Fetal Origins Hypothesis*. American Journal of Human Biology* 17, 113-118.

Galea, S., Ahern, J., Rudenstine, S., Wallace, Z. & Vlahov, D. (2005) Urban built environment and depression: a multilevel analysis*. Journal of* *epidemiology and community health* DOI: 10.1136/jech.2005.033084 59, 822-827.

Ginsburg, C., Norris, S. A., Richter, L. M. & Coplan, D. B. (2009) Patterns of Residential Mobility Amongst Children in Greater Johannesburg-Soweto, South Africa: Observations from the Birth to Twenty Cohort. *Urban Forum* 20, 397-413.

Glass, T. A. & McAtee, M. J. (2006) Behavioural science at the crossroads in public health: Extending horizons, envisioning the future*. Social science & medicine* 62, 1650-1671.

Kapuku, G. L., Treiber, F. A. & Davis, H. C. (2002) Relationships among socioeconomic status, stress induced changes in cortisol, and blood pressure in African American males*. Annals of Behavioral Medicine : A Publication of the Society of Behavioral Medicine* 24, 320-325.

Kawachi, I. & Subramanian, S. V. (2007) Neighbourhood influences on health*. Journal of epidemiology and community health* 61, 3-4.

Kearney, P. M., Whelton, M., Reynolds, K., Muntner, P., Whelton, P. K. & He, J. (2005) Global burden of hypertension: analysis of worldwide data*. Lancet* DOI: 10.1016/S0140-6736(05)17741-1 365, 217-223.

Krieger, N. (2005) Embodiment: a conceptual glossary for epidemiology*. Journal of Epidemiology and Community Health* 59, 350-355.

Kuzawa, C. W. (2005) Fetal Origins of Developmental Plasticity: Are Fetal Cues Reliable Predictors of Future Nutritional Environments?*. American Journal of Human Biology* 17, 5-21.

Lawlor, D. A., Ebrahim, S. & Davey Smith, G. (2002) Socioeconomic position in childhood and adulthood and insulin resistance: cross sectional survey using data from British women's heart and health study*. British Medical Journal* 325, 805.

Lawlor, D. A., Smith, G. D., Mitchell, R. & Ebrahim, S. (2006) Adult blood pressure and climate conditions in infancy: a test of the hypothesis that dehydration in infancy is associated with higher adult blood pressure*. American Journal of Epidemiology* DOI: 10.1093/aje/kwj085 163, 608-614.

Lohman, T. G., Roche, A. F. & Martorell, R. (1991) Anthropometric Standardization Reference Manual.

Longo-Mbenza, B., Lukoki Luila, E. & M'Buyamba-Kabangu, J. R. (2007) Nutritional status, socio-economic status, heart rate, and blood pressure in African school children and adolescents*. International journal of cardiology* DOI: 10.1016/j.ijcard.2006.11.004 121, 171-177.

Lucas, A. (1991) Programming by early nutrition in man. In Bock, G. R. & Whelan, J. (eds) *The childhood environment, and adult disease*. John Wiley, Chichester, pp. 38-55.

Macintyre, S. & Ellaway, A. (2000) Biological Approaches: Rediscovering the Role of the Physical and Social Environment. In Berkman, L. & Kawachi, I. (eds) *Social Epidemiology*. Oxford University Press, New York, pp. 174-190.

McGrath, J. J., Matthews, K. A. & Brady, S. S. (2006) Individual versus neighborhood socioeconomic status and race as predictors of adolescent ambulatory blood pressure and heart rate*. Social science & medicine* 63, 1442-1453.

Messer, L. C. (2007) Invited Commentary: Beyond the Metrics for Measuring Neighbourhood Effects*. American Journal of Epidemiology* 165, 868-871.

Miranda, J. J., Davies, A. R., Smith, G. D., Smeeth, L., Cabrera, L., Gilman, R. H., Garcia, H. H., Ortega, Y. R. & Cama, V. A. (2009) Frequency of diarrhoea as a predictor of elevated blood pressure in children*. Journal of hypertension* DOI: 10.1097/HJH.0b013e32831bc721 27, 259-265.

Mujahid, M. S., Diez-Roux, A. V., Morenoff, J. D. & Raghunathan, T. (2007) Assessing the Measurement Properties of Neighborhood Scales: From Psychometrics to Econometrics*. American Journal of Epidemiology* 165, 858-867.

Mujahid, M. S., Diez-Roux, A. V., Morenoff, D., Raghunathan, T. E., Cooper, R. S., Ni, H. & Shea, S. (2008) Neighbourhood Characteristics and Hypertension*. Epidemiology* 19, 590-598.

Pearce, M. S., Relton, C. L., Unwin, N. C., Adamson, A. J. & Smith, G. D. (2008) The relation between diarrhoeal episodes in infancy and both blood pressure and sodium intake in later life: The Newcastle Thousand Families Study*. Journal of human hypertension* DOI: 10.1038/jhh.2008.45 22, 582-584.

Pickett, K. E. & Pearl, M. (2001) Multilevel analyses of neighbourhood socioeconomic context and health outcomes: a critical review*. Journal of epidemiology and community health* 55, 111-122.

Pollitt, P. A., Rose, K. M. & Kaufman, J. S. (2005) Evaluating the evidence for models of a life course socioeconomic factors and cardiovascular outcomes: a systematic review*. BMC public health* 5.

Richter, L., Norris, S., Pettifor, J., Yach, D. & Cameron, N. (2007) Cohort Profile: Mandela's children: the 1990 Birth to Twenty study in South Africa*. International journal of epidemiology* DOI: 10.1093/ije/dym016 36, 504-511.

Richter, L. M., Norris, S. A. & De Wet, T. (2004) Transition from Birth to Ten to Birth to Twenty: the South African cohort reaches 13 years of age*. Paediatric* *and perinatal epidemiology* DOI: 10.1111/j.1365-3016.2004.00572.x 18, 290-301.

Riva, M., Gauvin, L. & Barnett, T. A. (2007) Toward the next generation of research into small area effects on health: a synthesis of multilevel investigations published since July 1998*. Journal of epidemiology and community health* DOI: 10.1136/jech.2006.050740 61, 853-861.

Sheppard, Z. A., Norris, S. A., Pettifor, J. M., Cameron, N. & Griffiths, P. L. (2010) How can we learn about community socio-economic status and poverty in a developing country urban environment? An example from Johannesburg-Soweto, South Africa*. African Population Studies* 24, 53-70.

UNDP. (2011) Human Development Reports 2011. http://hdr.undp.org/en/reports/global/hdr2011/download/ Date last accessed 24/10/11.

US Department of Health and Human Services & National Institutes of Health Heart Blood and Lung Institute. (2005) The Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents NIH Publication No 05-5267.

West, P. (1997) Health inequalities in the early years: is there equalisation in youth?*. Social science & medicine (1982)* 44, 833-858.

WHO. (2011) Global Infobase. 2011. https://apps.who.int/infobase/ Date last accessed 24/10/11.

WHO. (2002) The World Health Report 2002- Reducing Risks, Promoting Health Life.

Table 1 Mean (standard deviation (SD)) systolic blood pressure, birth weight, height, and body mass index (BMI); and percent with pre-hypertension, stage 1 hypertension, overweight, and obese by sex for Black South African adolescents aged 16 years

	Black (n=358)		**Total**
Sex (n)	Male (191)	Female (167)	Total (358)
Mean (SD) systolic blood pressure (mm Hg)	116.3 (10.4)	110.4 (9.4)[a]	114.8 (10.4)
Percent (n) systolic pre-hypertension[1]	12.0 (23)	10.2 (17)	11.2 (40)
Percent (n) systolic stage one hypertension[1]	1.6 (3)	2.4 (4)	1.9 (7)
Mean (SD) birth weight (g)[2]	3167.9 (513.6)	3010.0 (487.1)[a]	3094.3 (506.9)
Age 16 mean (SD) height (cm)	169.0 (7.5)	158.1 (5.8)[a]	163.9 (8.7)
Age 16 mean (SD) BMI (kg/m^2)	20.6 (3.9)	23.1 (4.3)[a]	21.8 (4.2)
Age 16 percent (n) overweight[3]	6.3 (12)	22.2 (37)[a]	13.3 (49)
Age 16 percent (n) obese[3]	3.7 (7)	8.4 (14)	5.7 (21)

[1]Prehypertension is defined using a systolic blood pressure at or above the National Heart Blood Lung Institute's 90th percentile sex age and height standardised value (US Department of Health and Human Services and National Institutes of Health Heart Blood and Lung Institute, 2005). Stage 1 hypertension is defined using a systolic blood pressure at or above the National Heart Blood Lung Institute's 95th percentile sex age and height standardised value plus 5mmHg.

[2] 10 cases did not have birth weight recorded.

[3]Overweight and obesity are defined using Cole et al.'s (Cole*, et al.*, 2000) age appropriate international cut-offs for children and adolescents .

[a]Indicates a significant ($p<0.05$) sex difference in this variable. Continuous variables were tested using an independent samples t-test and categorical variables using a multidimensional Chi-square test.

Table 2 Neighbourhood Principal Component Analysis (PCA) indices and percent of variation explained by the extracted index

Index	Cronbach's alpha	Percent of variation explained by PCA index
Neighbourhood economic index (includes perceptions of neighbourhood wealth, outsiders perceptions of neighbourhood wealth, perception of equity of living standards in the neighbourhood, housing quality and condition, availability of yard space, parking space and fencing/walls around properties)	0.59	29
Neighbourhood need for more services/facilities index (includes primary and secondary schools, hospitals, health centres, community centres, sports facilities, parks, street lighting, piped water, policing,)	0.98	91
Neighbourhood problem index (includes traffic congestion, road safety, sewerage, illegal dumping, pollution, overcrowding, in migration of non South Africans, homelessness, repossession of properties, unemployment, prostitution, alcohol/drug abuse, shebeens, and gangs)	0.81	29
Neighbourhood crime index (includes information on whether most households to prevent crime keep weapons, employ security, have dogs, have fences, security doors, barred windows, and security lights)	0.76	36
Neighbourhood social support/happiness index (includes information on the liveliness, spirit, and trust levels in the neighbourhood, as well as assessments of whether neighbours would help in a time of need, whether neighbours could be trusted to look after their house, happiness and level of pride in the neighbourhood)	0.60	27
School environment index (includes information on whether school is government or private, ethnic composition of the school, how safe the individual feels in the school, and school facilities including library, computer rooms, science labs, sports fields, swimming pool, and after school activities)	0.56	30
School problems index (includes whether the school has problems with poor academic standards, lack of resources, lack of discipline, overcrowding, lack of dedicated teachers, teachers who cannot teach well, bullying, bunking off, smoking, alcohol, drugs, weapons, violence, teen pregnancy, rape, and sexual relationships between learners and teachers)	0.85	30

Table 3 Infancy predictors of systolic blood pressure from initial regression analyses[1] for Black males and females and unadjusted odds ratios for prehypertension

Total n=358	Percent or mean (SD)	Linear regression unstandardised coefficient (se) systolic blood pressure males[1]	Linear regression unstandardised coefficient (se) systolic blood pressure females[1]	Unadjusted Odds Ratio (95% CI) of pre-hypertension
Birth weight (g)	3094.3 (506.9)	-0.003 (0.002)*	0.001 (0.002)	1.000 (0.999, 1.000)
Birth weight (ref[2] normal)				
Low birth weight	10.6	2.011 (2.793)	-2.280 (2.166)	1.555 (0.606, 3.988)
Term (ref full term)				
Preterm	13.4	1.712 (2.350)	-2.268 (1.873)	0.988 (0.365, 2.676)
Postterm	1.1	12.555 (5.868)**	40.120 (8.971)****	8.500 (1.157, 62.425)**
Missing data	0.6	17.654 (10.134)*	5.071 (8.989)	8.500 (0.519, 139.208)
Parity (ref 1)				
Parity 2	29.1	-0.155 (1.796)	-1.055 (1.791)	0.490 (0.198, 1.212)
Parity 3	15.9	0.024 (2.131)	0.682 (2.262)	0.799 (0.302, 2.114)
Parity 4 plus	12.8	2.648 (2.399)	0.309 (2.311)	1.219 (0.477, 3.112)
Parity missing	0.8	17.642 (10.303)*	0.386 (6.841)	3.395 (0.293, 39.272)
Maternal age (ref 35 plus)				
Maternal age 15-19 yrs	19.8	-3.221 (3.515)	-4.149 (3.143)	0.394 (0.112, 1.390)
Maternal age 20-24 yrs	29.6	-1.556 (3.341)	-5.499 (3.066)*	0.593 (0.191, 1.840)
Maternal age 25-29 yrs	25.7	-3.423 (3.396)	-7.018 (3.071)**	0.164 (0.040, 0.670)**
Maternal age 30-34 yrs	17.9	-0.555 (3.556)	-4.572 (3.186)	0.514 (0.149, 1.772)
Missing data	0.6	15.231 (10.663)	0.773 (9.793)	3.600 (0.190, 68.341)
Maternal status (ref married/ living together)				
Widowed/ divorced/ separated	0.6	1.382 (10.303)	-4.654 (9.609)	No cases of at risk
Single	74.6	-0.198 (1.665)	-0.538 (1.804)	0.938 (0.437, 2.013)
Missing data	0.6	17.169 (10.331)*	5.195 (9.665)	7.700 (0.446, 132.986)
Maternal education (ref up to grade 10)				
Maternal education grades 11-12	34.9	-2.411 (1.561)	0.822 (1.621)	0.945 (0.445, 2.008)
Maternal education post school	8.4	-1.353 (2.737)	-0.564 (2.703)	2.225 (0.813, 6.090)
Missing data	1.4	16.254 (10.224)	5.104 (4.838)	5.933 (0.935, 37.657)*
Hospital (ref public hospital)				
Private hospital	3.6	2.592 (3.933)	2.534 (3.931)	0.667 (0.084, 5.271)
Missing data	0.8	17.337 (10.228)*	0.601 (6.747)	4.000 (0.354, 45.165)
House (ref owns property)				
Rented private	17.3	4.405 (2.274)*	-3.145 (2.179)	0.755 (0.290, 1.968)
Rented local authority	48.9	1.528 (1.702)	-2.730 (1.732)	0.597 (0.282, 1.265)
Provided by employer	2.0	-2.136 (4.763)	-6.128 (6.819)	No cases of at risk
Missing data	2.8	8.337 (6.028)	-0.787 (3.819)	1.483 (0.287, 7.671)
Toilet and water facilities (ref all indoor facilities)				
Mixture of inside/ outside	24.3	3.795 (2.186)*	-1.795 (2.119)	2.923 (0.762, 11.211)

water and toilet facilities				
Outside only water and toilet facilities	48.3	4.341 (1.919)**	-0.154 (1.840)	4.279 (1.252, 14.627)**
Missing data	5.3	9.355 (3.449)***	-1.232 (3.665)	4.750 (0.878, 25.708)*
Water and toilet source information (ref sole use of water and toilet facilities)				
Both sole and shared use of toilet and water facilities	3.9	-0.943 (3.312)	-6.919 (4.816)	0.707 (0.089, 5.613)
Shared use of toilet and water facilities	14.0	3.244 (2.229)	-0.458 (2.027)	2.016 (0.885, 4.594)*
Missing data	5.3	6.437 (3.173)**	-0.950 (3.435)	1.722 (0.471, 6.291)
Index of infancy consumer durables (ref highest tertile)				
Middle tertile	38.8	-2.007 (1.950)	-1.031 (1.868)	0.602 (0.249, 1.454)
Lowest tertile	31.6	0.610 (2.033)	-2.257 (1.972)	1.071 (0.466, 2.465)
Missing data	5.0	0.948 (3.747)	2.620 (3.444)	1.400 (0.348, 5.628)

*p<0.1, **p<0.05, ***p<0.01, ****p<0.001 (two tailed)
[1]Adjusted for height at age 16 years.
[2]Ref = reference category.

Table 4 Year 16 predictors of systolic blood pressure from initial regression analyses[1] for Black males and females and unadjusted odds ratios for prehypertension

Total n=358	Percent or mean (SD)	Linear Regression unstandardised coefficient (se) systolic blood pressure males[1]	Linear regression unstandardised coefficient (se) systolic blood pressure females[1]	Unadjusted Odds Ratio (95% CI) of pre-hypertension
Water facilities (ref[2] indoor sole use running hot and cold water)				
Indoor shared use running hot and cold water	9.5	1.127 (2.632)	-0.829 (3.000)	1.733 (0.474, 6.334)
Indoor sole use running cold water	26.8	2.779 (2.033)	-0.588 (1.928)	1.182 (0.411, 3.397)
Indoor shared use running cold water	8.9	0.973 (2.952)	5.166 (2.649)**	3.000 (0.927, 9.708)*
Other water source sole or shared outside the home	24.9	3.160 (2.132)	2.568 (1.928)	2.224 (0.845, 5.854)
Missing data	2.5	3.306 (4.453)	14.760 (5.528)***	3.714 (0.646, 21.362)
Toilet facilities (ref sole use of indoor toilet)				
Shared use indoor flush toilet	10.1	1.017 (2.769)	1.281 (2.489)	1.667 (0.482, 5.763)
Sole use outdoor flush toilet	36.6	2.809 (1.743)	1.311 (1.700)	1.595 (0.665, 3.828)
Shared use outdoor flush toilet	12.3	2.437 (2.386)	4.041 (2.471)	4.444 (1.699, 11.625)***
Other toilet type/ missing data	5.0	-0.345 (3.338)	6.983 (3.757)*	1.667 (0.330, 8.410)
Neighbourhood safety (ref very unsafe/ unsafe)				
Neighbourhood has average safety	23.2	-0.096 (3.260)	0.372 (2.274)	1.186 (0.343, 4.098)
Neighbourhood is safe	47.5	0.304 (3.042)	1.222 (2.062)	1.155 (0.370, 3.607)
Neighbourhood is very safe	17.3	1.391 (3.322)	3.014 (2.562)	1.656 (0.475, 5.769)
Neighbourhood crime index (ref a lot of crime)				
Neighbourhood has some crime	30.2	-2.837 (2.254)	0.296 (2.022)	0.984 (0.381, 2.544)
Neighbourhood has average crime	23.7	-2.348 (2.324)	-0.241 (2.196)	0.933 (0.340, 2.558)
Neighbourhood has not much crime	22.9	-4.696 (2.394)*	1.476 (2.143)	0.971 (0.354, 2.666)
Neighbourhood has no crime	3.4	-1.231 (3.850)	6.736 (5.671)	1.575 (0.291, 8.510)
Neighbourhood economic index (ref highest tertile)				
Middle tertile	34.6	-0.570 (1.784)	-0.661 (1.847)	0.765 (0.338, 1.732)
Lowest tertile	33.5	-0.121 (1.879)	-1.483 (1.795)	0.943 (0.428, 2.078)

Neighbourhood index of need for more services/ facilities (ref highest tertile)				
Middle tertile	33.0	0.364 (1.805)	-3.830 (1.808)**	0.742 (0.322, 1.710)
Lowest tertile	33.8	2.447 (1.797)	-0.805 (1.805)	0.944 (0.429, 2.078)
Missing data	1.1	14.757 (7.278)**	0.218 (6.808)	2.405 (0.234, 24.745)
Neighbourhood problem index (ref highest tertile)				
Middle tertile	31.6	3.736 (1.704)**	-4.017 (1.969)**	1.065 (0.490, 2.316)
Lowest tertile	32.7	-0.863 (1.854)	-2.559 (1.860)	0.782 (0.344, 1.778)
Neighbourhood crime index (ref highest tertile)				
Middle tertile	33.0	-0.920 (1.900)	2.479 (1.695)	1.645 (0.683, 3.964)
Lowest tertile	33.8	1.336 (1.761)	4.303 (1.844)**	1.998 (0.853, 4.680)
Neighbourhood index of social support and happiness (ref highest tertile)				
Middle tertile	33.5	0.354 (1.739)	-2.470 (1.949)	1.071 (0.493, 2.330)
Lowest tertile	33.2	-1.425 (1.860)	-1.556 (1.835)	0.764 (0.332, 1.759)
Index of school environment (ref highest tertile)				
Middle tertile	33.0	-2.284 (1.864)	1.470 (1.788)	0.796 (0.317, 1.998)
Lowest tertile	32.7	1.620 (1.884)	3.582 (1.753)**	1.752 (0.788, 3.894)
Missing data	1.7	3.377 (7.333)	5.915 (4.822)	4.818 (0.791, 29.364)*
Index of school problems (ref highest tertile)				
Middle tertile	31.3	0.191 (1.909)	1.569 (1.728)	1.297 (0.563, 2.987)
Lowest tertile	33.2	003 (1.886)	3.086 (1.832)*	1.277 (0.547, 2.983)
Missing data	2.5	-1.235 (4.824)	5.757 (4.842)	2.779 (0.513, 15.055)
Index of year 16 consumer durables (ref highest tertile)				
Middle tertile	31.0	1.908 (1.820)	0.824 (1.761)	0.731 (0.304, 1.760)
Lowest tertile	28.2	0.617 (1.868)	3.005 (1.802)*	1.224 (0.548, 2.735)
Missing data	4.5	4.287 (3.317)	8.363 (4.430)*	2.762 (0.783, 9.738)
Height (cms)	163.9 (8.7)	0.300 (0.098)***	0.121 (0.125)	1.002 (0.965, 1.040)
BMI (wt(Kg)/ht(m^2))	21.8 (4.2)	0.754 (0.185)****	0.459 (0.168)***	1.082 (1.014, 1.156)**
Weight status (ref normal)				
Overweight[3]	13.7	2.997 (3.013)	2.508 (1.763)	0.737 (0.248, 2.188)
Obese[3]	5.9	10.205 (3.876)***	6.937 (2.614)***	2.591 (0.888, 7.561)*
Smoking status (ref currently smoke)				
Previously smoked	30.4	0.809 (1.917)	0.307 (2.601)	0.849 (0.301, 2.390)
Never smoked	45.3	2.146 (1.862)	1.841 (2.431)	1.404 (0.569, 3.468)
Missing data	3.9	1.677 (3.878)	7.934 (4.422)*	2.571 (0.576, 11.473)

*p<0.1, **p<0.05, ***p<0.01, ****p<0.001 (two tailed)

[1]Adjusted for height at age 16 years.

[2]Ref = reference category.

[3]Overweight and obesity are defined using Cole et al.'s (2000) age appropriate international cut-offs for children and adolescents.

Table 5 Adjusted unstandardised parameter estimates for systolic blood pressure in Black 16 year olds for variables that had a previous significant association with systolic blood pressure (adjusting for height only)

	Males				Females			
	N	**Step 1[1] Adjusted parameter estimate (standard error)**	**Step 2 Adjusted parameter estimate (standard error)**	**Step 3 Adjusted parameter estimate (standard error)**	**n**	**Step 1 Adjusted parameter estimate (standard error)**	**Step 2 Adjusted parameter estimate (standard error)**	**Step 3 Adjusted parameter estimate (standard error)**
Constant	191	70.036 (16.703)	64.752 (16.786)	62.880 (16.744)	167	100.807 (20.631)	116.088 (21.810)	102.658 (20.091)
INFANCY VARIABLES								
Maternal age at birth (ref[2] 35 plus)					12			
Maternal age 15-19 yrs					35	-4.149 (3.143)	-1.928 (3.231)	1.423 (3.043)
Maternal age 20-24 yrs					46	-5.499 (3.066)	-3.257 (3.144)	-0.664 (2.984)
Maternal age 25-29 yrs					42	-7.018 (3.071)*	-4.100 (3.100)	-0.512 (2.918)
Maternal age 30-34 yrs					31	-4.572 (3.186)	-1.966 (3.343)	0.996 (3.120)
Missing data					1	0.773 (9.793)	6.857 (10.186)	0.996 (3.120)
House ownership (ref owns property)	57							
Rented private	31	4.082 (2.290)	5.066* (2.341)	4.560 (2.319)				
Rented local authority	95	1.131 (1.701)	1.685 (1.730)	1.699 (1.760)				
Provided by employer	5	-0.137 (4.814)	0.882 (4.860)	0.915 (4.781)				
Missing data	3	2.197 (6.895)	3.427 (6.956)	9.181 (8.309)				
Toilet and water facilities (ref all indoor)	39							
Mixture of inside/ outside water and toilet facilities	47	3.191 (2.264)	2.594 (2.297)	1.814 (2.295)				
Outside only water and toilet facilities	94	3.732 (1.993)	2.750 (2.057)	2.263 (2.044)				
Missing data	11	9.073 (3.955)*	7.922 (3.969)*	6.301 (3.977)				
YR 16 SES VARIABLES								

Water facilities (ref indoor sole use running hot and cold water)					48			
Indoor shared use running hot and cold water					12		-1.299 (3.342)	-2.585 (3.052)
Indoor sole use running cold water					43		-2.859 (2.208)	-3.468 (2.055)
Indoor shared use running cold water					16		3.905 (2.807)	4.666 (2.624)
Other water source sole or shared outside the home					45		0.179 (2.283)	0.073 (2.142)
Missing data					3		12.427 (8.947)	17.730 (8.230)*
Neighbourhood crime (ref a lot)	32							
Neighbourhood has some crime	58		-2.953 (2.266)	-2.633 (2.246)				
Neighbourhood has average crime	49		-1.940 (2.352)	-1.807 (2.330)				
Neighbourhood has not much crime	43		-3.733 (2.409)	-4.544 (2.381)				
Neighbourhood has no crime	9		-0.701 (3.871)	-0.865 (3.810)				
Neighbourhood index of need for more services/ facilities (ref highest tertile)					53			
Middle tertile					56		-3.448 (1.859)	-3.075 (1.696)
Lowest tertile					58		-1.103 (1.913)	-0.161 (1.744)
Missing data					2		5.553 (7.465)	2.861 (6.863)
Neighbourhood crime index (ref highest tertile)					58			
Middle tertile					63		2.717 (1.757)	3.516 (1.609)*
Lowest tertile					46		3.390 (1.916)	1.924 (1.754)
Neighbourhood problem index (ref highest tertile)	88				40			
Middle tertile	58		3.072 (1.748)	3.230 (1.746)	55		-3.151 (2.115)	
Lowest tertile	45		-1.705 (1.885)	-1.975 (1.931)	72		-1.800 (1.930)	

Index of school environment (ref highest tertile)[4]					66			
Middle tertile					47		-	-
Lowest tertile					50		-	-
Missing data					4		-	-
Index of school problems (ref highest tertile)					62			
Middle tertile					46		0.368 (1.915)	0.113 (1.737)
Lowest tertile					47		2.450 (2.005)	1.836 (1.819)
Missing data					12		3.396 (5.220)	1.918 (4.744)
Index of year 16 consumer durables (ref highest tertile)					61			
Middle tertile					53		1.444 (1.978)	1.338 (1.831)
Lowest tertile					48		2.142 (2.154)	2.775 (2.014)
Missing data					5		-0.900 (6.971)	-3.690 (6.431)
MEDIATING VARIABLES								
Birth weight (g)	189			-0.004 (0.002)*				
Term birth (ref term)	166				138			
Preterm	21			-1.633 (2.639)	27			-2.030 (1.836)
Postterm	3			12.711 (6.632)	1			43.225 (9.180)***
Missing data	1			3.792 (15.044)	1			-
Weight status (ref normal)	172				116			
Overweight[3]	12			3.195 (3.073)	37			0.680 (1.687)
Obese[3]	7			3.731 (4.513)	14			8.232 (2.645)**
Height (cms)	191	0.248 (0.099)*	0.281 (0.099)**	0.373 (0.103)**	167	0.093 (0.128)	-0.021 (0.135)	0.042 (0.123)
Adjusted R^2		0.068	0.085	0.131		0.007	0.061	0.232

*p<0.05, **p<0.01, ***p<0.001 (two tailed)

[1]Multivariable regression models were adjusted for year 16 height and were built in steps; 1) infancy variables with a p-value < 0.1 from the initial analysis entered, 2) added year 16 household/neighbourhood SES variables with a p-value < 0.1 from the initial analysis, and 3) added other year 16 variables with a p-value < 0.1 from the initial analysis.

[2]ref = reference category.

[3]Overweight and obesity are defined using Cole et al’s (2000) age appropriate international cut-offs for children and adolescents.

[4]This variable violates the colinearity assumptions for the female model and could therefore not be included in the multivariate model.

Table 6 Adjusted odds ratios for risk of systolic pre-hypertension in Black 16 year olds for variables that had a significant unadjusted odds of prehypertension

	N	Step 1[1] Adjusted parameter Odds ratio estimate (95% CI)	Step 2 Adjusted parameter Odds ratio estimate (95% CI)	Step 3 Adjusted parameter Odds ratio estimate (95% CI)
INFANCY VARIABLES				
Maternal age at birth (ref[2] 35 plus)	23			
Maternal age 15-19 years	71	0.437 (0.120, 1.584)	0.422 (0.110, 1.626)	0.457 (0.115, 1.815)
Maternal age 20-24 years	106	0.603 (0.190, 1.916)	0.619 (0.180, 2.129)	0.547 (0.153, 1.953)
Maternal age 25-29 years	92	0.158 (0.037, 0.671)*	0.148 (0.033, 0.662)*	0.144 (0.031, 0.661)*
Maternal age 30-34 years	64	0.559 (0.156, 2.003)	0.635 (0.166, 2.430)	0.606 (0.153, 2.401)
Missing data	2	2.499 (0.088, 70.716)	3.054 (0.095, 97.755)	2.311 (0.047,113.794)
Toilet and water facilities (ref all indoor)	79			
Mixture of inside/ outside water and toilet facilities	87	3.059 (0.776, 12.053)	2.814 (0.659, 12.017)	2.912 (0.655, 12.939)
Outside only water and toilet facilities	173	3.824 (1.086, 13.468)*	3.297 (0.876, 12.405)	3.829 (0.977, 15.014)
Missing data	19	4.860 (0.714, 33.064)	4.599 (0.639, 33.119)	3.541 (0.387, 32.420)
Toilet and water source information (ref sole use of water and toilet facilities)	275			
Both sole and shared use of toilet and water facilities	14	0.615 (0.073, 5.160)	0.529 (0.060, 4.682)	0.472 (0.049, 4.512)
Shared use of toilet and water facilities	50	1.710 (0.701, 4.173)	1.694 (0.655, 4.385)	1.736 (0.671, 4.493)
Missing data	19	No cases at risk	No cases at risk	No cases at risk
YR 16 SES VARIABLES				
Water facilities (ref indoor sole use running hot and cold water)	98			
Indoor shared use running hot and cold water	34		0.888 (0.095, 8.324)	0.436 (0.046, 4.122)
Indoor sole use running cold water	96		0.991 (0.230, 4.275)	0.584 (0.142, 2.397)
Indoor shared use running cold water	32		1.624 (0.235, 11.212)	0.988 (0.144, 6.788)
Other water source sole or shared outside the home	89		1.280 (0.250, 6.552)	0.770 (0.168, 3.541)
Missing data	9		No cases at risk	No cases at risk
Toilet facilities (ref sole use of indoor toilet)	129			
Shared use indoor flush toilet	36		1.669 (0.198, 14.059)	2.648 (0.315, 22.251)
Sole use outdoor flush toilet	131		1.165 (0.287, 4.730)	1.412 (0.377, 5.283)
Shared use outdoor flush toilet	44		3.028 (0.567, 16.173)	4.707 (0.905, 24.479)
Other toilet type/ missing data	18		No cases at risk	No cases at risk
MEDIATING VARIABLES				
Term birth (ref term)	304			
Preterm	48			1.098 (0.356, 3.386)
Postterm	4			18.189 (1.227, 269.591)*
Term missing	2			Only one case at risk

Weight status (ref normal)	288			
Overweight[3]	49			0.481 (0.149, 1.552)
Obese[3]	21			1.651 (0.388, 7.035)
Cox/Snell and Nagelkerke R^2 estimates		0.053, 0.106	0.085, 0.168	0.096, 0.190

*p<0.05, **p<0.01, ***p<0.001 (two tailed)

[1]Multivariable regression models were built in steps; 1) infancy variables with a p-value < 0.1 from the initial analysis entered, 2) added year 16 household/neighbourhood SES variables with a p-value < 0.1 from the initial analysis, and 3) added other year 16 variables with a p-value < 0.1 from the initial analysis.

[2]ref = reference category.

[3]Overweight and obesity are defined using Cole et al.'s age appropriate international cut-offs for children and adolescents.

Figure 1 Transitioning relative household socio-economic profile of the sample between birth and age 16 years