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Cognitive Functioning, Cardiovascular Activity, and State Affect in Men with and without a Parental History of Hypertension

F. Aurelio Sita

A Thesis

in

the Department of

Psychology

Presented in Partial Fulfilment of the Requirements
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ABSTRACT

Cognitive Functioning, Cardiovascular Activity, and State Affect in Men with and without a Parental History of Hypertension

F. Aurelio Sita, Ph.D.
Concordia University, 1999

The present study investigated cognitive functioning in young normotensive males with and without a parental history of hypertension (PH+ and PH-, respectively). Cardiovascular and state affect responses at rest and during testing were examined in order to determine whether they can account for any parental history group differences in cognitive functioning. PH+ participants performed more poorly on Block Design, Visual Span, and Sternberg Memory Search Task when compared to PH- individuals. Also, PH+ participants reported higher anxiety and irritability during Block Design than PH- participants. PH+ participants performed more poorly on Block Design even after controlling for group differences in state affect responses. There were no parental history group differences in resting cardiovascular activity and cardiovascular reactivity during testing. However, cardiovascular activity at rest, and to a lesser degree, cardiovascular reactivity during testing were related to test performance for the entire sample. More specifically, decreased baseline peripheral resistance and increased baseline cardiac activity were related to better test performance. During testing, only increased cardiac reactivity was related to better test performance. The present results suggest that parental history group differences in cognitive functioning are independent of cardiovascular

activity and state affect, even though cardiovascular activity may be related to cognitive functioning.

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Cognitive Functioning, Cardiovascular Activity, and State Affect in Men with and without a Parental History of Hypertension

Hypertension, chronically elevated arterial pressure, is a major cause of heart failure and renal failure, and is an important risk factor for coronary artery disease and cerebrovascular disease (1984 Report of the Joint National Committee on the Detection, Evaluation, and Treatment of High Blood Pressure, 1984). According to the World Health Organization, hypertension is defined by a blood pressure greater than 160/95 mm Hg whereas borderline hypertension is defined as a systolic blood pressure between 140 and 160 mm Hg or a diastolic blood pressure between 90 and 95 mm Hg. In about 10 percent of cases, hypertension is caused by known medical conditions (e.g., renovascular disease or coarctation of the aorta) and is termed secondary hypertension. In the vast majority of cases, however, its etiology remains unclear. Such hypertension is referred to as primary or essential hypertension.

Cognitive Decrements in Hypertensives

Hypertension's effects on the heart and kidney are well documented; however, less is known about its effects on the brain and cerebral vasculature. Hypertension is a major risk factor for various types of strokes including ischemic stroke, intracerebral hemorrhage, and transient ischemic attacks (Philips & Whisnant, 1992). Risk for stroke increases with blood pressure level, particularly when systolic blood pressure is above 160 mmHg (Strandgaard, 1996). Data from observational and experimental studies

suggest that hypertension increases the likelihood of stroke by exacerbating atherosclerosis in large arteries and causing arteriosclerosis and lipohyalinosis in the small cerebral arteries (Philips & Whisnant, 1992). Hypertension is also a risk factor for vascular dementia (Lis & Gaviria, 1997). Abrupt and sustained blood pressure elevations in chronic hypertensives may lead to hypertensive encephalopathy. However, the use of anti-hypertensive medication has greatly decreased the incidence of this disorder (Phillips & Whisnant, 1992).

Even before any major complications arise (e.g., stroke), subtle pathological changes in the brain may occur as a result of the constantly elevated blood pressure. For example, increased blood pressure may cause vascular hypertrophy in cerebral arteries which increases vascular resistance and could alter cerebral blood flow (Shaw et al., 1984). Hypertension also accelerates the development of atherosclerosis (Doyle, 1991) and cerebral white matter lesions (Awad, Spetzler, & Hodak, 1986). It has been hypothesised that these and other hypertension related changes in the brain may affect cognitive functioning even before the occurrence of overt cerebrovascular events (Shapiro, Miller, King, Ginchereau, & Fitzgibbon, 1982). In this regard, numerous studies have examined cognitive functioning in hypertensives and normotensives. What follows is a summary of the major findings from these studies. For each of these studies, details regarding the samples employed, exclusion criteria, control of confounding variables, factors investigated, and major findings according to test and cognitive domain are presented in Table A1 of Appendix A. Only studies that have been conducted from the 1970's to the present were reviewed as many of the earlier studies consisted of small

samples, included participants who had experienced overt cerebrovascular events, or did not control for demographic variables (age, education) which could affect cognitive performance. Unless otherwise noted in Table A1, the studies reviewed have taken into account age and education and have screened participants for illnesses including those which are likely to have an impact on cognitive performance such as diabetes and neurological disorders. Many studies employed numerous neuropsychological tests but did not control for inflation of Type I error; however, the more recent studies have used a multivariate approach and, consequently, have minimised the number of statistical tests conducted.

The majority of studies examining the hypertension cognitive functioning relationship have reported poorer cognitive functioning in otherwise healthy hypertensives when compared to normotensives. Decrements in cognitive functioning are most often observed on tests of abstract reasoning, attention, memory, and psychomotor speed. With regards to abstract reasoning, hypertensives have been found to perform more poorly on the Category Test from the Halstead-Reitan Battery (e.g. Elias, Robbins, Schultz, Streeten, & Elias, 1987; Pentz, Elias, Wood, Schultz & Dineen, 1979) and Raven's Progressive Matrices (Franceschi, Tancredi, Smirne, Mercinelli, & Canal, 1982). However, other tests of abstract reasoning such as card sorting and the Similarities subtest from the Wechsler Adult Intelligence Scale-Revised WAIS-R (Wechsler, 1987) have yielded mainly null findings. More specifically, card sorting tasks have yielded positive findings in only one (Franceschi et al., 1982) of three studies (Boller,Vrtunski, Mack, & Kim, 1977; Francheschi et al., 1982; Grossman & Zalewski, 1995) and

Similarities failed to differentiate hypertensives from normotensives in one study (Franceschi et al., 1977).

Hypertensives tend to display poorer attention than normotensives. Hypertensives have displayed poorer performance on tests of attention such as the Digit Span task (e.g. Boller et al., 1977; Mazzuchi, Mutti, Poletti, Ravanetti, Novarini, & Parma, 1986), the calculation/attention subtest of the Mini-Mental State exam (Kussisto et al., 1993), and a visual attention task (Madden & Blumenthal, 1998). However, in a study by Schmidt et al., (1991), hypertensives and normotensives performed similarly on a visual selective attention task.

Hypertensives have been found to be slower on psychomotor tasks that involve speed of information processing. Light (1975, 1978) reported slower reaction times in hypertensives in a choice reaction time task. Speed of search through short-term memory has been found to be slower in hypertensives (Madden & Blumenthal, 1989; Blumenthal, Madden, Pierce, Siegel, & Appelbaum, M., 1993). Digit Symbol from the Wechsler Adult Intelligence Scale (WAIS) has yielded both positive (Blumenthal et al., 1993; Mazzuchi et al., 1986; Schultz, Dineen, Elias, Pentz & Wood, 1979; Shapiro et al., 1982), and null results (Boller et al., 1977; Elias et al., 1987; Franceschi et al., 1982; Perez-Stable et al., 1992; Waldstein et al., 1996). Except for one study, (Blumenthal et al., 1993), the Trail Making Test has failed to differentiate hypertensives from normotensives (Elias et al., 1987; Kussisto et al., 1993; Pentz et al., 1979; Waldstein et al., 1996).

Research suggests that hypertensives may have poorer memory than

normotensives. A number of studies have reported poorer verbal memory (Franceschi et al., 1982; Mazzuchi et al., 1986; Schmidt et al., 1991; Waldstein, Nixon, Jennings, Miller, & Shapiro, 1991) as well as poorer non-verbal memory in hypertensives (Franceschi et al., 1982; Pentz et al., 1979; Mazzuchi et al., 1986; Waldstein et al., 1991; Wilkie & Eisdorfer, 1976). However, some studies, including two recent ones, have found no differences between hypertensives and normotensives on memory tests (e.g. Boller et al., 1977; Blumenthal et al., 1993; Waldstein et al., 1996). In a review of studies examining neuropsychological functioning in hypertensives by Waldstein, Manuck, Ryan and Muldoon (1991), it was noted that for many memory tests which have yielded null results, the effect sizes were of reasonable magnitude but the studies lacked sufficient power to yield significant effects.

Studies that have examined visual-spatial ability in hypertensives have yielded mixed results. Some studies have reported poorer performance in hypertensives on Block Design (Franceschi et al., 1982; Mazzuchi et al., 1986; Schultz et al., 1979) and Object Assembly (Schultz et al., 1979) while in other studies, Block Design (Boller et al., 1977; Shapiro et al., 1982) and Object Assembly (Mazzuchi et al., 1986) have failed to differentiate hypertensives from normotensives. Null findings have also been obtained for the Rey-Osterreith Figure (Boller et al., 1977; Mazzucchi et al., 1986).

It is unclear whether perceptual processes are poorer in hypertensives. Perceptual processes have not been extensively investigated and their examination, for the most part, has been limited to the visual modality. In those studies that have included perceptual tests, the results have been mixed. (Mazzuchi et al., 1986; Shapiro et al., 1982). For

example, in study by Shapiro et al., (1982), hypertensives performed more poorly on Visual Recognition Threshold but not on Critical Flicker Fusion Frequency and Two Flash Fusion Threshold. Hypertension was also associated with poorer performance on Perception of Spaced Stimuli, but this finding only applied to female hypertensives.

It seems that language skills are not affected by hypertension. With the exception of one study in which Verbal IQ was found to be lower in young hypertensives than normotensives (Schultz et al., 1979), studies that have included Verbal IQ (Boller et al., 1977; Wilkie & Eisdorfer, 1971) or tests of language comprehension and writing (Boller et al., 1977; Wilkie & Eisdorfer, 1971) have yielded null findings. Furthermore, the effect sizes for these tests were quite small (Waldstein et al., 1991).

There is evidence that education may moderate the relationship between hypertension and cognitive functioning. Elias et al. (1987) tested very well-educated (16-22 years of education) and less well-educated (12-15 years of education) hypertensives on a number of tests from the Halstead-Reitan Battery. When compared to education matched normotensives, less well-educated hypertensives performed more poorly on tests of abstract reasoning, memory, and spatial localization. Furthermore, they scored lower on a composite score derived from tests used in the study (Average Impairment Index). However, there were no differences in cognitive performance between well-educated hypertensives and normotensives. Thus, educational level may buffer the effects of hypertension on cognitive functioning. Increased exercise of cognitive functions by very well-educated hypertensives may be one mechanism through which the deleterious effects of hypertension on cognitive functioning may be delayed or prevented (Costa &

Shock, 1980). On the other hand, it is possible that differences in cognitive functioning do exist between very well-educated hypertensives and normotensives, however, cognitive tests, including those from the Halstead-Reitan Battery, are not sufficiently difficult to detect them.

A number of cross-sectional studies have specifically examined the interaction between age and hypertension. Schultz et al. (1979) examined younger (21 to 39 years old) hypertensives and older (45 to 65 years old) hypertensives and age-matched normotensives on the WAIS. Younger, but not older hypertensives, obtained lower WAIS Verbal scale scores than their age matched controls. When younger and older hypertensives and normotensives were matched on Verbal Scale scores, WAIS Performance Scale scores were lower for hypertensives than for normotensives, and this effect was greater for the younger than for the older participants. The same participants were then administered tests from the Halstead-Reitan Battery (Pentz et al., 1979). Differences between hypertensives and normotensives on finger tapping and Tactual Performance Test- Memory were greater for the younger than the older participants. Consistent with above findings, young (23-40 years old) hypertensives performed more poorly than young normotensives on tests of attention/executive function and working memory, whereas middle-aged (41-56 years old) hypertensives and middle-aged normotensives performed similarly on all tests (Waldstein et al., 1996). In a recent study (Madden & Blumenthal, 1998), higher error rates on a visual search task were observed among young (18-59 years old) hypertensives as compared to young normotensives, however, there were no differences in error rates between older (60-78 years old)

hypertensives and normotensives.

The reason why, in cross-sectional studies, cognitive decrements are larger or more often observed in younger hypertensives as compared to older hypertensives is unclear. It has been hypothesised that early onset hypertension may be more severe than hypertension that begins later in life (Waldstein, 1995). Another explanation is related to survival effects. According to Waldstein (1995), it is possible that those with early onset hypertension are less likely to participate in studies when they are older because they develop cardiovascular complications that would exclude them from the study or because of a higher incidence of mortality due to cardiovascular disease.

In addition to age, education, and the presence of illnesses, two important factors that must be considered when evaluating cognitive functioning in hypertensives and normotensives are medication use and affect. There is evidence that anti-hypertensive medications may affect some aspects of cognitive functioning; however, the direction of their effects is unclear and may depend upon the type of anti-hypertensive medication and the cognitive domain tested (see Dimsdale, Newton, & Joist, 1989; Muldoon, Waldstein, & Jennings, 1995, for reviews). With regards to the studies reviewed above, in one study (Mazzuchi et al., 1986) medicated hypertensives performed better than unmedicated hypertensives, in another study, unmedicated hypertensives performed better than medicated hypertensives (Light, 1975), while other studies have reported no difference in performance between these two groups (Franceschi et al., 1982; Schultz et al., 1979). In a study by Miller et al. (1984), medicated hypertensives showed a greater improvement on tests of visual perceptual and psychomotor ability than unmedicated

hypertensives and normotensives at the end of a 15 month follow up period. In fact, the unmedicated hypertensives experienced a decrement in overall test performance. Interestingly, at study completion, the medicated hypertensives displayed significantly lower blood pressure as compared to their initial testing blood pressure whereas the blood pressures of the unmedicated hypertensives remained unchanged.

Although the effects of anti-hypertensive medication on cognitive performance are still unclear, it is unlikely that the poorer performance of hypertensives can be entirely attributed to the effects of anti-hypertensive medication use. With the exception of longitudinal studies (e.g. Schultz et al., 1986; Wilkie & Eisdorfer, 1971; Wilkie et al., 1976), in the majority of the studies reviewed above, hypertensives were required to discontinue their medications prior to testing or had never taken anti-hypertensive medications. More importantly, studies which have examined newly diagnosed hypertensives or hypertensives who had never taken anti-hypertensive medications have reported poorer performance in hypertensives as compared to normotensives (Blumenthal et al., 1993; Boller et al., 1977; Franceschi et al., 1982; Mazzucchi et al., 1986; Waldstein et al., 1991).

When examining cognitive performance in hypertensives it is also important to take affective factors into account. Although, in general, results are inconsistent, some studies have reported more symptoms of depression and higher anxiety (Cottier, Perini & Rauchfleisch, 1987; Wood, Elias, Schultz, & Pentz, 1979) and greater suppression of anger in hypertensives (Cottier, Perini & Rauchfleisch, 1987). Furthermore, there is evidence that hypertensives who are aware of their diagnosis score higher on measures of

neuroticism and anxiety than unaware hypertensives and normotensives (Irvine, Garner, Olmstead, & Logan, 1989). As such, it is conceivable that knowledge of hypertensive status may affect hypertensives' mood and, as a result, test performance. This point is relevant given that the majority of hypertensives recruited for studies on cognitive functioning are aware ot their diagnosis.

Unfortunately, the majority of studies reviewed above have not considered trait or state affect factors. However, in the studies that have examined affect factors, cognitive decrements in hypertensives have been found to be independent of state and trait anxiety, depression, and hostility (Blumenthal et al., 1993; Waldstein et al., 1996). Also, cognitive decrements have been observed in untreated hypertensives who were unaware of their diagnosis at the time of testing (Waldstein, Ryan, Manuck, Parkinson, & Bromet, 1991). Thus, poorer cognitive performance in hypertensives appears to be independent of affect factors as well as participants' knowledge of hypertensive status.

Hypertension and Cognitive Functioning: Longitudinal Studies

A number of studies have examined the effects of the course of hypertension on cognitive functioning using a longitudinal approach. Wilkie and Eisdorfer (1971) observed greater decreases in WAIS Performance scores over a 10 year period in hypertensives initially examined at ages 60-69 years as compared to same age normotensives and borderline hypertensives. Both borderline hypertensives and normotensives initially examined at ages 70-79 years displayed a decrease in Performance scores at the end of the 10 year period. None of the hypertensives in this

age group were alive at the end of the 10 year period. In a subsequent study, Wilkie, Eisdorfer, and Nowlin (1976) conducted a 6.5 year follow up of participants from the Wilkie & Eisdorfer study who were in their 60's at initial testing. At follow-up, hypertensives, when compared to borderline hypertensives and normotensives, displayed poorer performance on the Visual Reproduction test of the Wechsler Memory Scale, a test of visual memory, whereas these groups did not differ on this test at initial testing. There were no differences between borderline hypertensives and normotensives at follow up.

Schultz et al. (1986) retested some of the participants from the Schultz et al. (1979) study on the WAIS following a 5-6 year interval. Normotensives displayed higher Verbal scores than hypertensives. The authors concluded that this may be due to the fact that normotensives displayed an increase in Verbal Scale scores relative to initial scores, whereas for hypertensives, there were no significant changes in both Verbal and Performance Scale scores. In a 10 year follow up of the Schultz et al. (1979) sample, hypertensives performed more poorly on tests of abstract reasoning and memory and the Average Impairment Rating from the Halstead-Reitan Battery in comparison to normotensives; however, both hypertensives and normotensives displayed a similar rate of change in cognitive performance at the end of the 10 year period (Elias, Schultz, Robbins, & Elias, 1989).

It should be noted that attrition rates were high in some of the longer follow up studies (Elias et al., 1989; Schultz et al., 1986; Wilkie & Eisdorfer, 1971). High attrition rates should be a concern because non-returning and returning participants may differ on

important dimensions, thus biasing the composition of follow-up samples. For example, in the Schultz et al. (1986) follow-up, returning hypertensives had higher initial Verbal IQ's than non-returning hypertensives. Also, because of obvious ethical reasons, medication use cannot be controlled in longitudinal studies and this could complicate the interpretation of findings. In the Wilkie & Eisdorfer (1971) and Wilkie et al. (1976) studies, medication use was not taken into account in any of their analyses. However, in the Schultz et al. (1986) and Elias et al. (1989) studies, comparisons conducted according to type of anti-hypertensive medication (i.e. beta-adrenergic blockers, diuretics, beta-adrenergic blockers and diuretics together) revealed no systematic differences among hypertensives.

The results of these longitudinal studies are inconsistent to the extent that hypertensives in the studies by Wilkie & Eisdorfer (1971) and Wilkie et al. (1976) experienced a greater decline in performance over time than normotensives whereas in the follow up studies of the Schultz et al. (1979) sample, hypertensives and normotensives experienced similar rates of decline. The fact that hypertensives in the Schultz et al. (1979) study were younger (early 50's at initial testing) than those in the Wilkie et al. study (in their 60's at initial testing) may explain the discrepancy in rates of decline between the two studies.

Subgroups of Hypertensives

Recent studies have examined specific subgroups of hypertensives. For example, Kuusisto et al. (1993) compared elderly (65-74 years old) normotensives and non-

diabetic hyperinsulinemic and normoinsulinemic hypertensives. Although normoinsulinemic hypertensives performed similarly to normotensives after adjusting for fasting plasma glucose, age, sex, and education, hyperinsulinemic hypertensives performed more poorly than normoinsulinemic hypertensives and normotensives on the attention/calculation and copying subtests of the Mini-Mental State Exam and a test of verbal fluency. The lack of significant differences between normoinsulinemic hypertensives and normotensives may be due to the fact that these were elderly participants. As stated above, a number of cross-sectional studies have not observed differences in cognitive functioning between older hypertensives and normotensives.

Cognitive functioning has also been examined in middle-aged male and female hypertensives with and without a parental history of hypertension (PH+ and PH-, respectively; Thyrum et al., 1995). Hypertensive PH+ participants performed more poorly on Trail Making B, Digit Span backwards and displayed slower speed of search of short-term memory in the Sternberg task when compared to hypertensive PH- participants and normotensives. Both PH+ and PH- hypertensives performed more poorly than normotensives on Digit Symbol, however, there was no difference between PH+ and PH- hypertensives on this test. The results of this study suggest that a parental history of hypertension may make an independent contribution to the observed cognitive decrements in hypertensives. It is possible that individuals with a parental history hypertension are particularly vulnerable to the damaging effects of high blood pressure on the brain. On the other hand, it may be that the cognitive decrements observed in PH+ hypertensives are not only due to the damaging effects of high blood pressure on the

brain, but are caused by, or related to, an inherited CNS abnormality that predisposes one to becoming hypertensive. This point will be considered in a subsequent section.

In summary, hypertensives display decrements in cognitive functioning when compared to normotensives. The decrements in cognitive functioning are most often observed on tests of abstract reasoning, attention, memory and psychomotor speed and are not due to group differences in trait affect factors and medication. Interestingly, a number of studies have observed cognitive decrements in newly diagnosed untreated hypertensives (Boller et al., 1977; Franceschi et al., 1982; Mazzucchi et al., 1986). Cross-sectional studies examining the interaction of age and hypertension have revealed that cognitive decrements are larger and more often observed in younger hypertensives as compared to older hypertensives. Based on the longitudinal studies reviewed, it is unclear whether the rates of decline in cognitive performance differ between hypertensives and normotensives.

Although numerous studies have observed poorer cognitive functioning in hypertensives, it should be noted that some studies have not found a relationship between hypertension and cognitive functioning (Grossman & Zalewski, 1995; Perez-Stable, Coates, Halliday, Gardiner, & Hauck, 1992). Furthermore, it should be stressed that although, on the whole, hypertensives display poorer cognitive performance than normotensives, their performance is usually well within normal limits. For example, in the study by Elias et al. (1987), none of the hypertensives performed in the brain injured range as defined by a Average Impairment Rating of 3 or greater. Only 9.7 % of lower education hypertensives as compared to 7.4 % of lower education normotensives scored

within the mildly impaired range.

Blood Pressure and Cognitive Functioning

A number of studies have examined the relationship between blood pressure levels and cognitive functioning in hypertensives. The relationship between blood pressure, age, and cognitive functioning was tested in a sample of 301 participants ranging in age from 20 to 72 years old using tests from the Halstead-Reitan Battery (Elias, Robbins, Schultz, & Pierce, 1990). For the entire sample, regression analyses revealed that diastolic blood pressure predicted poorer performance on the Average Impairment Rating, Category Test, Tactual Performance Test-Localization, and Trail Making B, after adjusting for age, sex, education, medication use, state anxiety and depression. Systolic blood pressure was not related to cognitive performance after controlling for the same variables, although it did predict cognitive performance in univariate analyses. Diastolic blood pressure was also negatively associated with cognitive performance in a subsample of hypertensives who had never been prescribed antihypertensive medications and were free of hypertension associated diseases, and in a subsample comprised of untreated borderline hypertensives and normotensives. In the former subsample, diastolic blood pressure was negatively associated with Average Impairment Rating, Category Test, Tactual Performance Test-Memory and Localization whereas in the subsample of borderline hypertensives and normotensives, diastolic blood pressure predicted performance on the Category Test and Tactual Performance Test-Localization.

In a sample comprised of older unmedicated hypertensive women (aged 60- 80 years old), both systolic and diastolic blood pressure levels were inversely related to cognitive performance, after controlling for age, education, cigarette smoking, alcohol intake, and body mass index (Robbins, Elias, Croog, & Colton, 1994). Cognitive performance was quantified using a composite score derived from the following tests: Digit Symbol, Digit Span (Forwards and Backwards), and Trail Making A and B. There were a greater number of significant correlations involving diastolic blood pressure than systolic blood pressure. In a sample of middle-aged hypertensives, diastolic, but not systolic blood pressure, was found to be correlated with the number of errors on the Category Test, after adjusting for age (Goldman, Kleinman, Snow, Bidus, & Korol, 1974). Consistent with the above findings, Wallace et al. (1985) observed that diastolic but not systolic hypertension was related to poorer memory performance. In a sample comprised of middle-aged hypertensives and normotensives, systolic blood pressure predicted performance on the Digit Symbol and Trails Making B tests and diastolic blood pressure predicted speed of search of short-term memory in the Sternberg task, after adjusting for the effects of age and education (Blumenthal et al., 1993). In contrast, in a large sample from the Framingham Heart Study, Farmer et al. (1987) did not observe a relationship between blood pressure and cognitive functioning in persons aged 55-89 years regardless of whether or not they were taking anti-hypertensive medication.

A number of studies have examined the relationship between blood pressure levels and future cognitive performance. In the Wilkie and Eisdorfer (1971) study, diastolic blood pressure at initial testing negatively predicted change in WAIS Verbal

and Performance scores for a pooled sample of hypertensives, borderline hypertensives, and normotensives initially aged 60-69. Diastolic blood pressure was negatively correlated with change in Digit Span, Digit Symbol, Block Design and Object Assembly scores. Among borderline hypertensives and normotensives initially aged 70-79 years, diastolic blood pressure predicted a decrease in WAIS Verbal Scale score. Systolic blood pressure was not assessed in this study.

Sands and Meredith (1992) investigated the relationship between diastolic blood pressure and cognitive performance using the WAIS subtests that were found to be significantly related to diastolic blood pressure in the Wilkie and Eisdorfer (1971) study. Diastolic blood pressure predicted performance on the Digit Span Forwards and Object Assembly 11 years later using zero order correlations. After adjusting for age, gender, education and initial Digit Span performance, only the correlation involving Digit Span Forwards remained significant.

In a longitudinal study using participants in the Framingham study (Farmer et al., 1990), systolic and diastolic blood pressure values averaged over a 26 year period, prior to and including testing, were related to poorer cognitive functioning only in hypertensives who were no longer on anti-hypertensive treatment, but not in those still taking anti-hypertensive medications. In a reanalysis of the Framingham sample data, systolic and diastolic blood pressure averaged over five biannual periods between 1956 and 1964 predicted cognitive functioning between 1976 and 1978 for the entire sample, in participants who were not taking anti-hypertensive medications at the time of blood pressure sampling and in those who were not on anti-hypertensive medications for the

entire study period (Elias, Wolf, D'Agostino, Cobb, & White, 1993). Systolic and diastolic blood pressure predicted later performance on Logical Memory- Immediate and Delayed, Visual Reproduction and Digit Span Backwards. These associations were observed after controlling for age, education, occupation, cigarette smoking, alcohol consumption and gender. In a recent study, diastolic, but not systolic blood pressure, measured at age 50 predicted poorer cognitive performance 20 years later using a composite score derived from the Mini-Mental State Exam and Trail Making A and B (Kilander, Nyman, Boberg, Hansson, & Lithell, 1998).

In summary, blood pressure is negatively related to present and future cognitive functioning, even after potential confounding variables such as age, education, and medication use are controlled. Two interesting findings emerge: this relationship may apply even for blood pressure levels below the hypertensive range and, in cross-sectional studies, diastolic blood pressure seems to be a better predictor of cognitive performance than systolic blood pressure. It should be noted that, except for the Elias et al. (1990) study which included a few young participants, the participants in these studies were either middle-aged or elderly, thus it is unclear to what extent these findings apply to younger individuals.

Hypertension and Cognitive Functioning: Mechanisms

Numerous mechanisms by which hypertension may affect cognitive functioning have been proposed. Decreased cerebral blood flow has been implicated as a potential mechanism. Decreased global cerebral blood flow has been observed in chronic

hypertensives (Shaw et al., 1984) and in neurologically asymptomatic hypertensives (Nobili et al., 1993). However, there are studies which have reported no significant decreases in cerebral blood flow in hypertensives (eg. Strandgaard, Olesen, Skinhoj & Lassen, 1973). Reduced cerebral blood in hypertensives may be more evident in the frontal (Fujishima, Ibayashi, Fujii, & Mori, 1995; Rodriguez et al., 1987) and temporal regions (Rodriguez et al., 1987). There is evidence that regional cerebral blood flow may be even decreased in recently diagnosed hypertensives (Rodriguez et al., 1987). Reductions in cerebral blood flow may be due to vascular hypertrophy of either small or medium vessels and capillaries (Wine, Halley, & Berne, 1984) and, in chronic hypertensives, it may also be a result of accelerated atherosclerosis (Meyer, Rogers, & Mortel, 1985).

White matter lesions may also account for the poorer cognitive functioning in hypertensives, particularly in older hypertensives. White matter lesions are focal regions of high-signal intensity in deep and subcortical white matter. Hypertension and age are two important risk factors for white matter lesions (Awad, Spetzler, & Hodad, 1986). In two studies examining older hypertensives and normotensives, a higher incidence of white matter lesions was observed in hypertensives (Schmidt et al., 1995; van Swieten et al., 1991). More importantly, hypertensives with white matter lesions performed more poorly than hypertensives and normotensives without white matter lesions on tests of attention, reaction time, and psychomotor skills. However, in a study using young to middle aged hypertensives (mean age = 38.7), hypertensives with and without white matter lesions performed similarly on all tasks, thus suggesting that the presence of white

matter lesions may not account for the poorer performance of young to middle aged hypertensives (Schmidt et al., 1991).

Hypertension accelerates the development of atherosclerosis in large and medium sized vessels, including cerebral vessels (Doyle, 1991). As mentioned above, in chronic hypertensives, atherosclerosis may exacerbate the reduction in cerebral blood flow due to vascular hypertrophy. Hypertension is also associated with greater brain atrophy in older adults. For example, a MRI study revealed smaller volumes of thalamic nuclei and larger volumes of cerebrospinal fluid in the cerebellum and temporal lobes of older hypertensives when compared to older normotensives (Strassburger et al., 1997).

The cognitive decrements observed in hypertensives may not only be due to hypertension's effects on the CNS, but may be related to processes involved in the etiology of hypertension. For example, it is possible that an inherited CNS abnormality may predispose one to becoming hypertensive and may contribute to the cognitive decrements. There is indirect evidence for this hypothesis. Areas of the cerebral cortex may affect blood pressure via innervation of the hypothalamus and limbic system (Folklow & Averill, 1991; Ganong, 1985; Oparil et al., 1995). Animal studies have found that stimulation of the medial prefrontal, insular and orbital cortex causes changes in blood pressure (Neafsey, 1990). Furthermore, there is some evidence of CNS dysregulation in hypertension (Ferrario & Averill, 1991; Folklow, 1987). For example, CNS sympathetic outflow may be increased in some hypertensives (Oparil et al. 1995) and certain types of anti-hypertensive medications (eg. alpha-2 adrenoceptor agonists such as clonidine) lower blood pressure by directly acting on the CNS (Oparil et al.

1995). Thus, it is conceivable that an inherited alteration in CNS functioning may be responsible for both hypertension development and cognitive decrements. In fact, it has been suggested that altered CNS functioning may first be manifested as cognitive decrements before any permanent elevation of blood pressure occurs (e.g. Waldstein et al., 1991).

Cognitive Functioning in Those at Risk for Hypertension

One way to investigate whether cognitive decrements may be observed before the onset of hypertension would be to examine those who are biologically or genetically susceptible for developing hypertension but who are not yet hypertensive. Both the spontaneously hypertensive rat (SHR) and individuals with a parental history of hypertension are at increased risk for developing hypertension. The SHR is a rat strain selectively bred to develop hypertension and the most widely used animal model for studying genetic factors in hypertension. Around 5-6 weeks of age, SHRs begin to exhibit marked increases in blood pressure, and by 6 months, they develop hypertension. Hypertensive SHRs have been found to display poorer learning and short-term memory in the execution of tasks in a radial arm maze (Mori, Kato, & Fujishima, 1995) and poorer performance in a two-way shuttle box avoidance task (Sutterer, Perry, & De Vito, 1980) when compared to normotensive strains, although this is not a consistent finding (see Knardahl & Karlsen, 1984; Widy-Tyszkiewicz, Scheel-Kruger, & Christensen, 1993). More germane to this discussion, there is evidence that the deficits observed in hypertensive SHRs may precede the onset of hypertension. For example, pre-

hypertensive SHRs have been found to perform more poorly on a spatial memory task (i.e. water maze) when compared to age matched normotensive strains (Gattu, Terry, Pauly, & Buccafusco, 1997). These same pre-hypertensive SHRs displayed decreased density of nicotinic acetylcholine receptors in various brain regions including the frontal cortex. Thus, in the SHR, cognitive decrements and altered CNS functioning may observed before the onset of hypertension.

With regards to humans, normotensive individuals with a parental history of hypertension (PH+) are more likely to develop hypertension than those without a parental history of the disorder (PH-) (Corvol, Jeunemaitre, Charru, & Soubrier, 1992). To date, three studies have examined cognitive functioning in normotensive PH+ individuals (McCann, Whitley, Shapiro, Manuck, & Miller, 1990; Pierce & Elias, 1993; Waldstein, Ryan, Polefrone, & Manuck, 1994). The results of these studies will now be reviewed. Specific details regarding the samples employed, exclusion criteria, control of confounding variables, factors investigated, and results according to test and cognitive domain are presented in Table A2 of Appendix A.

In a study by McCann et al. (1990), PH+ and PH- male and female undergraduate students were administered a battery mainly comprised of perceptual and psychomotor tests. There were no parental history differences with regards to age, education and resting heart rate and blood pressure. Results indicated that PH+ participants were less accurate than PH- participants on one of four measures of time judgement. PH+ males displayed poorer performance on the Perception of Spaced Stimuli test, a visual perceptual test, when compared to PH- males, however, PH+ and PH- females performed

similarly on this test. Although PH+ participants tended to perform more poorly on Digit Symbol, the group difference did not reach significance. This study can be criticised on the grounds that there was no control for increase in Type I error as result of multiple tests and while it was stated that participants were healthy there was no mention of which illnesses were screened.

Pierce and Elias (1993) compared PH+ and PH- undergraduate males on tests of memory and tests which placed an emphasis on speed. There were no group differences with regards to age and education. Participants were screened with regards to hypertension, heart disease, and diabetes. Group differences in cognitive functioning were evaluated using a multivariate approach, therefore, the use of multiple tests was minimized. Results revealed that PH+ participants exhibited slower speed of search through short-term memory in the Sternberg task than PH- participants. This is consistent with studies which demonstrated slower speed of search through short-term memory in hypertensives as compared to normotensives (Blumenthal et al., 1993; Madden & Blumenthal, 1989).

A recent study examined cognitive functioning in two groups of PH+ undergraduate males, those with one hypertensive parent and those with two hypertensive parents (Waldstein, Ryan, Polefrone, & Manuck, 1994). Young PH+ individuals with two hypertensive parents are at higher risk for developing hypertension than those with one hypertensive parent (Watt, 1991). A comprehensive battery of tests was used which included tests of abstract reasoning, attention, memory, perception, psychomotor ability, and visual-spatial ability. Numerous variables which could potentially affect cognitive

functioning were assessed including age, education, alcohol consumption, trait anxiety, and depression. According to multivariate analyses, PH+ participants with two hypertensive parents displayed poorer performance on tests of visual-spatial ability (Block Design and Visual Span) when compared to PH- participants. Both PH+ groups performed more poorly than PH- participants on the Critical Flicker Fusion test, a test of visual-perceptual ability. It should be noted that the test battery did not include the Sternberg memory task.

Collectively, these three studies have found that PH+ individuals display poorer performance on tests of visual perceptual and visual-spatial ability and slower search of short-term memory when compared to PH- individuals. On the basis of these studies, it has been suggested that the cognitive decrements observed in PH+ individuals may not be the same as those observed in hypertensives (Waldstein et al., 1994). This may seem puzzling at first, however, hypertension is thought to have various etiologies (Page, 1987). Furthermore, according to a survey by Stamler et al. (1979), only about 40% of hypertensives have a positive parental history of hypertension. It is possible that cognitive decrements vary according to etiology and that hypertensives with and without a parental history of hypertension exhibit different cognitive decrements. The results of Thyrum et al. (1994) in which hypertensive PH+ participants displayed poorer cognitive performance than hypertensive PH- participants do lend support to this notion.

Little is known about the mechanisms underlying the poorer performance of PH+ individuals. It is conceivable that the cognitive decrements exhibited by PH+ individuals may be related to increased cardiovascular reactivity. PH+ individuals have been found

to exhibit increased sympathetically mediated cardiovascular reactivity to stress (Frederickson & Matthews, 1990; Matthews and Rakaczky, 1986; Miller & Ditto, 1991), although this is not a consistent finding (Muldoon, Terrell, Bunker, & Manuck, 1993). Increased cardiovascular reactivity in PH+ individuals has been observed during physical tasks such as the cold pressor (e.g. Sausen, Lovallo & Wilson, 1991), but particularly during interpersonal tasks (Holroyd & Gorkin, 1983; Miller, Dolgoy, Friese, & Sita, 1998), and active coping tasks including cognitive tasks. As an example of the latter, PH+ individuals have been found to display higher heart rate, systolic blood pressure and diastolic blood pressure responses during mental arithmetic (Manuck, Proietti, Rader & Polefrone, 1985; Russo & Zuckerman, 1992; Sausen, Lovallo, & Wilson, 1991) and Digit Span (Sausen et al., 1991; Ballard, Cummings, & Larkin, 1993).

Increased cardiovascular reactivity in PH+ individuals may be related to the cognitive decrements for a number of reasons. There is evidence that increased physiological arousal may be detrimental to performance of complex tasks (Duffy, 1957; Easterbrook, 1959), including those which assess short-term memory (Humphreys & Revelle, 1984). Therefore, given that PH+ individuals may exhibit increased cardiovascular reactivity during mentally challenging tasks, it is possible that increased cardiovascular reactivity accounts, in part, for the poorer performance of PH+ individuals. It has been hypothesised that the increased cardiovascular reactivity in PH+ individuals may be due to altered CNS control of sympathetic activity (Folklow, 1987). It is possible that the increased cardiovascular reactivity and the cognitive decrements are both manifestations of the same CNS abnormality, and may, therefore, be correlated with

each other. This notion may be plausible since, as stated above, higher order CNS areas such as the cerebral cortex do play a role in cardiovascular regulation (Ferrario & Averill, 1991; Folklow, 1987; Ganong, 1985; Oparil et al., 1995). In this case, increased cardiovascular reactivity is not necessarily a causal factor with regards to the cognitive decrements, rather both are markers for the same CNS abnormality.

One study (Pierce & Elias, 1993) directly examined the relationship between cardiovascular activity and cognitive performance in PH+ and PH- individuals using heart rate and systolic and diastolic blood pressure. PH+ individuals displayed higher heart rate responses to a number of tests (e.g. Sternberg task), however, there were no group differences in blood pressure responses and no consistent associations between cardiovascular activity and cognitive functioning were observed. No study to date has investigated whether parental history group differences in hemodynamic activity (e.g. total peripheral resistance, cardiac output) during testing may be related to the cognitive decrements. Investigation of hemodynamic responses may be relevant given that parental history group differences in peripheral vascular resistance responses to stress have been observed in the absence of group differences in blood pressure (Anderson, Mahoney, Lauer, & Clarke, 1987; Ditto & Miller, 1989; Miller & Ditto, 1991).

It is also unclear to what extent the poorer performance of normotensive PH+ individuals may be related to state affect factors. There is a great deal of evidence suggesting that state affect factors affect cognitive performance. For example, increased state anxiety has been shown to be related to poorer performance on tests of mental arithmetic (e.g. Manuck et al., 1985) and short-term memory (Watts, 1995). In fact, state

anxiety may be a better predictor of short-term memory recall than trait anxiety (Watts, 1995). Also, there is evidence that inducing low mood in non-depressed individuals will lead to poorer memory performance (Ellis, Thomas, & Rodriguez, 1984; Leight & Ellis, 1981).

There is some evidence that PH+ individuals may differ from PH- individuals with regards to state affect responses to stress. For instance, normotensive PH+ individuals have been found to display increased state anxiety (Holroyd & Gorkin, 1983; Jorgenson & Houston, 1981), state anger (Miller & Sita, 1994), and depressed mood (Lawler et al., 1998) responses to laboratory tasks when compared to PH- individuals. In the study by Thyrum et al. (1995) examining cognitive functioning in hypertensive PH+ and PH- individuals, hypertensive PH+ participants reported higher state anxiety than PH- participants, although this did not account for the observed parental history group differences in cognitive functioning. However, state affect was recorded only prior to testing and not during the testing period. Furthermore, this study did not consider other state affect factors such as sadness and anger. Of greater relevance to the present study, none of the previous studies that have examined cognitive functioning in normotensive PH+ participants have taken state affect factors into account. It would be important to rule out state affect factors before any genetic and/or pathophysiological hypotheses regarding the poorer performance of PH+'s are to be considered.

Study Hypotheses

The present study investigated cognitive functioning in normotensive PH+ and

PH- males. In addition to commonly studied cardiovascular measures such as heart rate and blood pressure, hemodynamic measures such as total peripheral resistance, cardiac output, stroke volume and pre-ejection period were examined before and during testing. State affect measures including anxiety, tension, sadness, discouragement, anger, and irritability were also obtained. These cardiovascular and state affect responses to the tests were examined in order to determine whether they can account for any parental history group differences in cognitive functioning.

It was hypothesised that 1) PH+ participants, in general, would display poorer test performance than PH- participants, particularly on tests that have been found to differentiate PH+ from PH- participants (e.g. Sternberg task); 2) PH+ participants would display greater cardiovascular responses during testing, particularly on speeded tests such as the Stroop, PASAT, and Block Design; 3) increased cardiovascular reactivity would be correlated with poorer test performance, particularly on the Stroop, PASAT, and Block Design; and would account, in part, for the poorer performance of PH+ participants on these tests; 5) PH+ participants would exhibit greater state affect responses during testing as compared to PH- participants.

Method

Participants

Participants were university undergraduate males between the ages of 18 and 30 year recruited from the Concordia University student population by means of a booth located on campus. Only males were recruited for the following reasons: 1) parental history group differences in cardiovascular reactivity tend to be more consistently observed in males (Russo & Zuckerman, 1992); 2) given that two of the three previous studies which examined cognitive functioning in PH+ individuals used only males, testing only males facilitated comparisons with those two studies while keeping sample size to a minimum.

Participants were confirmed to be normotensive with no participant exhibiting a resting blood pressure greater than 130/80 mmHg as determined by three blood pressure readings taken in a sitting position before testing. The sample consisted of 33 PH+ and 37 PH- males. The hypertensive status of the parents was confirmed by obtaining information from parents concerning the history of the disorder, medication names and usage, and the frequency of physician contact. Information regarding the presence of heart disease, diabetes, kidney disease, and circulatory problems was also obtained from parents. All PH+ individuals had at least one biological parent with hypertension that was not accompanied by kidney disease or diabetes and was of unknown origin (essential hypertension). It was the study's intention to compare PH+ individuals with one hypertensive parent and those with two hypertensive parents as had been done in the study by Waldstein et al., however, the vast majority of PH+ individuals recruited had

only one hypertensive parent. Finding PH+ individuals with two parents proved to be exceedingly difficult given the time constraints of a thesis project, therefore, the intended comparison was not possible.

Demographic and health information was obtained from all participants (see Appendix B for health questionnaire). Additionally, participants completed Spielberger's Trait Anxiety Inventory (Spielberger, Gorusch, & Luschene, 1970) and the Beck Depression Inventory (Beck, 1987). In the study by Waldstein et al. (1994), there was a tendency for PH+ participants to display higher trait anxiety and Beck Depression Inventory scores than PH- participants, although this did not account for group differences in cognitive performance. Nevertheless, trait anxiety and depression should be assessed as both could potentially influence cognitive performance. The Spielberger Trait Anger Inventory (Spielberger, Jacobs, Russell, & Crane, 1983) and Cook Medley Hostility Scale (Cook & Medley, 1954) were included to assess whether trait-anger and hostility could account for parental history group differences in cognitive performance. In a study by Johnson (1989), PH+ individuals were found to exhibit higher trait-anger scores than PH- individuals. It is possible that individuals who tend to be hostile and angry may be less cooperative during testing and may not be inclined to perform to the best of their ability. Given that some studies suggest a positive relationship between alcohol consumption and mild decrements in cognitive functioning (e.g. poorer short-term recall and increased perseveration) (MacVane, Butters, Montgomery, & Farber, 1982), participants' weekly alcohol consumption was also recorded.

Participants reported being free of any chronic illnesses and having no history of

diabetes, cardiovascular, neurological and psychiatric illnesses. Participants were not taking any medications at the time of testing. The two parental history groups did not differ with regards to age, years of education, average weekly alcohol consumption, trait anxiety, depression, trait anger and hostility (see Table 1). The parental history groups were also equivalent with regards to race. Ninety-five percent of participants were Caucasian. There was one Oriental participant in the PH+ group and one Oriental participant and one Black participant in the PH- group.

Table 1

Demographic and Psychological Data for Parental History Groups

Variable	PH+		PH-	
	M	SE	M	SE
Age	23.3	0.6	22.2	0.5
Education (years)	15.9	0.4	16.2	0.7
Alcohol consumption (drinks/week)	4.0	1.0	4.2	0.4
Beck Depression Inventory	10.3	0.5	7.7	1.1
Trait anxiety	42.8	1.7	41.7	1.6
Trait anger	31.2	1.4	30.0	1.3
Cook Medley Hostility	22.5	1.2	22.0	1.2

Cardiovascular Measures and Apparatus

The following cardiovascular measures were recorded: heart rate, cardiac output, stroke volume, pre-ejection period, total peripheral resistance and systolic and diastolic

blood pressure. These measures will now be defined. Cardiac output is the volume of blood ejected by the heart in a given period of time, usually one minute. Stroke volume is the amount of blood ejected by the heart in a given cardiac cycle. Pre-ejection period is the time during which the left ventricle contracts before ejecting blood. Pre-ejection period was used as an index of myocardial sympathetic activity since, in addition to being highly sensitive to changes in myocardial beta-adrenergic activity, it is, unlike heart rate, relatively unaffected by parasympathetic activity (Obrist et al., 1987). Decreases in pre-ejection period have been found to occur concomitantly with the administration of beta-adrenergic as well as positive inotropic agents (Weissler, 1974). Systolic blood pressure is the arterial pressure during contraction of the ventricles while diastolic blood pressure is the arterial pressure during ventricular relaxation. Total peripheral resistance refers to the resistance to flow in the entire systemic vasculature.

Measurements of systolic and diastolic blood pressure (in mm Hg) were obtained at one minute intervals using an IBS Model SD-700A automatic blood pressure monitor and an arm cuff placed on the non-dominant arm. Heart rate (in beats/minute), cardiac output (in litres/minute), stroke volume (in millilitres), pre-ejection period (in msec) and total peripheral resistance (in dyne-sec.cm-5) were recorded non-invasively by way of impedance cardiography using a Minnesota Impedance Cardiograph (Model 304B), the Cardiac Output Program developed by Bio-Impedance Technology Chapel Hill, North Carolina, an IBM compatible 486 computer and a tetrapolar band-electrode configuration. The inner two recording electrode bands were positioned around the base of the neck and around the thorax over the tip of the xiphoid process. The outer two

current electrode bands were positioned around the neck and thorax at least 3 cm away from each of the inner recording electrodes. The EKG was recorded independently using two recording spot electrodes placed on opposite sides of the rib cage at the level of the seventh rib approximately and a ground spot electrode placed on the right hip bone. The EKG signal was filtered through a Coulbourn bypass filter and then routed to the Minnesota Impedance Cardiograph. Recordings for these cardiac measures were obtained during the first 50 seconds of each minute. Ensemble averaged values of heart rate, cardiac output, stroke volume, pre-ejection period and total peripheral resistance were obtained from these recordings by the Cardiac Output Program for each minute.

Procedure

Prior to coming to the laboratory, participants were asked to refrain from drinking alcohol for 24 hours and drinking coffee and smoking for 4 hours. Participants were told that the purpose of the study was to examine the relationship between cardiovascular activity and cognitive functioning. They were not informed that parental history of hypertension would be a focus of the study. Participants took part in one 2 hour session. Following instrumentation, participants were requested to sit quietly for 10 minutes. Baseline recordings were obtained for each cardiovascular measure from minutes 7 to 10. Participants were then administered the tests listed below in order by a Clinical Psychology graduate student who was blind to the participants' group membership. Cardiovascular recordings were obtained for the entire duration of each test. During tests which required the use of the hands, participants were instructed to use only their

dominant hand in order to not interfere with blood pressure recording. A 5 minute rest period followed each test. During this rest period baseline recordings were obtained during minutes 4 and 5.

Tests. 1. Stroop test (Trenerry, Crosson, DeBoe, & Leber, 1989). This version of the Stroop test contained two conditions: colour and colour-word. In the colour condition the participant was given 120 seconds to read 112 words arranged in 4 columns of 28 words on a sheet of paper. The words were red, green, blue and tan. They were printed in colour but never in their matching colours. In the colour-word condition the sheet was identical to that used in the colour condition except that the word order was different. In this condition, the participant was given 120 seconds to name the colour of the ink in which the words were printed. The dependent variable for this test was the number of correct responses in the colour-word condition.

2. Paced Auditory Serial Addition Task (PASAT). In this test devised by Gronwall (1977), a series of single digit numbers were presented using a prerecorded audio tape. The participant was asked to add pairs of numbers such that each number was added to the immediately preceding number. The participant was presented trials 1 and 4 of this four trial test. In trial 1 the numbers were presented 2.4 seconds apart whereas in trial 4 the numbers were presented 1.2 seconds apart. The dependent variable for this test was the total number of correct responses in trials 1 and 4.

3. Self-Ordered Pointing Task (Petrides & Milner, 1982). The Self-Ordered Pointing Task measures aspects of frontal lobe control on working memory. It places an emphasis on conceptual organization, self-directed planning, and response inhibition. 1) Concrete

condition: This condition consisted of three trials. For each trial, 12 different figures of nameable objects (eg. table, stove) were presented on each of 12 pages using a 3 X 4 rectangular array. The figures were arranged in a different order on each page. The participant was required to point to one figure on each page without pointing to a previously selected figure and without pointing to the same position for more than two consecutive pages. Whenever a participant pointed to a previously selected figure, an error was recorded. 2) Abstract condition: This test was identical to the concrete test except that, instead of concrete objects, the participant was presented 12 abstract designs that are difficult to encode verbally. The dependent variable for this test was the total number of errors in the Concrete and Abstract conditions.

4. Block Design (Wechsler, 1981). This test is part of the WAIS-R battery. The test was administered according to the standard WAIS-R instructions except for the fact that the participant used only his dominant hand to complete the trials. The participant was not allowed to use his non-dominant hand so as to not interfere with blood pressure measurements which were being taken from the non-dominant arm. For this test, the participant was given four or nine blocks (depending on the trial), each block having two red and two white sides and two half-white, half-red sides. Using the blocks, the participant was required to reproduce one block design prepared by the experimenter and eight designs appearing in a booklet. The dependent variable for this test was the raw score. The age scale score was not used because participants did not complete the test according to standard instructions.

5. Visual Span (Wechsler, 1987). This test is part of the Wechsler Memory Scale-

Revised. In this test, the participant was presented a card containing an array of eight squares. This test consisted of two conditions: forward and backward. In the forward condition the experimenter pointed to a given number of squares in sequences of increasing length. Immediately following each presentation, the participant was required to reproduce the sequence. In the backward condition, the participant was required to reproduce the presented sequence in backwards order. The dependent variable for this test was the number of correct trials in both conditions.

6. Sternberg Memory Search Task. Using a Macintosh computer, a Sternberg type task (Sternberg, 1969) was presented to the participant. The task consisted of 72 trials. For each trial, the participant was shown a set of numbers consisting of either 1, 2, 3, 4, 5 or 6 single digit numbers. Each number of a given set was displayed sequentially for 1 second. Following the presentation of a set, a warning signal appeared for 1 second, followed by a single probe digit. Upon seeing the probe digit, the participant was required to indicate by means of "yes" and "no" response keys whether or not the probe digit appeared in the memory set. The probe digit remained on screen until the participant made a response. Three dependent variables were derived from this task: percentage of correct response trials (Sternberg Recognition, Reaction Time Slope and Reaction Time Intercept. Reaction Time Slope is the slope of the function relating probe reaction time to number set size. This variable refers to the rate at which the memory set is searched. Reaction Time Intercept is the zero intercept of the reaction time function and represents the duration of processes not specifically related to memory search such as probe identification, response selection and execution.

7. Wisconsin Card Sorting Task. A computerised version of the WCST was employed. Using an IBM compatible AT computer, the participant was presented pictures of four stimulus cards displaying one red circle, two green stars, three yellow crosses and four blue circles, respectively. The participant's task was to match cards depicting the same aforementioned symbols to the stimulus cards according to one of three dimensions: colour, shape or number. The participant was required to deduce the principle from accuracy feedback provided by the computer. Unbeknownst to the participant, the matching principle changed following 10 consecutive correct responses. The dependent variable in this test was the number of perseverative errors as calculated by the Heaton scoring system (Heaton, Chelune, & Talley, 1993).

The rationale for the selection of these tests is as follows: Block Design, Visual Span and the Sternberg task were chosen because they have previously been found to differentiate PH+ from PH- participants (Pierce & Elias, 1993; Waldstein et al., 1994). The Wisconsin Card Sorting Task, Self-Ordered Pointing Task and the Stroop test are three tests that are purported to assess abilities associated with executive/frontal lobe functioning. In a recent study by Waldstein et al. (1996), young hypertensives, as compared to young normotensives, were found to perform more poorly on tests that are thought to assess frontal lobe functioning (eg. Stroop, maze learning). To the author's knowledge, frontal lobe functioning has never been assessed in normotensive PH+ individuals. The PASAT was used because it is a difficult test that assesses aspects of cognitive functioning (eg. attention, speed of information processing) that have been found to differentiate hypertensives from normotensives. Given that the sample consisted

of healthy, well-educated participants, it was thought that parental history group differences would more likely be observed on such a challenging test. Furthermore, the PASAT is not only difficult but it is also fast paced and, therefore, expected to elicit large increases in cardiovascular reactivity. Hence, this is another reason why parental history group differences on this test were expected.

State Affect Measures. State affect ratings were taken during the initial rest period. Additionally, immediately following each test, the participant was asked to rate how he felt during the preceding test. State affect measures included anxiety, tension, anger, irritability, sadness, and discouragement. State affect was measured using a visual analogue scale. For example, in order to measure state anxiety the participant was asked to place a mark along a 10 cm line which ranged from not anxious to very anxious. The same principle applied to the other measures.

Cardiovascular Data Reduction

Cardiovascular data were reduced in the following manner. For each participant, a mean value was calculated for each rest and test period for each cardiovascular measure. The mean value for the rest period preceding commencement of testing served as the individual's baseline. Analyses of cardiovascular responses to the tests were carried out on rest - test change scores. Rest - test change scores were obtained by subtracting the test mean and the mean of the immediately preceding rest period for each measure.

Results

Analyses of Variance

Cognitive measures. A one-way (PH+ vs PH-) MANOVA was used to analyze parental history group differences in cognitive performance. The MANOVA revealed a significant parental history effect for cognitive performance, $F(9, 60) = 2.20$, $p < .03$. According to follow up univariate ANOVAs, PH+ individuals performed more poorly on Block Design, $F(1, 68) = 8.06$, $p < .01$, and Visual Span, $F(1, 68) = 5.92$, $p < .02$, when compared to PH- individuals. PH+ individuals also had lower percentage correct response trials in the Sternberg task, $F(1, 68) = 4.54$, $p < .04$, and longer Sternberg Reaction Time Intercept scores than PH- individuals, $F(1, 68) = 6.33$, $p < .01$, (see Table 2 for means and effect sizes).

Table 2

Cognitive Test Scores by Parental History Group

Test	PH+ M	PH+ SE	PH- M	PH- SE	Eta^2
Stroop (no. correct)	103.7	2.4	108.8	1.1	0.04
PASAT (no.correct)					
trial 1	44.8	2.0	46.6	1.4	
trial 4	23.3	1.4	24.7	1.1	
trials 1& 4	34.0	1.6	35.6	1.2	0.01
SOPT (no. errors)	8.6	0.7	8.2	0.7	0.01
Block Design (raw score)*	34.1	1.7	40.5	1.3	0.11
Visual Span (no. correct trials)*	16.9	0.5	18.4	0.4	0.08
Sternberg RT Slope	43.8	3.9	47.1	3.4	0.01
Sternberg RT Intercept (msec)*	621.6	24.9	548.7	18.3	0.07
Sternberg Recognition (% correct trials)*	93.3	1.0	96.1	0.8	0.06
WCST (no. perseverative errors)	15.9	2.9	12.3	1.4	0.02

Note. PASAT = Paced Auditory Serial Addition Task;

SOPT = Self-Ordered Pointing Task; WCST = Wisconsin Card Sorting Task.

* $p < .05$; Visual Span forward span (PH+: M = 6.2, SE = 1.1; PH-: M = 7.2, SE = 1.0);

Visual Span backwards span (PH+: M = 5.6, SE = 1.1; PH-: M = 6.4, SE = 0.8).

Cardiovascular measures. Separate one-way (PH+ vs PH-) MANOVAs were conducted for baseline and rest - test change scores. Multivariate analyses revealed

no significant group differences for baseline cardiovascular measures, $F(7, 62) = 1.22$, $p < .30$, and rest - test change scores, (Stroop: $F(7,62) = 0.32$, $p < .94$; PASAT: $F(7, 62) = 0.47$, $p < .85$; SOPT: $F(7, 62) = 0.45$, $p < .86$; Block Design: $F(7, 62) = 0.61$, $p < .75$; Visual Span: $F(7, 62) = 1.77$, $p < .11$; Sternberg: $F(7, 62) = 0.77$, $p < .62$; WCST: $F(7, 62) = 1.68$, $p < .13$. The lack of significant parental history differences may be due to the fact that, apart from the Stroop and PASAT, the increases in cardiovascular reactivity elicited by tests were small in comparison to those elicited by stressors which have yielded parental history differences in our laboratory (shock avoidance video game, interpersonal conflict; Miller & Ditto, 1991; Miller, Dolgoy, Friese, & Sita, 1998). See Table 3 for means and standard errors for baseline cardiovascular measures and rest - test change scores for each cardiovascular measure and test.

Table 3

Cardiovascular Change Scores as a Function of Test and Parental History Group

Test	HR		CO		SV		PEP		TPR		SBP		DBP	
	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE
Baseline														
PH+	64.9	1.9	7.7	0.4	120.3	5.3	108.8	2.2	894.6	48.4	113.8	1.5	62.8	1.4
PH-	64.8	1.7	7.6	0.3	118.9	3.5	106.3	1.7	837.7	33.3	111.6	1.6	59.2	1.2
Stroop														
PH+	14.6	1.6	1.3	0.2	-7.3	1.9	-7.4	2.1	-0.9	21.4	15.5	1.5	11.0	1.2
PH-	15.2	1.5	1.3	0.2	-5.6	1.6	-8.1	1.6	-8.5	20.8	15.2	1.2	10.9	1.1
PASAT														
PH+	15.6	1.9	1.1	0.2	-10.2	1.7	-5.5	1.8	12.5	17.9	15.1	1.9	8.4	1.2
PH-	13.8	1.3	1.0	0.2	-8.8	1.8	-4.8	1.5	-9.0	21.1	11.4	1.2	7.3	1.3
SOPT														
PH+	9.2	1.1	0.5	0.1	-9.0	1.5	-1.5	0.9	20.2	15.4	6.6	1.1	6.7	1.0
PH-	10.8	1.0	0.7	0.1	-8.6	1.5	-2.3	1.2	9.6	13.3	6.9	1.2	7.8	1.1
Block Design														
PH+	8.2	1.0	0.5	0.1	-6.6	1.6	-2.0	1.2	2.8	13.8	6.1	1.1	5.1	0.9
PH-	9.4	1.1	0.4	0.1	-9.1	1.5	-1.1	1.4	27.6	16.6	7.4	1.0	6.7	1.2
Visual Span														
PH+	4.4	1.1	0.3	0.1	-1.1	1.2	-2.4	0.9	-16.7	13.6	2.7	1.1	2.4	0.9
PH-	5.8	1.0	0.2	0.1	-2.5	1.6	-1.7	1.0	-25.2	14.4	4.1	1.4	2.9	0.8
Sternberg Task														
PH+	4.7	1.2	0.3	0.1	-4.2	1.9	0.1	1.2	15.0	13.8	3.6	1.0	3.2	0.9
PH-	4.9	1.0	0.2	0.1	-4.7	1.1	-1.1	1.0	8.7	13.1	2.3	0.9	4.1	1.0
WCST														
PH+	3.3	1.2	0.2	0.1	-3.0	1.2	-1.6	1.0	3.0	15.1	2.0	1.3	2.0	0.9
PH-	4.2	1.0	0.0	0.1	-7.1	1.6	1.1	0.8	27.7	14.1	2.6	1.1	3.4	1.0

Note. PASAT = Paced Auditory Serial Addition Task; SOPT = Self-Ordered Pointing Task; WCST = Wisconsin Card Sorting Task; HR = heart rate (bpm); CO = cardiac output (l/min); SV = stroke volume (ml); PEP = pre-ejection period (msec); TPR = total peripheral resistance

(dyne-sec.cm^{-5}); SBP = systolic blood pressure (mmHg); DBP = diastolic blood pressure (mmHg).

State affect measures. Analyses of state affect ratings were conducted on baseline and baseline - test change scores. Baseline - test change scores were obtained by subtracting the baseline rating and the post-test rating for each state affect measure from each test.

In order to examine whether parental history group differences existed in baseline or baseline - test state affect measures, separate one-way (PH+ vs PH-) MANOVAs were conducted for baseline affect scores and baseline - test change scores for each test. Significant MANOVAs were followed up by univariate ANOVAs.

Multivariate analysis of variance indicated that PH+ individuals displayed greater state affect increases than PH- individuals during Block Design, $F(6, 63) = 2.89$, $p < .02$. Follow up ANOVAs revealed that PH+ individuals experienced greater increases in irritability, $F(1, 68) = 4.83$, $p < .03$, and anxiety, $F(1, 68) = 4.08$, $p < .05$, than PH- individuals. Multivariate analyses revealed no parental history group differences for baseline - test change scores for the other tests, (Stroop: $F(6, 63) = 0.79$, $p < .58$; PASAT: $F(6, 63) = 0.69$, $p < .66$; SOPT: $F(6, 63) = 1.73$, $p < .13$; Visual Span: $F(6, 63) = 1.27$, $p < .28$; Sternberg: $F(6, 63) = 1.07$, $p < .39$; WCST: $F(6, 63) = 0.93$, $p < .47$) and for baseline state affect ratings, $F(6, 63) = 0.89$, $p < .51$ (see Table 4 for baseline affect scores and affect change scores).

Table 4

Baseline Affect Scores and Affect Change Scores as a Function of Test and Parental History Group

Test	Anxiety		Tension		Anger		Irritability		Sadness		Discouragement	
	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE
Baseline												
PH+	3.0	0.5	3.1	0.5	0.6	0.2	1.0	0.2	1.7	0.3	1.5	0.4
PH-	2.8	0.4	2.3	0.4	0.7	0.2	1.3	0.2	1.4	0.3	1.5	0.4
Stroop												
PH+	3.0	0.5	0.4	0.5	0.4	0.2	0.4	0.3	-0.4	0.3	0.7	0.4
PH-	2.2	0.4	1.1	0.5	0.4	0.3	0.8	0.4	-0.3	0.2	0.7	0.3
PASAT												
PH+	3.7	0.5	1.8	0.6	1.2	0.3	2.1	0.5	0.1	0.3	2.3	0.5
PH-	3.3	0.5	2.1	0.5	0.8	0.4	1.1	0.4	0.0	0.4	2.1	0.5
SOPT												
PH+	2.5	0.5	0.1	0.5	0.7	0.2	0.9	0.4	-0.3	0.3	0.7	0.5
PH-	1.6	0.4	0.2	0.4	-0.3	0.1	0.0	0.3	-0.5	0.2	0.3	0.3
Block Design												
PH+	2.5	0.4	0.2	0.5	0.2	0.2	1.1	0.4	-0.2	0.3	0.9	0.5
PH-	1.4	0.4	0.4	0.6	0.3	0.3	0.0	0.4	-0.3	0.3	0.0	0.3
Visual Span												
PH+	2.5	0.4	0.7	0.5	0.9	0.3	1.3	0.4	0.0	0.4	1.0	0.4
PH-	1.9	0.4	0.3	0.5	0.5	0.3	0.4	0.3	-0.2	0.3	0.5	0.3
Sternberg Task												
PH+	3.0	0.5	0.3	0.7	1.0	0.3	1.5	0.4	-0.2	0.4	0.9	0.4
PH-	1.7	0.4	-0.3	0.4	0.3	0.2	0.3	0.4	-0.1	0.3	0.3	0.3
WCST												
PH+	3.0	0.5	0.5	0.6	0.8	0.3	1.4	0.5	-0.3	0.4	0.7	0.4
PH-	2.0	0.4	0.0	0.5	0.4	0.2	0.3	0.4	0.3	0.3	0.1	0.4

Note. PASAT = Paced Auditory Serial Addition Task; SOPT = Self-Ordered Pointing Task; WCST = Wisconsin Card Sorting Task.

Correlational Analyses

Given the association between resting blood pressure and cognitive performance in hypertensives, and the present study's hypothesis that cardiovascular reactivity would be related to poorer performance, the relationship between test performance and cardiovascular levels during the initial baseline and rest - test change scores was examined. Pearson correlations were conducted between age, years of education, and cardiovascular baseline values, rest - test change scores and test performance in order to evaluate whether age and education may mediate the relationship between cardiovascular activity and test performance. Age was correlated with the following cardiovascular baseline and rest - test changes scores: baseline diastolic blood pressure ($r = 0.36$, $p < .05$), stroke volume change during the PASAT ($r = 0.24$, $p < .05$), and total peripheral resistance change score during Self-Ordered Pointing Task ($r = -.27$, $p < .05$). Years of education was correlated with total peripheral resistance change scores during the Visual Span ($r = -.26$, $p < .05$). Both age and years of education were not correlated with any test scores. This is not surprising since, given the nature of the sample, the range of values for age and years of education was somewhat restricted. Given that age was correlated with some cardiovascular measures, it was subsequently used as a covariate in analyses involving cardiovascular activity and test performance.

Baseline cardiovascular measures and test performance. In order to determine whether cardiovascular activity was related to test performance, partial correlations adjusted for age were conducted between test scores and cardiovascular levels during the initial baseline period for the entire sample. Analyses revealed a significant negative

association between baseline total peripheral resistance and performance on Block Design, the PASAT, the Stroop and the Sternberg task (Sternberg Recognition). Total peripheral resistance was also positively associated with Sternberg Reaction Time Intercept, which, again, suggests a negative relationship between total peripheral resistance and test performance. Baseline diastolic blood pressure was negatively correlated with performance on the PASAT. In general, these correlations suggest a negative association between increased peripheral resistance at baseline and performance on the Stroop, PASAT, Block Design and the Sternberg task.

Resting cardiac output was positively associated with performance on Block Design, the PASAT and the Stroop and negatively associated with Sternberg Reaction Time Intercept. Resting stroke volume was positively associated with performance on the Stroop and negatively associated with Sternberg Reaction Time Intercept. Heart rate was positively associated with performance on the PASAT and negatively correlated with Sternberg Reaction Time Slope. The latter correlation indicates a positive relationship between heart rate inverse and performance on the Sternberg task. Additionally, systolic blood pressure was positively correlated with performance on the Stroop. The associations involving cardiac output, heart rate, stroke volume and systolic blood pressure suggest a positive relationship between baseline cardiac activity and performance on the Stroop, PASAT, Block Design, and Sternberg task (see Table 5).

Table 5

Partial Correlations Between Baseline Cardiovascular Levels and Cognitive Test Scores Adjusted for Age

Test	HR	CO	SV	PEP	TPR	SBP	DBP
Stroop	.09	.36**	.33**	-.04	-.39**	.25*	-.23
PASAT	.32*	.44**	.23	-.18	-.43**	.16	-.25*
Block Design	.14	.24*	.14	-.23	-.32**	-.05	-.09
SOPT	-.03	-.07	-.04	.01	.07	.01	-.06
Sternberg RT Slope	-.25*	-.04	.10	.08	.02	-.02	.02
Sternberg RT Intercept	-.22	-.44**	-.29*	.09	.59**	-.10	.13
Sternberg Recognition	.16	.19	.06	-.14	-.25*	.06	-.09
Visual Span	-.01	.15	.17	-.15	-.16	.05	-.13
WCST	-.08	-.12	-.06	-.05	.12	-.02	-.04

Note. PASAT = Paced Auditory Serial Addition Task; SOPT = Self-Ordered Pointing Task; WCST = Wisconsin Card Sorting Task; HR = heart rate; CO = cardiac output; SV = stroke volume; PEP = pre-ejection period; TPR = total peripheral resistance; SBP = systolic blood pressure; DBP = diastolic blood pressure.

* $p < .05$. ** $p < .01$.

Cardiovascular reactivity and test performance. In order to determine whether cardiovascular reactivity was related to test performance, partial correlations adjusted for age and resting cardiovascular values were conducted between test scores and cardiovascular rest - test change scores for the entire sample. Resting cardiovascular levels preceding each test were covaried in order to calculate associations between reactivity scores and test performance that were independent of resting levels.

Analyses revealed that heart rate was positively associated with performance on the Block Design and negatively associated with the number of errors on the Self-Ordered Pointing Task. Systolic blood pressure was positively correlated with performance on the PASAT and negatively correlated with the number of perseverative errors on the Wisconsin Card Sorting Task. Pre-ejection period was negatively associated with performance on the PASAT. Given that decreases in pre-ejection period are suggestive of increased myocardial sympathetic activity, the latter association suggests a positive relationship between myocardial sympathetic activity and performance on the PASAT. Stroke volume was positively associated with performance on the Stroop, on the other hand, increased stroke volume reactivity was also associated with slower search of short-term memory (stroke volume correlated positively with Sternberg Reaction Time Slope). Except for the correlation involving stroke volume and Sternberg Reaction Time Slope, the aforementioned correlations suggest a positive relationship between cardiac activity and test performance. Consistent with baseline correlations, total peripheral resistance was positively correlated with Sternberg Reaction Time Intercept (see Table 6).

It should be noted that there was no control of inflation of Type I error despite the numerous correlations conducted. However, the number of observed significant correlations was greater than chance (15 of 63 correlations for baseline correlations and 8 of 63 correlations for testing correlations). Furthermore, as detailed above, the significant correlations suggest a systematic relationship between cardiovascular activity and test performance.

Table 6

Partial Correlations Between Cardiovascular Change Scores and Cognitive Test Scores Adjusted for Age and Resting Cardiovascular Levels

Test	HR	CO	SV	PEP	TPR	SBP	DBP
Stroop	.15	.20	.28*	.14	-.16	.14	.24
PASAT	.22	.07	-.05	-.33**	.05	.31*	.09
Block Design	.26*	-.03	-.16	-.12	-.02	-.03	.03
SOPT	-.25*	-.18	.06	.21	.15	-.19	.14
Sternberg RT Slope	-.15	-.08	.25*	.10	-.08	-.22	-.22
Sternberg RT Intercept	.02	.07	-.20	.17	.26*	-.05	.01
Sternberg Recognition	-.07	-.09	.01	-.21	-.01	.04	-.10
Visual Span	.10	.02	.02	-.12	-.03	.20	.07
WCST	-.01	.01	-.04	.10	-.04	-.32*	.01

Note. PASAT = Paced Auditory Serial Addition Task; SOPT = Self-Ordered Pointing Task; WCST = Wisconsin Card Sorting Task; HR = heart rate; CO = cardiac output; SV

= stroke volume; PEP = pre-ejection period; TPR = total peripheral resistance; SBP = systolic blood pressure; DBP = diastolic blood pressure.

* $p < .05$.

State affect responses and test performance. In order to determine whether state affect was related to test performance, Pearson correlations were conducted between test scores and state affect scores for the initial baseline period and state affect baseline - test change scores for the entire sample. Baseline Pearson correlations revealed only one significant correlation out of 42 correlations. Baseline anxiety was negatively correlated with performance on the Stroop (see Table 7). There were only three significant correlations involving baseline - test change scores and test scores. Increased irritability was associated with poorer performance on Block Design, increased anger was associated with a higher number of errors on the Self-Ordered Pointing Task, and increased discouragement was associated with poorer Recognition on the Sternberg task (see Table 8). Given that there was only one significant correlation involving baseline affect and test performance and that only three significant correlations involving baseline - test change scores and test performance were observed with different state affect measures being associated with different tests, it is concluded that there were no systematic relationships between test performance and baseline and testing state affect measures..

Table 7

Partial Correlations Between Baseline Affect Scores and Cognitive Test Scores

Test	Anxiety	Tension	Anger	Irritability	Sadness	Discouragement
Stroop	-.27*	.00	-.04	-.11	-.06	-.12
PASAT	.13	.02	-.11	-.09	.09	.03
Block Design	- .14	.03	-.06	.02	-.05	-.09
SOPT	.21	-.08	-.04	.00	-.06	.04
Sternberg RT Slope	-..03	.14	. 22	.13	.03	.08
Sternberg RT Intercept	-.01	.11	.08	.07	.17	-.05
Sternberg Recognition	.18	.09	-.18	.17	.00	.13
Visual Span	-.08	-.15	- 18	-.11	-.15	-.19
WCST	.11	-.02	.04	.10	-.05	.10

Note. PASAT = Paced Auditory Serial Addition Task; SOPT = Self-Ordered Pointing Task; WCST = Wisconsin Card Sorting Task.

* $p < .05$.

Table 8

Partial Correlations Between Affect Change Scores and Cognitive Test Scores

Test	Anxiety	Tension	Anger	Irritability	Sadness	Discouragement
Stroop	-.20	.01	-.20	-.07	.05	.07
PASAT	.15	. 08	-.12	-.09	- .15	.06
Block Design	- .13	-.14	-.06	-.24*	-.17	-.07
SOPT	.10	-.08	.24*	.00	-.06	-.11
Sternberg RT Slope	-.05	-.19	. 01	-.01	.10	- .08
Sternberg RT Intercept	-.11	-.07	-.10	-.12	.14	-.02
Sternberg Recognition	-.04	-.20	.06	-.17	-.10	-.24*
Visual Span	-.03	-.01	- 17	-.13	-.03	-.04
WCST	.10	.17	.12	.14	.20	.07

Note. PASAT = Paced Auditory Serial Addition Task; SOPT = Self-Ordered Pointing Task; WCST = Wisconsin Card Sorting Task.

* $p < .05$.

Covariance Analyses

Although no systematic relationships were observed between state affect measures and test performance, PH+ participants reported greater increases in anxiety and irritability during Block Design. Thus, a one way (PH+ vs PH-) ANCOVA using anxiety and irritability baseline - test change scores as covariates was conducted on the Block Design scaled scores in order to determine if these group differences in state affect could account for the poorer performance of PH+ participants on this test. The ANCOVA revealed that PH+ participants had lower Block Design scores than PH- participants,

even after controlling for group differences in anxiety and irritability change scores, $F(1, 66) = 5.64$, $p < .02$.

Discussion

The present study investigated cognitive functioning in normotensive males with and without a parental history of hypertension. Cardiovascular and state affect responses during testing were examined in order to determine whether they can account for any parental history group differences in cognitive functioning. PH+ participants performed more poorly on Block Design and Visual Span than PH- participants. Although PH+ participants displayed greater increases in irritability and anxiety to the Block Design test than PH- participants, these group differences in state affect did not account for the poorer performance of PH+ participants on this test. Parental history group differences were also observed for the Sternberg task. More specifically, PH+ participants displayed lower percentage Recognition accuracy scores and longer Reaction Time Intercept scores than PH- participants on this test.

The fact that PH+ participants performed more poorly on Block Design and Visual Span is consistent with findings from Waldstein et al.'s (1994) study to the extent that in both studies these tests differentiated PH+ from PH- participants. However, in the Waldstein et al. (1994) study, the parental history group differences on these tests were observed between PH+ participants with two hypertensive parents and PH- participants. There were no group differences between PH+ participants with one hypertensive parent and PH- participants on these two tests. One possible reason why Block Design yielded differences between PH+ participants with one hypertensive parent and PH- participants in the present study, but not in the Waldstein et al. study, may be due to differences in the administration of the test. In the present study, participants were required to complete

the test using one only hand so as to not interfere with cardiovascular recording. Thus, in the present study, Block Design was more difficult than in the Waldstein et al. study, and this may have increased the likelihood of observing group differences. It is unclear why, in the present study, PH+ participants with one hypertensive parent displayed poorer performance on Visual Span whereas this was not the case in the study by Waldstein et al.

PH+ participants displayed lower percentage accuracy scores and longer Reaction Time Intercept scores on the Sternberg task than PH- participants. No parental history group differences were observed on the Reaction Time Slope measure of this test. In contrast, in previous studies using the Sternberg task, only the Reaction Time Slope measure has differentiated PH+ and PH- participants (Pierce & Elias, 1994; Thyrum et al., 1995) and hypertensives from normotensives (Blumenthal et al., 1993; Madden & Blumenthal, 1989). It is unclear why the results from the Sternberg task in the present study are inconsistent with those from the aforementioned studies. The means for the Reaction Time Slope for PH+ and PH- participants in the present study (43.8 ± 3.9 msec and 47.1 ± 3.4 msec, respectively) are consistent with those typically reported for young adults (approximately 37 msec; Sternberg, 1975) and participants' percentage accuracy scores rates are sufficiently high so as to not invalidate the assumptions of the test. Therefore, it seems that the data from this test are valid.

Although PH+ participants performed more poorly than PH- participants on some tests, it should be stressed that parental history of hypertension accounted for a very small portion of the variance in test performance even on tests for which parental history

differences were observed (i.e. effect sizes ranged from 1 to 11%). Furthermore, the performance of PH+ participants was well within normal limits. For example, the mean Block Design raw score for PH+ participants is equivalent to an age corrected scale score of 10.9 which is in the Average range. In fact, this score is very likely an underestimate as participants completed this test using one hand rather than two hands so as not to interfere with cardiovascular recording.

It would be important to examine what the observed parental history group differences in the present study may reflect in terms of cognitive function. Before doing so, it should be stressed that no measure of IQ was obtained in the present study. Even though there is no a priori reason to suspect parental history group differences in IQ and both groups didn't differ with regards to years of education and age, it is possible that the observed differences were related to group differences in general intellectual level. Also, information on the socioeconomic status (SES) of the participants' parents was not obtained. SES has been found to be related to level of cognitive functioning (Lezak, 1995), thus it is possible that parental history group differences may be due to group differences in SES.

In order to determine which cognitive domains may underlie the observed parental history group differences in test performance it is first necessary to review the abilities tapped by the tests which yielded significant results. Sternberg Recognition is a measure of short-term memory. Sternberg Reaction Time Intercept represents the time required to identify the probe and to perform the motoric actions necessary to respond. Visual Span is a test of visual-spatial short-term memory. Interpreting the significance of

the parental history group differences in Block Design is less straightforward. Block Design is purported to be a test of visual spatial-constructional ability (Lezak, 1995). However, Block Design taps into other domains of functioning such as psychomotor speed and nonverbal reasoning (Lezak, 1995).

The next step would be to consider which domains of function these measures share with each other. As mentioned above, some tests (eg.Visual Span and Block Design) reflect performance on more than one cognitive domain, thus identifying shared domains among tests would help clarify interpretation of test results. Both Visual Span and Sternberg Recognition reflect short-term memory ability, thus the parental history group differences on Visual Span and Sternberg accuracy scores suggest that PH+ participants displayed poorer short-term memory than PH- participants. Block Design and Visual Span are similar to the extent that they are both visual-spatial tasks, thus poorer performance on these tasks may reflect poorer visual-spatial ability on the part of PH+ participants. Sternberg Reaction Time Intercept shares one domain with Block Design as they both, to some degree, tap into psychomotor speed. However, parental history group differences on Sternberg Reaction Time Intercept may also be due group differences in probe identification (perhaps a reflection of perceptual processes).

Thus, according to the preceding discussion, it is hypothesised that the parental history group differences on the Block Design, Visual Span and the Sternberg Recognition and Reaction Time Intercept may be indicative of poorer short-term memory, visual-spatial ability and perhaps psychomotor speed/reaction time. Poorer short-term memory in PH+ participants is consistent with previous studies that have

found poorer short-term memory in hypertensives (e.g. Boller et al., 1987; Mazzuchi et al., 1986). Although hypertensives have been found to display poorer visual-spatial ability in some studies (Franceschi et al., 1982; Mazzucchi et al., 1986; Schultz et al., 1979), this has not been a consistent finding. Similarly, psychomotor and reaction time tests have yielded significant in some studies (Light, 1975, 1978; Miller et al., 1984; Shapiro et al., 1982) but not in others (Kussisto et al., 1993; Grossman & Zalewski, 1995; Perez-Stable et al., 1992; Schmidt et al., 1991).

There were no parental history group differences on tests purported to tap into abilities related to frontal lobe functioning (i.e. Wisconsin Card Sorting Task, Self-Order Pointing Task, Stroop). Although Waldstein et al. (1996), observed differences between hypertensives and normotensives on the Stroop and other tests that pertain to frontal lobe functioning, it should be noted that the Stroop has yielded mixed results (Blumenthal et al., 1993; van Swieten et al., 1991) while the Wisconsin Card Sorting Task has yielded null results (Boller et al., 1977; Grossman & Zalewski, 1995). The Self-Ordered Pointing Task has never been included in studies using hypertensives. Thus, according to the present study's results PH+ individuals do not display decrements on tests of frontal lobe functioning.

There were no parental history group differences on the PASAT. This is surprising because the PASAT not only taps into a number of abilities such as attention and speed of information processing which have been found to differentiate hypertensives from normotensives, but it is also a difficult task. Therefore, it was expected that this test would yield significant results in a sample of young well-educated

participants. One reason why parental history group differences were not observed on this test may be due to the choice of trials. In order to reduce testing time, only trials 1 and 4 were administered. Trial 1 was the slowest with regards to the presentation of digits while trial 4 was the fastest. It is possible that trial 1 may not have been very challenging for participants (% correct trials for the entire sample = 76% while trial 4 was probably too demanding (% correct trial for the entire sample = 40%). Thus, this may have reduced the likelihood of observing group differences on this test.

It was hypothesised that PH+ participants would exhibit increased cardiovascular activity at rest and particularly during testing. Contrary to expectations there were no parental history group differences in resting and testing cardiovascular activity. This is not a surprising result given that although a number of studies have reported higher cardiovascular reactivity during behavioural tasks in PH+ individuals (eg. Ballard, Cummings, & Larkin, 1993; Manuck, Proietti, Rader & Polefrone, 1985; Russo & Zuckerman, 1992; Sausen, Lovallo, & Wilson, 1991), this has not been a consistent finding. However, it was believed that the inclusion of hemodynamic measures would yield parental history groups differences in cardiovascular activity since some studies have reported parental history group differences in peripheral vascular resistance responses in the absence of group differences in blood pressure (Anderson et al., 1987; Ditto & Miller, 1989; Miller & Ditto, 1991). This did not turn out to be the case.

The lack of significant parental history differences during testing may be due to the fact that, with the possible exception of the Stroop and PASAT, the increases in cardiovascular reactivity elicited by the tests were not large. For example, disregarding

the Stroop and PASAT, the mean increases in heart rate elicited during testing were 10 beats per minute or less and the mean increases in systolic blood pressure were less than 7 mm Hg (see Table 3). In fact, the increases in cardiovascular reactivity were smaller than the values elicited by tasks (e.g. shock avoidance, interpersonal conflict) which have yielded parental history differences in our laboratory (Miller & Ditto, 1994; Miller et al., 1998).

In contrast, Pierce and Elias (1993), observed higher heart rates for PH+ participants than PH- participants during a number of tests including the Sternberg task according to univariate, but not multivariate analyses. Examination of the mean heart rate reactivity scores from the Pierce & Elias study and those from the present study reveals that, in general, the heart rate reactivity scores in the Pierce & Elias study were probably higher than those observed in the present study. The heart rate reactivity scores for the Sternberg task will be used as an example since this test was included in both studies. In the Pierce & Elias study, the first session mean heart rate change scores for the Sternberg task were 16.9 ± 1.1 and 13.9 ± 0.6 beats per minute for PH+ and PH- participants, respectively, whereas in the present study the mean heart rate change scores for the whole sample was 4.8 ± 0.8 beats per minute. One reason why the reactivity values in the present study are lower compared to those observed in the Pierce & Elias study may be due to methodological differences between the two studies. In the Pierce & Elias study, half of the participants in the first session were told that their performance was being evaluated by a hidden observer which quite likely increased participants' degree of physiological arousal.

With regards to state affect responses, PH+ participants displayed greater state affect increases than PH- participants during Block Design. More specifically, PH+ participants reported greater increases in irritability and anxiety than PH- participants during Block Design. As stated above, these parental history group differences in irritability and anxiety during Block Design did not account for the poorer performance of PH+ participants on this test. The parental history group differences in anxiety and irritability during Block Design are consistent with previous studies which have observed increased state anxiety (Holroyd & Gorkin, 1983; Jorgenson & Houston, 1981) and state anger responses (Miller & Sita, 1994) to laboratory tasks in PH+ individuals. There were no parental history group differences for the other tests including those for which parental history group differences in performance were observed. That few parental history differences in state affect responses to the tests were observed is not surprising given that, with the exception of anxiety, the tests elicited small changes in state affect responses. It was somewhat surprising that the Stroop and PASAT did not elicit larger state affect responses or parental history group differences in state affect given that they both are difficult tasks.

Although no parental history group differences in resting and testing cardiovascular activity were observed, cardiovascular activity at rest and during testing was related to cognitive functioning for the entire sample. In general, partial correlations corrected for age revealed a negative association between increased peripheral resistance at baseline and performance on the Stroop, PASAT, Block Design and Sternberg task. These associations are consistent with previous studies showing a negative relationship

between diastolic blood pressure and cognitive functioning in hypertensives (Elias et al., 1990; Goldman et al., 1974; Wilkie & Eisdorfer, 1971) and in a sample of borderline hypertensives and normotensives (Elias et al., 1990). To the author's knowledge, this is the first study to observe a negative relationship between resting peripheral resistance and cognitive functioning in a sample comprised solely of young healthy normotensives.

The correlations involving baseline heart rate, cardiac output, stroke volume, and systolic blood pressure and test performance suggested a positive relationship between baseline cardiac activity and performance on the Stroop, PASAT, Block Design and Sternberg task. The negative relationship between increased peripheral resistance and test performance may underlie, in part, the positive correlations involving cardiac output, stroke volume and test performance since increased peripheral resistance will lead to decreased venous return to the heart which, in turn, will lead to decreased cardiac output and stroke volume. Hence, peripheral resistance may also underlie the positive relationship between cardiac output, stroke volume and test performance.

The mechanisms underlying the relationship between increased resting peripheral resistance and poorer test performance are unclear. It is well known that under normotensive blood pressure levels, cerebral perfusion pressure is relatively constant (Ganong, 1985), therefore, changes in total peripheral resistance are not likely to result in changes in overall blood flow to the brain. As well, it is unlikely that either atherosclerosis or white matter lesions were present in these young healthy normotensive men to the extent that they could affect cognitive functioning.

However, it is possible that increased arterial stiffness underlies the relationship

between increased peripheral resistance and poorer cognitive performance. Arterial stiffness is one factor which can increase resistance to flow in blood vessels (Ganong, 1985). Assuming that the processes which cause arterial stiffness are the same in all vascular beds, the relative degree of arterial stiffness and resistance to flow in the cerebral vasculature may be proportional to the total peripheral resistance. Thus, it is possible that increased resistance to flow in cerebral vessels due to arterial stiffening may underlie the relationship between total peripheral resistance and cognitive performance. Increased arterial stiffness in cerebral vessels may, in turn, lead to decreased regional cerebral blood flow and regional metabolic activity and, could ultimately, cognitive performance.

Related to the above hypothesis, it is possible that participants with lower peripheral resistance are more physically fit than those with higher peripheral resistance and that physical fitness mediates the relationship between peripheral vascular resistance and cognitive performance. Although findings are inconsistent, there is evidence that physical fitness is related to faster reaction time and speed of information processing in correlational and experimental studies (eg. Spirduso, 1995; Stacey, Kozma, & Stones, 1985) Exercise may improve cognitive functioning by acting on factors that directly impact on cerebrovascular integrity and brain functioning such as plasma LDL levels, triglyceride levels, platelet aggregation and neurotransmitter function (Spirduso, 1995). Unfortunately, no measure of physical fitness (e.g. VO_2 max) was obtained in the present study.

There were two positive associations between baseline heart rate and test

performance. If heart rate is assumed to be an indicator of arousal, this suggests that increased arousal is related to better cognitive performance. According to the Yerkes-Dodson Law, the relationship between arousal and performance follows an inverted U-shaped curve such that at low to moderate levels of arousal, performance is facilitated by increased arousal whereas at high levels, arousal and performance are inversely related. Given that, in general, resting heart rate levels for the sample were not high (mean = 64.8 bpm), the positive association between heart rate and performance would be consistent with the Yerkes-Dodson Law. Additionally, the positive relationship between heart rate and cognitive performance may be mediated by participant level of motivation. Increasing motivation via experimental manipulations (eg. monetary incentives) has been found to lead to increases in heart rate in some studies (Elliot, 1974; Fowles, Fisher, & Tranel, 1982). It is possible that participants with higher resting heart rates were more motivated and, therefore, performed better during testing.

Partial correlations between cardiovascular reactivity and test performance adjusted for age and resting cardiovascular levels revealed a positive relationship between cardiac activity and performance on Block Design, PASAT, Self-Ordered Pointing Task and the Wisconsin Card Sorting Task. The positive association between cardiac activity during testing and test performance is inconsistent with the present study's hypotheses. However, it is consistent with the Laceys' (1974) hypothesis that increased heart rate facilitates cognitive elaboration. Also, it is in agreement with results from a study by Caccioppo, (1979) in which induced heart rate increases in participants wearing pacemakers resulted in better reading comprehension scores and a study in

which heart rate following the presentation of to be recalled stimuli was found to be positively correlated with memory performance (Jennings & Hall, 1980).

On the other hand, the positive relationship between cardiac reactivity and performance on these tasks may be simply due to faster motoric movements. It is likely that participants who performed well also completed the tests more quickly and, hence, displayed faster motoric responses which served to increase cardiac activity. This explanation especially applies to Block Design and the PASAT. For Block Design, the participant used his hand to complete the test and points were accorded for faster performance. During the PASAT, participants vocalized their responses. The more likely a person knows an answer, the more likely he is to reply. Given that speaking is associated with increased heart rate and blood pressure (Lynch, Long, Thomas, Milnow, & Katcher, 1981), the greater the number of vocalizations, the higher one's cardiac activity is likely to be.

Consistent with baseline correlations, total peripheral resistance change scores were positively correlated with Sternberg Reaction Time Intercept. However, given that this was the only positive correlation between a measure of peripheral vascular resistance and test performance, there seems to be no systematic relationship between peripheral vascular resistance during testing and test performance.

Contrary to the results of the present study, Pierce & Elias (1994) did not observe any systematic associations between cardiovascular activity and cognitive functioning in PH+ and PH- individuals. A number of factors might account for the discrepancy in the results. First, Pierce & Elias only recorded heart rate and systolic and diastolic blood

pressure, whereas many of the significant associations reported in the present study involved hemodynamic measures such as total peripheral resistance and cardiac output. In the present study, cardiovascular measures were sampled every minute whereas in the Pierce & Elias study readings were taken every 2 minutes. Additionally, in the present study, heart rate was sampled using a more sensitive procedure.

The present results suggest that the poorer performance of PH+ individuals is not accounted for by cardiovascular activity and state affect. Therefore, what can account for the observed group differences in cognitive functioning? As suggested by Waldstein et al. (1991), it is possible that an inherited CNS abnormality which predisposes one to becoming hypertensive is also partly responsible for the decrements in cognitive functioning and that altered brain functioning may first be manifested in terms of subtle cognitive decrements before any permanent elevation of blood pressure occurs. The study by Gattu et al. (1997) using pre-hypertensive SHRs suggests that, like in humans, cognitive decrements in those at risk for hypertension may precede hypertension onset. Furthermore, they observed differences in acetylcholine receptor distribution between SHRs and controls, which suggests that a CNS abnormality may exist in those at risk for hypertension before the onset of hypertension. In this regard, it may be useful to examine brain functioning in PH+ individuals. Positron emission tomography may aid in elucidating parental history differences in brain metabolic activity and neurotransmitter function. Examination of regional cerebral blood flow in PH+ individuals may also prove to be useful. There is evidence of vascular abnormalities in the peripheral arteries and veins of young PH+ males (Ito, Takeshita, Higuchi, & Nakmura, 1985; Takeshita et al.,

1982). For example, Takeshita et al. (1982) observed a reduced maximal vasodilator capacity in forearm vessels of PH+ individuals. It is conceivable that, like in peripheral vessels, there may be structural and/or functional differences in cerebral vessels of PH+ individuals which could affect regional cerebral blood flow, and, perhaps, cognitive functioning.

It is possible that baroreceptor functioning may underlie some of the cognitive decrements in PH+ individuals. The baroreceptor system consists of stretch receptors in the carotid sinus and aortic arch. Information regarding changes in blood pressure is transmitted from the stretch receptors to the brainstem vasomotor centre causing appropriate increases or decrease in central autonomic outflow from the vasomotor centre. This, in turn, causes the needed changes in heart rate and vascular resistance leading to restoration of normal blood pressure. Hence, the main function of the baroreceptor system serves to protect against large fluctuations in blood pressure. Interestingly, it has been hypothesised that altered baroreceptor functioning may be related to hypertension development (Dworkin, 1988).

In addition to regulation of blood pressure, there is evidence that baroreceptor stimulation affects cortical activity. For example, baroreceptor activation has been found to decrease pain sensitivity (Dworkin et al., 1994; Mini, Rau, Montoya, Palomba, & Birbaumer, 1995). Baroreceptor activation causes reductions in slow cortical negative potentials, especially the contingent negative variation, (Elbert, Roberts, Lutzenberger, & Birbaumer, 1992; Rau, Pauli, Brody, Elbert, & Birbaumer, 1993), which may reflect cortical arousal (Birbaumer, Elbert, Canavan, & Rockstroh, 1990). In fact, it has been

hypothesised that baroreceptor functioning may be related to specific cognitive and perceptual processes (Lacey & Lacey, 1974). According to the Laceys' theory, increased baroreceptor firing through its inhibitory effects on cortical activity increases sensory threshold thereby making it easier to disregard external stimuli and to process internal information. Decreased baroreceptor firing, on the other hand, decreases sensory threshold and facilitates the detection of external stimuli.

A number of studies have reported that baroreceptor sensitivity to experimentally induced changes in blood pressure is reduced in PH+ as compared to PH- individuals (Ookuwa, Takata, & Ogawal, 1987; Yamada, Miyajima, & Tochikubo, 1988; Parmer, Cervenka, & Stone, 1992). This reduced baroreceptor sensitivity has been observed even in the absence of parental history group differences in resting blood pressure (Takata et al., 1985). Furthermore, there is evidence that baroreceptor sensitivity during mental arithmetic is reduced to a greater extent in PH+ than PH- individuals (Ditto & France, 1990). As stated above, there is evidence that baroreceptor functioning affects cortical activity (Rau et al., 1993). Hence, it is possible that baroreceptor activity may underlie some of the cognitive decrements observed in PH+ individuals. To date, no study has examined the possibility that baroreceptor sensitivity may be related to cognitive performance in PH+ individuals.

In addition to studies exploring mechanisms which underlie cognitive decrements in PH+ individuals, more studies that directly examine cognitive performance in PH+ individuals are needed. Ideally, future studies examining cognitive functioning in PH+ individuals should, like Waldstein et al. (1994), use batteries which sample a wide range

of cognitive domains. In the present study, given that cardiovascular recordings were sampled throughout the testing session, a small testing battery was used in order to keep testing time to a minimum. As a result, important domains such as perceptual and psychomotor functioning were not specifically evaluated. The studies by McCann et al. (1990) and Pierce & Elias, 1993) also used small batteries which focussed on a few cognitive domains. Instead, future studies should use batteries which sample a wide range of cognitive domains and within these batteries, one should include, as others have suggested (Blumenthal et al., 1993; Elias & Elias, 1994), information processing tests that isolate specific cognitive processes. Sampling a wide range of cognitive domains would allow for an examination of interrelationships among cognitive domains within a given sample. One would be able to compare the performance of PH+ individuals along various cognitive domains using the same sample. This would be preferable to comparing the results of different studies which have examined different cognitive domains. Including tests which isolate specific processes would facilitate interpretation of test results. As mentioned previously, the majority of neuropsychological tests tap into more than one cognitive domain, thereby complicating the interpretation of individual test results.

Furthermore, future studies should include measures of IQ and/or measures which would not be expected to elicit differences between PH+ and PH- individuals (e.g. vocabulary test). As mentioned above, it is possible that the observed group differences in test performance were not related to parental history of hypertension per se but to group differences in general intellectual level. The inclusion of an IQ measure, for

example, would have made it possible to rule this out. As well, except for health information, no study to date has thoroughly examined the characteristics of the parents of PH+ individuals. It would be important to obtain information on parents' age, level of education, and SES as these factors may have an impact on their offspring's cognitive functioning.

To date, all studies that have examined cognitive functioning in PH+ individuals have used a cross-sectional approach. In addition to cross-sectional studies, longitudinal studies of PH+ individuals could provide valuable information. It would be interesting to follow up PH+ individuals over time to examine the significance of the cognitive decrements with regards to future hypertension development. Are PH+ individuals who exhibit cognitive decrements more likely to develop hypertension than those who don't display any decrements? Are PH+ individuals who display cognitive decrements more likely to develop hypertension at an earlier age? On the other hand, it possible that the decrements observed in PH+ individuals are unrelated to processes involved in hypertension development. Longitudinal studies of PH+ individuals would help answer these questions.

Longitudinal studies would also be important with regards to obtaining a better understanding of the nature and progression of the cognitive decrements. It is well known that certain aspects of cognitive functioning (eg. memory, speed of information processing) decline as one ages (Hultsch & Dixon, 1990). Are PH+ individuals more vulnerable to the deleterious effects of age on cognitive performance than PH- individuals? It would be interesting to examine the impact of conditions which affect

cognitive functioning on PH+ individuals. For example, does the severity and type of decrements in PH+ individuals change if they develop hypertension, if they develop diabetes?

Thus far, all studies that have examined cognitive functioning in PH+ individuals, including the present study, have used only university undergraduates. Elias et al. (1987) observed cognitive decrements in less well-educated (12-15 years) but not in very well-educated (16-22 years) hypertensives. Given these findings, it is possible that few cognitive decrements have been in observed in PH+ individuals because only well educated individuals have been tested. Furthermore, it is unclear to what extent the results of studies examining PH+ individuals, including the present study, are generalizable to PH+ individuals of lower education. Therefore, future studies should include PH+ and PH- individuals of lower education as it will enhance the external validity of results and may lead to more consistent findings.

All participants in the present study were males. It was decided to include only male participants because parental history group differences in cardiovascular reactivity tend to be more consistently observed in males (Russo & Zuckerman, 1992) and because two of the three previous studies which examined cognitive functioning in PH+ individuals used only males. It is unclear to what extent the present results are generalizable to women. Of the three previous studies which examined PH+ individuals, only the study by McCann et al. (1990), included women. In that study, one gender by parental history group interaction was observed. More specifically, male PH+ participants performed more poorly on the Perception of Spaced Stimuli test, a visual

perceptual test, when compared to male PH- participants, however, there was no difference between female PH+ and PH- participants on that test. Thus, parental history differences in cognitive functioning may vary according to gender. This is not surprising since there are gender differences in some cognitive domains (e.g. perceptual skills, visual-spatial ability) (Maccoby & Jacklin, 1974). Hence, it would be important to test female PH+ and PH- participants in future studies.

Finally, the results of the present study have direct implications for future studies examining cognitive functioning in hypertensives. The majority of significant correlations between resting cardiovascular activity and cognitive functioning involved hemodynamic measures. Although a number of studies have reported a significant relationship between blood pressure and cognitive functioning in hypertensives (Elias et al., 1990; Goldman et al., 1974; Robbins et al., 1994) some studies have found no relationship (e.g. Farmer et al., 1987). To date, hemodynamic measures have not been used in studies of hypertensives. Including such measures in studies of hypertensives might yield more significant associations between cardiovascular activity and cognitive functioning and could lead to a better understanding of the hemodynamic mechanisms underlying the relationship between elevated blood pressure and cognitive functioning.

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Appendix A

Table A1

Studies Examining Neuropsychological Performance in Hypertensives

Author(s)	Sample/Factors	Main Findings	Controls/Comments
Blumenthal et al., (1993)	68 hypertensives, age=45.4, SD=7.7 32 normotensives, age=44.5, SD=9.6 Factors: hypertension status hypertensive: 140≤ SBP≤ 180 mmHg or 90 ≤ DBP ≤ 105 mm Hg normotensive: SBP < 140 and DBP < 90 mm Hg	Speed of Processing: hypertensives poorer on Digit Symbol, Trails B, short-term memory search speed (Sternberg RT slope) NS: Stroop Interference Digits Backwards, Sternberg RT Intercept Verbal Memory: NS: Logical Memory-Immediate and Delayed; Paired Associates Figural Memory: NS: Figural Memory-Immediate and Delayed	participants free of cardiovascular disease, not taking anti-hypertensive medications groups equivalent with regards to age, education, SES, trait anxiety, depression, hostility, Type A behaviour hypertensives reported higher state anxiety used a multivariate approach to investigate group differences

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; NS = non significant.

Boller et al., (1977)	20 newly diagnosed untreated hypertensives, age=49.1, SD=7.0 20 normotensives, age=51.1, SD=6.2 Factors: hypertensive status hypertension: DBP > 105 mmHg	hypertensives exhibited longer reaction times (auditory stimuli) and poorer Digit Span - Forward (attention) than normotensives hypertensives exhibited greater right hand-grip strength than normotensives NS: WAIS subtests: Digit Span (Backward), Arithmetic, Vocabulary, Block Design, Object Assembly, Digit Symbol, Verbal IQ, Performance IQ NS: Purdue Pegboard Test (manual dexterity); Wisconsin Card Sorting Task (executive function); Rey Osterreith Figure Copy (visual-spatial); De Renzi Rods test (visual spatial), Logical Memory-Immediate and Delayed (verbal memory); Rey-Osterreith Figure- Recall (figural memory); Seashore Tonal Memory (non verbal auditory ability); Token test (auditory comprehension); writing test from Boston Diagnostic Aphasia test; Hand Grip (left hand)	participants free of illness including diabetes, neurological disorder, alcoholism groups equivalent with regards to age, education, occupational status majority of participants in both groups had abnormal MMPI profiles (groups were equivalent in this regard) no control for increase of Type I error

Note. DBP = diastolic blood pressure; NS = non significant.

Elias et al., (1987)	23 high education (16-22 years) hypertensives, age=43.8, SD=9.6 27 high education normotensives, age=40.6, SD=10.9 31 lower education (12-15 years) hypertensives, age=42.0, SD=9.9 27 lower education normotensives, age=44.7, SD=10.1 Factors: hypertension status hypertension: MAP> 105 mm Hg SBP > 140 mm Hg, DBP >90 mm Hg normotensive: MAP < 100 mm Hg educational level (low, high)	AIR lower for lower education hypertensives than high education normotensives lower education hypertensives poorer on Categories (concept formation), TPT memory, TPT-localization (spatial memory) than lower education hypertensives no performance differences between high education hypertensives and normotensives hypertensives poorer on TPT-memory, TPT-localization and finger tapping than normotensives NS: Digit Symbol, TPT-time, Trail Making B	exclusion criteria: screening of numerous diseases including cardiovascular or cerebrovascular disease, diabetes, kidney disease, neurological or psychological disorders, retinopathy hypertensives were asked to stop taking medication 21 days prior to testing

Note. AIR = Average Impairment Rating from the Halstead Reitan Battery; AIR comprised of Category Test, Tactual Performance Test- time (TPT-time), memory (TPT-memory), and localization (TPT-localization), finger tapping, Trail Making B, Digit Symbol; SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial pressure; NS = non significant.

Elias et al., (1989)	10 year follow up of Schultz et al. (1979) sample 10 hypertensives, age=62.9, SD=3.2 (at end of follow up period) 9 normotensives, age=63.6, SD=7.4 (at end of follow up period) Factors: hypertensive status hypertensive: MAP > 105 mmHg normotensive: MAP < 100 mmHg	At end of follow up period: hypertensives performed more poorly on Categories, Tactual Performance Test-Memory and Localization, and AIR from Halstead- Reitan Battery hypertensives and normotensives exhibited similar rates of change in cognitive performance during follow up period NS: Digit Symbol, Tactual Performance Test-time, finger tapping, Trails A and B	exclusion criteria: cardiovascular and cerebrovascular disease, diabetes, neurological or psychiatric disorder, kidney dysfunction, primary aldosteronism, hypercortisolism, pheochromocytoma participants stopped taking anti-hypertensive medication 21 days prior to testing

Note. Average Impairment Rating (AIR) is comprised of Category Test, Tactual Performance Test-Time, Memory and Localization, Digit Symbol, finger tapping, Trail Making B; MAP = mean arterial pressure; NS = non significant.

Franceschi et al., (1982)	15 normotensives, age=39, SD=7 (DBP < 90 mm Hg) 17 newly diagnosed, untreated hypertensives, age=35, SD=9 (DBP > 95 mm Hg) 22 chronic (8± 2 years) hypertensives on anti-hypertensive treatment, age=43, SD=6 (DBP < 95 mm Hg) Factors: hypertension status	untreated hypertensives performed more poorly than normotensives on Raven's Matrices, Block Design, WMS Memory Quotient, Logical Memory Immediate chronic medicated hypertensives performed more poorly on Raven's Matrices, Card Sorting, Benton Visual Retention test, Picture Arrangement, Block Design, WMS Memory Quotient, Logical Memory Immediate when compared to normotensives no differences in test performance between newly diagnosed untreated hypertensives and chronic medicated hypertensives NS: Similarities, Digit Symbol, WMS Paired Associates, Logical Memory Delayed, Visual Reproduction	exclusion criteria: neurological disorders, diabetes, dyslipidemia, alcoholism, psychiatric diagnoses, psychoactive medications newly diagnosed untreated hypertensives had higher DBP than chronic hypertensives multiple univariate tests conducted, no control for Type I error

Note. DBP = diastolic blood pressure; WMS = Wechsler Memory Scale; NS = non significant.

Grossman & Zalewski, (1995)	166 hypertensive males, age=38 176 normotensive males, age=38 Factors: hypertension status hypertensive: SBP≥ 140 mmHg or DBP≥ 90 mmHg normotensive: SBP< 140 mmHg and DBP < 90 mmHg	no differences between hypertensives and normotensives according to multivariate analyses univariate analyses revealed trend for poorer performance on the Wisconsin Card Sorting Test and Word List Generation Test for hypertensives NS: Attention/Speed of Information Processing: Paced Auditory Serial Addition Test Memory/Learning: California Verbal Learning Test, Rey-Osterrieth Complex Figure (immediate and delayed recall) Executive Function: Wisconsin Card Sorting (percent perseverative response), Word List Generation (FAS) Visual-Spatial: Block Design, Rey-Osterrieth Complex Figure Copy Motor function: Grooved Pegboard	exclusion criteria: diabetes, heart disease, neurological and psychological disorders, cancer, head injury, liver disease, history of memory loss, left-handedness, use of any medication,history of substance abuse none of the hypertensives were taking anti-hypertensive medications hypertensives had mild hypertension (mean SBP=132; mean DBP=94) groups equivalent with regards to age, race, alcohol use, smoking, history of drug use hypertensives had fewer years of education and lower level of income than normotensives multivariate analyses covaried for education and income

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; NS = non significant.

Kuusisto et al., (1993)	57 hyperinsulinemic hypertensives, age=73.6, SE=0.4 312 normoinsulinemic hypertensives, age=73.0, SE=0.2 366 normotensives, age=72.7, SE=0.2 Factors: hypertensive status hypertensive: SBP≥ 160 mmHg or DBP≥95 mmHg fasting plasma insulin: normoinsulinemic and hyperinsulinemic	hypertensives performed more poorly than normotensives on calculation/ attention items of MMSE and verbal fluency (letter P) hyperinsulinemic hypertensives performed more poorly than normotensives on calculation/attention and copying items of MMSE and verbal fluency (letter P) no differences in performance between normoinsulinemic hypertensives and normotensives NS: MMSE orientation, registration, recall, language, total score; Visual Reproduction (copying, immediate and delayed recall), BSR (short-term and long term recall), verbal fluency (letters S, A, animals); Trail Making A, B, and C	participants free of diabetes and had no history of stroke two hypertensive groups equivalent with regards to age, education, previous myocardial infarction, prevalence of abnormal EKG, anti-hypertensive medication use, DBP hypertensive groups different with regards to gender distribution, SBP, glucose tolerance, and fasting plasma glucose hypertensives older than normotensives; more women in hypertensive groups analyses adjusted for age, gender, education fasting glucose no control of inflation of Type I error

Note. MMSE = Mini Mental State Exam; BSR = Buschke Selective Reminding Test; SBP = systolic blood pressure; DBP = diastolic blood pressure; NS = non significant.

Light, (1975)	160 hypertensives: 118 medicated hypertensives age=43.0, SD=10.7 42 unmedicated hypertensives, age=38.1, SD=10.7 43 normotensives, age=36.2, SD=12.3 Factors: hypertension status hypertensive: SBP > 140 mm Hg or DBP > 90 mm Hg normotensive: BP < 140/90 mmHg treatment status (unmedicated, medicated) plasma renin level (low, normal, high)	medicated hypertensives slower reaction time than unmedicated hypertensives and normotensives medicated high renin hypertensives faster reaction time than unmedicated high renin hypertensives medicated low and normal renin hypertensives slower than unmedicated low and normal renin hypertensives unmedicated high renin hypertensives slower than unmedicated low and normal renin hypertensives	exclusion criteria: cerebrovascular accident, congestive heart failure, coronary heart disease medications discontinued from 3 to 21 days prior to testing participants received a diuretic 1-2 hours prior to testing treatment status group differences independent of age, blood pressure before and after testing, and duration of hypertension used multivariate tests

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure.

Light (1978)	130 previously treated hypertensives (age range = 18-77) 47 untreated hypertensives; (age range = 18-77) 52 normotensives (age range = 18-77) Factors: hypertensive status hypertension for 18-59 year olds: SBP≥ 140 mmHg or DBP ≥90 mmHg for 60 years old and above SBP ≥ 150 mm Hg or DBP ≥90 mm Hg treatment status (treated, untreated) plasma renin level (low, normal, high)	treated hypertensives displayed slower reaction time than normotensives treated hypertensives tended to display slower reaction time than untreated hypertensives reaction times of untreated hypertensives with low or normal plasma renin similar to those of normotensives reaction time of untreated hypertensives with high plasma renin tended to be slower than those for untreated hypertensives with low or normal plasma renin	participants screened for cardiovascular and neurological disorders anti-hypertensive medication discontinued 3-21 days prior testing participants given diuretic prior to testing to normalize blood pressure used multivariate tests

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure.

Madden & Blumenthal (1989)	24 hypertensives, age=42.1, SD=8.0 28 normotensives, age=43.3, SD=8.8 Factors: hypertensive status hypertension 90 ≤ DBP ≤ 110 mmHg	normotensives exhibited higher error rate in Sternberg task hypertensives exhibited slower search of short-term memory in Sternberg task than normotensives independent of error rate and educational level no group differences in Sternberg RT intercept	exclusion criteria: coronary heart disease, renal disease hypertensives had not taken anti-hypertensive medication for at least 4-6 weeks prior to testing normotensives tended to have more years of education than hypertensives

Note. DBP = diastolic blood pressure.

Madden & Blumenthal (1998)	9 young hypertensives (18-40 years old), age=32.3, SD=5.1 9 young normotensives, age=27.6, SD=6.4 29 middle-aged hypertensive (41-59 years old), age=49.2, SD=5.7 27 middle-aged normotensives age=51.3, SD=6.4 13 older hypertensives (60-78 years old), age=66.2, SD=5.2 12 older normotensives, age=69.9, SD=7.1 Factors: hypertension status hypertension X age group hypertensive: SBP≥ 140 mmHg or DBP≥ 90 mmHg normotensive: SBP< 140 and DBP < 90 mmHg	young and middle aged hypertensives displayed a higher error rate in a visual selective attention task than young and middle aged normotensives older hypertensives and normotensives had similar error rates NS: reaction time in visual attention task	exclusion criteria: cardiovascular disease, secondary hypertension, renal disease, pulmonary disease, diabetes, psychiatric illness, medications with cardiovascular or CNS effects hypertensives discontinued antihypertensive medications at least 4 weeks prior to testing

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; NS = non significant.

Mazzucchi et al. (1986)	group 1: 20 untreated, recently diagnosed (< 1 year) hypertensives, age=33.5, SD=10.3 group 2: 20 diet treated hypertensives, previously diagnosed (3-5 years), age=34.5, SD=10,4 group 3: 20 medicated or diet treated, previously diagnosed (6-10 years) hypertensives, age=39.2, SD=8.0 group 4: 60 normotensives, mean age =34.5, SD=9.7 Factors: hypertension status hypertensive: BP > 160/95 mmHg normotensive: BP < 140/80 mmHg each hypertensive group compared to matched controls	hypertensives performed more poorly on Verbal memory (Logical memory: immediate and delayed); figural memory (immediate and delayed); iconic memory (neologisms), Digit Span, Block Design, Digit Symbol, Street Completion, Finger Tapping (left hand) NS: Verbal Learning, Verbal Fluency, Maze Learning and Recall, Finger tapping (right hand), Iconic memory (figures), WAIS subtests: Information, Arithmetic, Picture Completion, Object Assembly group 1 hypertensives performed more poorly than normotensives on Figural Memory, Logical memory: immediate and delayed group 2 hypertensives performed more poorly than normotensives on Digit Span, Logical memory: immediate and delayed group 3 hypertensives performed more poorly than normotensives on Figural Memory, Finger tapping (eft hand, Street completion within group 3, medicated hypertensives performed better than diet-treated ones hypertension duration not related to cognitive decline	participants free of diabetes, chronic liver disease, renal disease, neurological disorders, groups matched for age, SES, education, and WAIS vocabulary hypertensive groups had similar blood pressures no control of inflation of Type I error

Note. NS = non significant.

Miller et al. (1984)	21 medicated hypertensives, (10 men, 11 women), age = 32.9 13 unmedicated hypertensives, (6 men, 7 women), age= 35.9 24 normotensives, (12 men, 12 women), age = 33.9 15 month follow up of Shapiro et al. (1982) study sample using the same battery with the exception of the Movement Reversal test Factors: hypertension status treatment status (medicated, unmedicated)	Perceptual: hypertensives no longer performed more poorly on Visual Recognition Threshold Psychomotor: hypertensives still slower on Tapping Speed, Digit Symbol group differences on Traverse Time, Coordination Time no longer significant Time Estimation: time estimation no longer significant group differences on other tests remained nonsignificant medicated hypertensives improved their overall test performance whereas unmedicated hypertensives declined and normotensives remained the same	BP for normotensives and unmedicated hypertensives did not change over 15 month period, whereas SBP and DBP decreased for medicated hypertensive males and SBP decreased in medicated females

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure.

Pentz et al. (1979)	11 young hypertensives, age=29.2, SD=5.4 16 young normotensives, age=26.3, SD=3.7 14 older hypertensives, age=49.6, SD=6.3 21 older normotensives, age=50.8, SD=8.5 Factors: hypertension status hypertension X age	hypertensives made more errors on the Category test (concept formation) differences between hypertensives and normotensives on Tactual Performance Test-Memory and Finger Tapping were larger for younger participants than older participants NS: Tactual Performance Test -Time (speed of information processing); Tactual Performance Test-Localization (spatial memory); Trail Making A (psychomotor ability); Trail Making B (psychomotor ability and mental flexibility); Average Impairment Index	exclusion criteria: cerebralvascular accident, congestive heart failure, coronary heart disease, kidney disease, type II or type III eye ground changes 7 of 25 hypertensives were on anti-hypertensive medication at time of testing conducted multivariate analyses

Note. All tests used in this study are from the Halstead-Reitan Battery; Average Impairment Index is comprised of Category errors, Tactual Performance Test-Time, Memory, Localization and finger tapping;. NS = non significant.

Perez-Stable et al. (1992)	173 hypertensives (90≤ DBP≤ 94), age=45.4, SD=8.2 139 hypertensives (95≤ DBP ≤104), age=45.5, SD=8.4 47 normotensives, age=42.0, SD=7.6 Factors: hypertension status hypertension 90 < DBP < 104 mmHg normotensive SBP≤ 135 mmHg and DBP ≤ 85 mmHg	No significant differences between hypertensives and normotensives NS: Stimulus evaluation/ response selection test (speed and accuracy for processing visual information); Continuous Performance Task (sustained attention); Digit Symbol (psychomotor) California Verbal Learning Test (learning/memory)	exclusion criteria: cardiovascular and cerebrovascular disease, secondary hypertension, use of insulin, bronchodilators antidepressants 43% of hypertensives on anti-hypertensive medication anti-hypertensive medication discontinued for at least 4 weeks prior to testing

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; NS = non significant.

Schmidt et al., (1991)	24 medicated hypertensives, age=39.1, SD=7.2 11 unmedicated hypertensives, age=35.5, SD=8.8 20 normotensives, age=37.9, SD=4.7 Factors: hypertension status hypertension: SBP >160 mmHg or DBP > 95 mmHg normotensive: SBP < 140 mmHg and DBP < 85 mmHg	medicated and unmedicated hypertensives performed more poorly on verbal memory and total learning and memory components of Baumler's LGT3 no differences between hypertensives with and without white matter hyperintensities NS: visual- spatial memory from Baumler's LGT3, d2 test (visual selective attention), reaction time	exclusion criteria: cardiovascular disease cerebrovascular disease, diabetes, any systemic disease that could affect cognitive functioning, psychiatric illness, head injury, alcohol or drug abuse 24 hypertensives were on taking anti-hypertensive medication at time of testing 11 hypertensives had not been taking medication for at least 1 month prior to testing incidence of white matter hyperintensities twice as high in hypertensives as in normotensives no control for inflation of Type I error

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; NS = non significant.

Schultz et al., (1979)	14 young previously unmedicated hypertensives, age=29.9, SD=6.6 17 young previously medicated hypertensives, age=29.8, SD=4.0 9 older previously unmedicated hypertensives, age=52.9, SD=5.2 28 older previously medicated hypertensives, age= 52.2, SD=5.3 23 young normotensives, age=26.5 19 older normotensives, age=55.3 Factors: hypertensive status hypertensive: MAP≥ 105 mmHg (equivalent to SBP≥ 140 mmHg and DBP≥ 90 mm Hg) normotensive: MAP≤ 100 mm Hg	no differences between previously medicated and unmedicated hypertensives on WAIS subtests hypertension associated with lower WAIS Verbal IQ scores for younger participants but not older participants After matching for Verbal IQ: hypertensives exhibited lower WAIS Performance IQ than normotensives (effect larger for younger than older participants) hypertensives performed more poorly than normotensives on Digit Symbol, Block Design, Object Assembly, and Picture Arrangement	exclusion criteria: cardiovascular disease, cerebrovascular disease, kidney failure, type II or III eye ground changes medicated hypertensives stooped taking their medications 3 to 21 days prior to testing hypertensives and normotensives were given a diuretic prior to testing

Note. All tests used in this study were from the WAIS; SBP = systolic blood pressure; diastolic blood pressure; MAP = mean arterial pressure.

Schultz et al., (1986)	5-6 year follow up of Schultz et al. (1979) sample 30 hypertensives, age=47.5, SD=14.1 24 normotensives, age=52.0, SD=10.9 Factors: hypertension status hypertensive: MAP > 105 mmHg (equivalent to SBP > 140 mmHg and DBP < 90 mm Hg) normotensive: MAP < 100 mm Hg time	at end of follow up period: significant increase in WAIS Verbal IQ scores for normotensives; Verbal IQ scores of hypertensives did not change hypertensives performed more poorly than normotensives on Verbal IQ scale no change in WAIS Performance IQ scores for hypertensives and normotensives hypertensives had lower Performance IQ scores than normotensives when initial testing and follow up scores were averaged	exclusion criteria: cardiovascular and cerebrovascular disease, kidney dysfunction, diabetes, retinopathy, neurological, psychiatric disorder many participants from initial study did not participate in the follow up (developed complications which disqualified them or refused to participate) hypertensives and normotensives were not different with regards to depression and anxiety

Note. MAP = mean arterial pressure; WAIS = Wechsler Adult Intelligence Scale.

Shapiro et al. (1982)	41 recently diagnosed (24 men and 17 women) hypertensives, age=33.7, SE=1.6 41 matched normotensives, age=33.8, SE=1.1 Factors: hypertensive status hypertension: 90 ≤ DBP≤ 105 mmHg	Perceptual: hypertensives performed more poorly on Visual Recognition Threshold female hypertensives performed more poorly on Perception of Spaced Stimuli than normotensives NS: Critical Flicker Frequency, Two Flash Fusion Threshold Psychomotor: hypertensives performed more poorly on Digit Symbol, Traverse Time, Coordination Time and Tapping Speed NS: Movement Reversal Time, Lift and Jump Reaction Times, Grip Strength Time Estimation: female hypertensives performed more poorly on time estimation NS: time judgement reproduction Memory: NS: Benton Visual Retention test Visual-Spatial: NS: Block Design	participants matched according to age, gender, education and race participants demonstrated no neurological signs and no visual or hearing problems 18 hypertensives were medicated anti-hypertensive medications discontinued at least 10 days prior to testing no control of inflation of Type I error

Note. DBP = diastolic blood pressure; NS = non significant.

Thyrum et al. (1995)	62 hypertensives with a positive parental history of hypertension (PH+), age=45, SD=8 28 hypertensives with a negative parental history of hypertension (PH-), age=45, SD=7 32 normotensives, age=45, SD=10 parental history of hypertension was not assessed in normotensives participants were from the Blumenthal et al., (1993) study Factors: hypertension status hypertensive 140 ≤ SBP≤ 180 mmHg or 90 ≤ DBP≤ 105 mmHg parental history of hypertension (PH+, PH-)	PH+ hypertensives performed more poorly than PH- hypertensives and normotensives with regards to rate of search of short-term memory (Sternberg RT slope), Trails B, Digit Span (Backwards) hypertensives performed more poorly than normotensives on Digit Symbol NS: Stroop, Sternberg RT Intercept Verbal Memory: Logical Memory-immediate and delayed recall. Paired Associate Learning from W MS (Russell Revision) Figural Memory: figural memory from WMS	participants had no history of cardiovascular disease hypertensives were not taking ant-hypertensive medication at time of testing parental history of hypertension determined by self-report groups equivalent with regards to age, education, and vocabulary score PH+ hypertensives reported more depressive symptoms and higher state anxiety than PH- hypertensives and normotensives PH- hypertensives reported higher Type A behaviour than PH+'s and normotensives Type A behavior, depression, state-anxiety, were included as covariates in multivariate analyses

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; WMS = Wechsler Memory Scale; NS = non significant.

van Swieten et al., (1991)	24 chronic hypertensives with normal white matter or focal lesions, age=66.2, SD=4.9 10 chronic hypertensives with confluent white matter lesions, age=67.8, SD=5.3 18 normotensives with normal white matter or focal lesions, age=65.5, SD=4.9 Factors: hypertension status hypertension: SBP > 160 mmHg and DBP > 95 mmHg presence of white matter lesions	hypertensives with confluent lesions performed more poorly than hypertensives with focal or no white matter lesions and normotensives on Mini-Mental State Exam (total score), Stroop, and Trail Making A and B hypertensives with confluent lesions performed more poorly on Visual Reproduction-delayed recall of WMS than normotensives no differences between hypertensives and normotensives with focal or no white matter lesions NS: Digit Span, Digit Symbol, auditory verbal learning test, Visual Reproduction- immediate recall	exclusion criteria: stroke, transient ischemic attack, alcoholism, drug abuse, neurological signs 10 hypertensives had a stenosis of the renal artery 5 hypertensives had diabetes; 6 hypertensives had angina and 6 hypertensives had previous myocardial infarction 1 normotensive had angina and 1 hypertensive had previous myocardial infarction all hypertensives were taking anti-hypertensive medication at time of testing

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; WMS = Wechsler Memory Scale; NS = non significant.

Waldstein et al., (1991)	20 untreated hypertensives, age=43.0, SD=10.6 20 normotensives, age=41.9, SD=10.9 participants unaware of blood pressure status at time of testing Factors: Hypertension status hypertension SBP≥ 140 mm Hg and DBP≥ 95 mm Hg normotensive SBP < 140 mm Hg and DBP≤ 85 mm Hg	hypertensives recalled fewer items on Symbol Digit Learning Test and performed more poorly on Visual Reproduction -Immediate and Delayed recall (test of visual memory) NS: rate of learning and delayed recall on Symbol Digit Learning Test	participants were unmedicated, free of cardiovascular disease, stroke, neurological disorders, diabetes, cancer, thyroid dysfunction, renal, hepatic, or metabolic disorders, psychiatric disorders, depression groups equivalent with regards to age, education, family income, alcohol consumption, trait anxiety

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure.

Waldstein et al. (1996)	59 young (≤ 40 years old) male hypertensives, age=35.1, SD=3.9 26 young male normotensives, age=35.1, SD=3.8 64 middle-aged (> 40 years old) male hypertensives, age=48.1, SD=4.8 24 middle-aged male normotensives, age=46.4, SD=4.5 Factors: hypertension status hypertension X age hypertensive: DBP ≥ 90 mmHg normotensive: SBP < 140 mmHg and DBP < 90 mmHg	young hypertensives performed more poorly than young normotensives on tests of Attention/Executive function: Stroop (interference score) and Maze Learning test and Information Processing: Letter Transformation Task No significant differences between middle-aged hypertensives and normotensives hypertensives performed more poorly than normotensives on test of Manual Dexterity: Grooved Pegboard test NS: Learning/Memory : Verbal Paired Associate test, Logical Memory, Digit Symbol (incidental recall) Attention/Perceptuo-Motor Speed: Digits Forward & Backward,Verbal Fluency, Digit Symbol, Trail Making A & B Grip Strength: Hand Dynamometer Motor Speed: Finger Tapping Recognition Memory: Recurring Words, Recurring Faces Attention/Executive Function: Corsi Blocks	exclusion criteria: cardiovascular and neurological disease, chronic renal failure psychotropic medication use medicated hypertensives discontinued medication for at least 2 weeks prior to testing groups equivalent with regards to age,education, depression and WAIS-R vocabulary scores trend for hypertensives to consume more alcohol than normotensives young hypertensives had higher trait anxiety than young normotesives multivariate analyses covaried for education, alcohol consumption, trait anxiety, and depression

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; NS = non significant.

Wilkie & Eisdorfer (1971)	participants aged 60-69 at initial assessment; 31 normotensives , 10 borderline hypertensives, 10 hypertensives participants aged 70-79 at initial assessment: 28 normotensives, 8 borderline hypertensives Factors: hypertension status hypertensive: DBP >105 mmHg borderline hypertensive: 96 < DBP > 105 mm Hg normotensive: 66 < DBP > 95 mm Hg	60-69 year olds: at 10 year follow up, WAIS Performance IQ decreased more in hypertensives than normotensives and borderline hypertensives no group differences in Verbal IQ change 70-79 year olds: at 10 year follow up, no differences between normotensives and borderline hypertensives no hypertensives were alive 10 year follow up	groups were equated for education, gender, race and SES; participants free of cerebrovascular disease all participants had evidence of end-organ damage did not control for anti-hypertensive medication use

Note. DBP = diastolic blood pressure; WAIS = Wechsler Adult Intelligence Scale.

Wilkie, Eisdorfer, & Nowlin (1976)	participants aged 60-69 years old at initial assessment (subsample from Wilkie & Eisdorfer, 1971) 9 hypertensives, 10 borderline hypertensives, 23 normotensives Factors: hypertension status hypertensive: DBP >105 mmHg borderline hypertensive: 96 < DBP > 105 mm Hg normotensive: 66 < DBP > 95 mm Hg	Verbal memory: initial testing and 6.5 year follow up: no group differences on Logical Memory, Paired Associates Non-verbal memory: initial testing: no differences on Visual Reproduction at 6.5 year follow up: hypertensives poorer on Visual Reproduction when compared to normotensives and borderline hypertensives	participants matched for age and SES participants had evidence of end-organ damage did not control for anti-hypertensive medication use used multivariate analyses

Note. DBP = diastolic blood pressure.

Table A2

Studies Examining Neuropsychological Performance in Normotensives with a Parental History of Hypertension

McCann et al. (1989)	40 undergraduate normotensive PH+ participants (20 white males and 20 white females), 39 undergraduate normotensive PH- participants, (20 white males and 19 white females) no ages reported Factors: parental history of hypertension	Sensory-perceptual: PH+ males performed more poorly on Perception of Spaced Stimuli than PH- males NS: Visual Recognition Threshold, Critical Flicker Frequency Visual-Spatial : NS: Block Design Time Judgement: Reproduction/Cross Modality: PH+ participants performed more poorly than PH- participants NS: Time Judgement : Method of Reproduction, Method of Operative Estimation, Uncued Estimation Psychomotor: NS: Lift and Jump Reaction Times, Tapping Speed, Transfer Coordination Speed, Traverse Time, Movement Reversal Time and Reaction Time, Digit Symbol	participants were reported to be healthy but no information on which illnesses were screened PH groups did not differ according to age, education, resting HR, SBP, and DBP

Note. HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure; NS = non significant.

Pierce & Elias (1993)	32 normotensive PH+ males 45 normotensive PH- males mean age for entire sample = 18.9, SD=1.2 all participants were introductory psychology undergraduates Factors: parental history of hypertension evaluation condition: evaluation (stressor) vs non evaluation (control) session: participants were tested in two sessions; (order of evaluation condition was counterbalanced across sessions)	PH+ participants performed more poorly than PH- participants on Sternberg speed of short-term memory search (Stember RT slope) only in the first session NS: Sternberg RT Intercept and recall, Mental Arithmetic, Paired Associates (difficult), Digit Symbol, Free Recall, Trails A and B, Letter Cancellation, Digit Span (Forwards and Backwards) PH+ participants exhibited higher heart rates during Sternberg task, Digit Symbol, Mental Arithmetic, Digit Span, Free Recall and Letter Cancellation, Paired Associates (according to univariate tests; multivariate test nonsignificant) No significant relationship between cardiovascular activity and test performance no significant PH X evaluation condition interactions for test performance	PH groups did not differ with regards to age or years of education none of the participants reported having diabetes, hypertension, or heart disease used multivariate analyses

Note. NS = non significant.

Waldstein et al. (1994)	35 normotensive PH+ males with two hypertensive parents (PH+/+), age= 20.4, SD=1.82 35 normotensive PH+ males with one hypertensive parent (PH+/-), age=20.3, SD=1.5 35 normotensive male PH-'s, age=20.5, SD=1.6 all participants were undergraduate students Factors: parental history of hypertension	Visual-Spatial/ Constructional: PH +/+ 's performed more poorly on Block Design and Visual Span than PH+/- and PH- participants NS: Maze learning, Rey-Osterreith Copy Visual Perceptual: PH +/+ 's performed more poorly on Critical Flicker Fusion test than PH+/-'s and PH-'s; PH+/-'s performed more poorly than PH-'s on Critical Flicker Fusion Abstract Reasoning: NS: Category Test, Similarities Attention/Mental Flexibility: NS: Digit Span (Forwards and Backwards), Continuous performance test, Trails B, Verbal Fluency Memory NS: Newspaper story (immediate and delayed recall), Verbal Paired Associates (immediate and delayed recall), Symbol Digit Learning (immediate and delayed recall) Rey-Osterrieth delayed recall Psychomotor Speed / Manual Dexterity: NS: Digit Symbol, Finger Tapping, Grooved Pegboard, simple reaction time, Trails A, Handgrip Information Processing: NS: Letter memory and transformation test	participants free of cardiovascular or pulmonary disease, psychiatric or neurological disorder and obesity no group differences in age, education or WAIS-R Information subscores, resting SBP and DBP, weekly alcohol intake, handedness, history of head injury trait anxiety and Beck Depression Inventory scores somewhat higher for PH+/+ and PH+/- than PH- participants (trend) used multivariate analyses main analyses covaried for trait anxiety, depression, DBP, weekly alcohol consumption, and eyeglass use

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; NS = non significant.

Appendix B

Health Questionnaire

Subject Health Questionnaire

Name:_____ Age: _____ Phone:_____

Major subject studied:_____
Minor subject studied:_____

Please answer all of the following questions carefully.

Have you had any medical or surgical problems during the last year? Yes _____ No _____
Please specify _____

Do you suffer from any chronic illnesses?
Yes _____ No _____
Please specify _____

Have you ever had heart trouble of any kind?
Yes _____ No _____
Please specify _____

Do you now, or have you ever had high blood pressure?
Yes _____ No _____
Please specify _____

Do you have diabetes? Yes _____ No _____
Have you ever had kidney trouble of any kind?
Yes _____ No _____
Please specify _____

Do you suffer from epilepsy? Yes _____ No _____
Have you ever had liver trouble of any kind?
Yes _____ No _____
Please specify _____

Do you have asthma? Yes _____ No _____

Do you now suffer from bronchitis or do you suffer from chronic bronchitis? Yes _____ No _____

Have you ever had a fainting spell? Yes _____ No _____
If yes, please explain_____

Are you presently, or have you ever been treated for psychological or psychiatric reasons? Yes _____ No _____
If yes, please explain briefly_____
_____

Please list any medication that you are presently taking and the reason for taking it _____
_____

Please give the date (or approximate date) of you last medical check-up _____

Signature: _____ Date: _____

NAME: _____
Last First Middle

Present address and telephone number

_____
Address

_____
City Province Area Code

DATE OF BIRTH: _____
Month Day Year

The following 4 questions refer to your biological parents.

Have either of your parents ever suffered

a. angina or heart pain _____ _____ _____ _____
Father Mother Neither Don't Know

b. a heart attack _____ _____ _____ _____
Father Mother Neither Don't Know

c. a stroke _____ _____ _____ _____
Father Mother Neither Don't Know

Do either of your parents have

a. high blood pressure _____ _____ _____ _____
Father Mother Neither Don't Know

b. some other significant circulatory problem? _____
(if yes, please describe _____)

c. diabetes? _____ _____ _____ _____
Father Mother Neither Don't Know

d. kidney disease? _____ _____ _____ _____
Father Mother Neither Don't Know

Do either of your parents take medicine for high blood pressure?

_____ _____ _____ _____
Father Mother Neither Don't Know

We would like to contact your parents to verify the family health history that you just described. If you do not object to this, please print their names and addresses below.

Mother:

Name (Area Code) Phone

Address

City Province/State Postal Code

Father:

Name (Area Code) Phone

Address

City Province/State Postal Code