

**THE MEDIATING AND MODERATING RELATIONSHIPS
BETWEEN AGE, BLOOD PRESSURE, AND EVERYDAY
PROBLEM SOLVING IN OLDER ADULTS**

by

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ABSTRACT

Blood pressure is an important indicator of vascular health that is associated with cognitive performance. However, few studies have explored its effects on everyday cognitive tasks, which may better predict real-world functioning than traditional measures. We examined blood pressure as a continuous variable to more comprehensively analyze hypotensive and prehypertensive effects on traditional and everyday cognitive abilities, specifically everyday problem solving (EPS). In non-demented community-dwelling women ($N = 74$; age: 51-91), lower systolic blood pressure and lower pulse pressure predicted worse EPS performance after accounting for age, education, and anti-hypertensive medication use. Lower diastolic blood pressure predicted worse performance on executive functioning and perceptual speed. No moderating or mediating relationships between age and blood pressure were observed. Findings extend previous models by demonstrating that continuous blood pressure predicts both traditional and everyday cognition. Furthermore, lower blood pressure is not necessarily optimal for cognitive performance in middle-aged and older adults.

Keywords: blood pressure; cognitive aging; everyday problem solving; hypertension

DEDICATION

To my siblings, extended family and friends for their encouragement and unconditional support.

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INTRODUCTION

Blood pressure is an important marker of vascular health that is related to changes in cognition and quality of life (Roca-Cusachs, Dalfó, Badia, Arístegui, & Montserrat, 2001). Uncontrolled blood pressure is often associated with cardiovascular and cerebrovascular deterioration, which may manifest as decreased cognitive performance and everyday functional ability. While a relationship between blood pressure and cognition is generally established, the specific effects of blood pressure on cognitive abilities are not entirely clear and have been inconsistent across middle- to older age (Birns & Kalra, 2009). For example, extant research has indicated that mid-life high blood pressure, or hypertension, is a risk factor for earlier or accelerated decline in cognitive ability (Birns, Morris, Donaldson, & Kalra, 2006; Elias, Elias, Robbins & Budge, 2004) and onset of dementia (Grodstein, 2007; Kivipelto et al., 2001; Skoog et al., 1996; Tzourio, Dufouil, Ducimetière, & Alperovitch, 1999). However, various studies have failed to find this relationship (see Birkenhäger, Forette, Seux, Wang, & Staessen, 2001 for a review). Alternative evidence also supports the notion that low blood pressure is associated with cognitive impairment in older age (Nilsson et al., 2007; Qui, von Strauss, Fastbom, Winblad, & Fratiglioni, 2003), while mild blood pressure elevations may be cognitively advantageous in older adults (Paran, Anson, & Reuveni, 2003).

The current study investigates the effects of continuous blood pressure on cognitive performance among community-dwelling non-demented older women. In addition to assessing traditional cognitive domains typically examined in previous literature, we examined the relationship between blood pressure and the ability to solve everyday problems. Some authors suggest that tasks of everyday problem solving (EPS), which represent a form of everyday cognition, may better predict real-world functioning compared to traditional cognitive measures such as episodic memory and semantic knowledge (Allaire & Marsiske, 2002; Allaire & Willis, 2006). Previous studies indicate a relationship between self-reported hypertension (i.e., a dichotomous category of hypertensive versus non-hypertensive, where hypertensive is defined as a self-reported physician's diagnosis of hypertension and taking anti-hypertensive medications; Campbell, Joffres, & McKay, 2005) and EPS in older adults (Thornton, Deria, Gelb, Shapiro, & Hill, 2007). A closer examination of the relationships between EPS and blood pressure measured as a continuous variable was conducted to clarify how small differences in arterial pressure are associated with cognitive differences among a spectrum of hypertensive and non-hypertensive individuals, while accounting for the use of anti-hypertensive medications. By observing a wide age range of middle-aged and older adults (51-91 years old), potential moderating and mediating influences of blood pressure on the relationship between age and EPS were also explored.

Mixed Findings: Blood Pressure and Cognition

Existing research on blood pressure and cognition has predominantly focused on the association between diagnosed hypertension and general cognitive function. Defined as having a systolic (SBP) and diastolic blood pressure (DBP) of ≥ 140 mmHg and ≥ 90 mmHg respectively, hypertension is prevalent in over 50% of individuals between the ages of 60 and 69 (National Institute of Health [NIH], 2004). Importantly, chronic hypertension is associated with declines in traditional cognitive abilities, particularly executive functioning, memory, and attention (Moss & Jonak, 2007), and accelerated dementia onset (Grodstein, 2007; Launer et al., 2000). For example, in a longitudinal study involving a group of middle-aged Japanese males, hypertension was linked to an increased risk of dementia 25 years later (Launer et al., 2000). Additionally, an association has been established between mid-life hypertension and the development of Alzheimer's disease pathology including neuritic plaques and neurofibrillary tangles in the hippocampus and neocortex (Li et al., 2007; Petrovitch et al., 2000; Qui, von Strauss et al., 2003). Such studies indicate that hypertension, or at least mid-life hypertension, could be detrimental to cognitive function and cerebrovascular integrity.

Conversely, various other studies have observed the opposite relationship in more senior adults, where lower blood pressure was linked to decreased cognitive performance (Nilsson et al., 2007; Qui, von Strauss et al., 2003). In a community-based sample of older adults aged 75 and over, lower blood pressure predicted cognitive decline, independent of other vascular illnesses (Zhu,

Viitanen, Quo, Winblad, & Fratiglioni, 1998). As well, four cross-sectional studies observed associations between low blood pressure and decreases in cognitive performance on tests of global cognition (see Qui, Winblad, & Fratiglioni, 2005 for a review); however, these studies were limited to less sensitive cognitive screening measures and did not examine more selective neuropsychological domains.

Dementia is another example of the demonstrable effects that low blood pressure may have on cognitive performance. Low blood pressure is associated with an increased risk of dementia (Qui, von Strauss, et al., 2003; Verghese, Lipton, Hall, Kuslansky, & Katz, 2003) and is common in individuals with Alzheimer's disease (Davis, Massman, & Doody, 2003). Very low blood pressure may reflect limited cerebral blood flow (i.e., cerebral hypoperfusion), which could lead to neuronal death and accelerate cognitive decline (Qui et al., 2005). Consistently, in one study, individuals with lower blood pressure performed worse on various cognitive tests compared to mildly hypertensive participants (Paran et al., 2003). Maintaining a certain level of blood pressure may be necessary to ensure sufficient cerebral perfusion and optimal cognitive performance in older age.

In light of these mixed findings, we investigated whether increased or decreased blood pressure was associated with cognitive performance in a group of non-demented women with low blood pressure to mild hypertension. Further, we examined whether blood pressure affected cognitive performance differently

across various traditional and everyday cognitive domains including executive functioning, perceptual speed, episodic memory, and EPS.

Hypertensive Status and Women

To determine whether there is an optimal blood pressure range that promotes or maintains cognitive ability, blood pressure is ideally assessed continuously. Measuring blood pressure at the time of assessment differs from focusing only on a diagnosis of hypertension by allowing for a more detailed, continuous measurement of vascular impact on cognitive performance. While some research suggests that high blood pressure produces detrimental effects on everyday cognition, such literature is based heavily on examining blood pressure as a dichotomous variable (hypertensive vs. normotensive; Thornton, Deria et al., 2007; Whitfield, Allaire, & Wiggins, 2004). The question remains regarding the generalizability of these findings to individuals with very low blood pressure (i.e., hypotension) or those with prehypertension. According to the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (NIH, 2004), blood pressure classifications have been revised into four groups (i.e., normal, prehypertension, hypertension stage 1 and 2). Physicians now acknowledge increased health risks to prehypertensive or borderline hypertensive individuals with a blood pressure of 120-139mmHg systolic and 80-89mmHg diastolic. A dichotomous examination of hypertension would categorize individuals identified as having “optimal” or “normal” blood pressure with prehypertensive individuals, masking subtle relationships between blood pressure and cognitive performance (Paran et al., 2003). Studies that

examine hypertensive effects based solely on a self-reported diagnosis also do not consider individuals who are unaware of their hypertensive condition, which typically includes 31% of the general population (Hyman & Pavlik, 2001).

Analyses based on this type of hypertensive classification may dilute potential cognitive differences between those with high and low blood pressure.

Furthermore, a number of studies use different or outdated cut-offs for hypertension to classify their groups (i.e., >160mmHg or 180mmHg for systolic cut-offs; Li et al., 2007; Kivipelto et al., 2001; Ruitenberg et al., 2001). High cut-offs limit analyses to more serious cases of hypertension and disregard potential differences between individuals with hypotension, prehypertension or mild hypertension who make up a large percentage of community-dwelling older adults. Such analyses may also vary the degree to which elevated blood pressure affects cognition.

To supplement the current literature, we examined blood pressure at the time of assessment as a predictor of everyday problem solving (EPS) and traditional cognitive ability in a sample of women. We also considered the effects of a dichotomous hypertensive diagnosis and use of anti-hypertensive medication to minimize confounds attributed to treatment and whether participants were aware of their hypertensive condition (see Appendix A for further details). Importantly, community-dwelling women were assessed in the study to ensure that a range of blood pressure in the lower and prehypertensive spectrum was available. Research on strictly women and blood pressure is relatively understudied in the cognitive literature. Yet, epidemiological studies

reveal a higher prevalence of hypertension and lower blood pressure control in elderly women compared to men (Lloyd-Jones, Evans, & Levy, 2005; Wassertheil-Smoller et al., 2000). A female cohort including middle-aged and older adults may reveal unique relationships between blood pressure and cognitive function. Such an examination is valuable considering that the majority of current studies, which demonstrate an association between mid-life hypertension and cognitive performance, are based on men (see Qui et al., 2005 for review). See Appendix B for a more detailed discussion on hypertension in women.

Discrepancies between Blood Pressure Predictors

Beyond different findings that may be observed when examining blood pressure continuously versus dichotomously, discrepant relationships between blood pressure and cognition may be attributed to which measure of blood pressure is being assessed. Over the natural course of aging, SBP tends to escalate, while DBP tends to decline (Hense, Maziak, & Heidrich, 2002; Sander, 2004). SBP and DBP may be associated with performance on different cognitive domains to varying degrees and may even display reverse associations (Davis, et al., 2003; Waldstein et al., 2008). Although clinical research supports SBP as being more important than DBP in determining risk of stroke and heart failure in the elderly (Aiyagari & Gorelick, 2009), it is not yet established how SBP or DBP differ in predicting cognitive function. Some studies have found that high SBP is associated with an increased risk of cognitive decline (Li et al., 2007; Qui, von Strauss et al., 2003), while others observe associations between only high DBP

and dementia risk (Launer et al., 2000; Posner et al., 2002). Additionally, in very old adults aged 80 and over, one study found that only low SBP was associated with cognitive decline on follow-up (Nilsson et al., 2007). Unlike studies of hypertensive status, a continuous measurement of blood pressure provides a means to tease out the differences between SBP and DBP effects on cognitive performance, as well as any interacting effects these variables may have with age.

Pulse pressure (PP) is another blood pressure variable that increases with age and can be indicative of vascular health (Davis et al., 2003). PP is calculated as the difference between SBP and DBP, and is considered a surrogate marker of arterial stiffness and reduced vascular compliance (Qui, Winblad, Viitanen, & Fratiglioni, 2003). Some authors speculate that PP may better predict cognitive outcomes than SBP or DBP alone (Davis et al., 2003). Previous research indicates that PP uniquely contributes to the association between blood pressure and cognition after controlling for SBP and DBP, but the direction of this association is unclear. Higher PP has been linked to lower cognitive function in non-demented older adults (Robbins, Elias, Elias, & Budge, 2005; Waldstein et al., 2008) as well as an increased prevalence of white matter lesions (Liao et al., 1997). Conversely, non-demented adults aged 75 and older with lower PP (<70mmHg) and higher PP (>85mmHg) had a greater risk of developing dementia compared to those with a PP in the median range (70-84mmHg; Qui, Winblad, et al., 2003). In patients with Alzheimer's disease, increased PP was also associated with better performance on tasks of attention and concentration

(Davis et al., 2003). These findings further support the hypothesis of an optimal blood pressure range required to maintain cerebrovascular health. We attempted to elucidate these relationships by examining SBP, DBP, and PP at the time of assessment as separate predictors of cognitive performance.

Age and Blood Pressure

Blood Pressure as a Moderator. Age differences in previously examined samples may partially account for discrepant associations between blood pressure and cognitive performance. Past studies indicate that vascular diseases including hypertension may moderate the relationship between age and cognition (Madden & Blumenthal, 1998; Raz, Rodrigue, Kennedy, & Acker, 2007; Wahlin, MacDonald, deFrias, Nilsson, & Dixon, 2006). As a moderator, blood pressure may interact with the independent variable (e.g., age), and affect the direction and/or strength of the relationship between age and the dependent variable (e.g., cognitive performance; Baron & Kenny, 1986). It is possible that blood pressure levels affect cognitive ability differently across age. The likelihood of having moderating influences of blood pressure is heightened in older adults where intraindividual variability is high, and patterns of cognitive aging are not necessarily uniform across a large age range (Hultsch, Hertzog, Dixon, & Small, 1998; Zelinski, Crimmins, Reynolds, & Seeman, 1998). Therefore, a certain range of blood pressure that optimizes cognitive function may not be uniform across middle-aged and older adults. In the Honolulu Asia Aging Study, an SBP > 160mmHg between ages 50-55 increased the risk of cognitive decline at follow-up, while SBP < 110mmHg predicted poorer cognitive function at age 70-80

(Launer et al., 2000). Two recent studies found that increasing SBP was related to decreased performance on traditional cognitive measures even in participants whose blood pressure was classified as “normotensive” (Knecht et al., 2008). However, these findings were restricted to adults under age 65 (Knecht, Wersching, Lohmann, Berger, & Ringelstein, in press). Given that lower blood pressure has been associated with both increased and decreased cognitive performance in the elderly, it is possible that risks for cognitive decline change continuously, depending on the range of age and blood pressure that is examined. While midlife hypertension may be linked to cognitive decline, low blood pressure in old age may actually impair cognitive performance (Anson & Paran, 2005).

Two potential factors responsible for this change in the relationship between blood pressure and cognition during aging have been posited. As previously stated, the first suggests that low blood pressure in very old age may lead to hypoperfusion, causing cognitive impairment (Glynn et al., 1999). It is also possible that blood pressure reduction in late life is a consequence of dementia (Ruitenberg et al., 2001). While sustained hypertension is deleterious to cardiovascular and cerebrovascular health (NIH, 2004), it remains to be proven whether a certain blood pressure threshold must be reached for optimal cognitive performance (Anson & Paran, 2005), and whether this range changes with age.

Diverse relationships between blood pressure and cognition across different age groups (i.e., an interaction between blood pressure and age) may

exist, but are often unexamined (Wahlin et al., 2006). Of the few studies that have examined such relationships (Alves de Moraes, Szklo, Knopman, & Sato, 2002; Brady, Spiro III, & Gaziano, 2005; Elias et al., 2004), none have addressed the effects of continuous blood pressure and age on everyday cognition. One study observed an interaction between age and hypertensive status among 70-103 year olds, where blood pressure-related cognitive deficits on a mental status exam were only found in young older adults (Zelinski et al., 1998). However, this study used less sensitive global cognitive measures and was limited to analysing hypertensive status as a dichotomous variable. Brady and colleagues (2005) found that the relationship between hypertensive status and performance on tasks of verbal fluency and episodic memory were inconsistent across ages in a group of 52-85 year old men. In the current study, we addressed similar questions by using tasks of traditional and everyday cognition in women 50 years and older.

Blood Pressure as a Mediator. Several authors also suggest that health factors such as chronic illness are important mediators of cognitive function and should be explored (Wahlin et al., 2006; Whitfield & Wiggins, 2003). It is possible that blood pressure may act as a mediator (i.e., a mechanism that accounts for some variance in the dependent variable originally attributed to the independent variable; Baron & Kenny, 1986) and a moderator between age and cognitive performance depending upon the age range and cognitive tasks examined. If no moderating effects are found (i.e., the direction of the relationship between blood pressure and cognitive performance is consistent across age), blood pressure

may play a mediating role by accounting for variance in cognitive performance originally attributed to age. As such, the effects of age on cognitive performance may be reduced when blood pressure is taken into account. For example, Wahlin and colleagues (2006) found that health variables, including a composite of vascular diseases, acted as significant mediators of age differences in cognitive performance. However, they did not examine the contribution of continuous blood pressure or a hypertensive diagnosis as a mediator. Another study found that blood pressure accounted for a significant amount of age-related variance in cognitive performance, but these findings were limited to a visual selective attention task (Madden & Blumenthal, 1998). We attempted to extend this literature by focusing on continuous blood pressure as a mediator of age and cognition using both traditional and everyday cognitive measures.

Everyday Problem Solving

EPS. A large focus of the current study is the examination of everyday cognition through a task of everyday problem solving (EPS). EPS provides a means of assessing functioning in the real world (Thornton, Deria et al., 2007; Thornton & Dumke, 2005) and may be an important indicator of cognitive impairment. EPS involves the ability to derive multiple solutions to everyday problems. One's performance on a task of EPS may hold substantial implications with regards to maintenance of quality of life (Thornton & Dumke, 2005) and the mental capacity to deal with issues that arise naturally in old age such as being diagnosed with a chronic illness (e.g., hypertension). Performance on cognitive lab-based tests may not be as reflective of real world functioning, and may

underestimate how individuals would perform in their normal environments (Allaire & Marsiske, 1999; Schaie, 1978). EPS measures may possess stronger ecological validity since people can draw on experience and contextual information to enhance cognitive capacity. Furthermore, one study found that EPS had higher predictive validity of future functioning compared to traditional cognitive tests (Allaire & Willis 2006). By measuring the ability to produce sensible responses to real-life scenarios, performance on this task may reflect one's ability to solve problems and live functionally in their everyday environments (Burton, Strauss, Hultsch, & Hunter, 2006).

Similar to previously used tests in the EPS literature (see Thornton & Dumke, 2005 for review), we employed a measure that relies on fluency of responses, while taking into account the safety and effectiveness of each solution to a given problem. The quality and effectiveness of a solution was taken into account to eliminate any incomplete answer from being considered reasonable. Such scoring methods allowed us to connect our findings to previous literature that similarly apply a fluency-based scoring protocol that is more objective and easier to replicate (Allaire & Marsiske, 2002). See Appendix C for a more detailed discussion of EPS.

EPS and Blood Pressure. Health and aging factors heavily influence everyday functional competence both physically and cognitively. It is, therefore, essential to assess the impact of health variables such as blood pressure on EPS, particularly considering the high prevalence of hypertension in old age. Previous studies indicate that diagnosed hypertension predicts worse EPS

performance (Thornton, Deria et al., 2007). However, no studies to date have examined continuous blood pressure in relation to EPS ability. Assessing specific measures of health including anti-hypertensive medication use and blood pressure at the time of assessment may elucidate whether health status is related to EPS. This research may have considerable implications for community-dwelling adults with or at risk for developing hypertension. It is possible that these individuals may perform poorly on traditional laboratory tasks, but may function adequately in their everyday environments, or vice versa.

EPS Ability vs. Traditional Cognitive Abilities. We examined whether unique relationships between blood pressure and EPS ability existed, while considering broader relationships using traditional cognitive measures (i.e., executive functioning, perceptual speed, episodic memory). Generally, the literature examining traditional cognitive abilities indicates that low blood pressure may affect cognitive domains such as episode memory, which implicates certain subcortical brain areas that are more susceptible to ischemia such as the hippocampus (Davis et al., 2003). Considerably high blood pressure can also increase blood flow resistance and decrease cerebral perfusion, which affects similar regions including subcortical matter of the frontal lobe (Birns & Kalra, 2009). Poorly regulated blood pressure may be more greatly associated with performance on tests sensitive to subcortical functioning such as attention, executive functioning, episodic memory, and perceptual processing (Birns & Kalra, 2009). Executive functioning and episodic memory appear to be most sensitive to decline in hypertensive individuals (Moss & Jonak, 2007; Saxby,

Harrington, McKeith, Wesnes, & Ford, 2003; Waldstein, 1995). Since uncontrolled blood pressure is related to traditional cognitive measures, we hypothesized that these relationships may generalize to tasks of everyday cognition, particularly since EPS shares related variance with executive functioning and memory (Thornton, Deria et al., 2007).

Objectives and Hypotheses

The main objective of the current study was to examine the relationships between blood pressure, everyday problem solving (EPS), and traditional cognitive ability in a group of community-dwelling middle-aged and older women. In addition to accounting for a hypertensive diagnosis, which requires the use of anti-hypertensive medications, measurements of systolic blood pressure (SBP), diastolic blood pressure (DBP), and pulse pressure (PP) were taken at the time of assessment to see whether blood pressure emerged as a significant predictor of cognitive performance. The first two research questions address the strength and direction of the relationship between blood pressure and cognitive abilities: (1) Does blood pressure at the time of assessment account for a significant proportion of variance in EPS ability above and beyond the effects of age, use of anti-hypertensive medication, and related demographic variables?; and (2) Does blood pressure at the time of assessment account for a proportion of variance in traditional cognitive ability above and beyond demographic variables? Traditional cognitive ability was defined by tasks that were highly correlated with blood pressure in our sample (e.g., executive functioning, perceptual speed, episodic memory). We were particularly interested in determining whether a positive or

negative relationship existed between blood pressure and cognitive performance. The last two questions referred to potential mediating and moderating effects of blood pressure: (3) Does an interaction between age and blood pressure account for a unique proportion of variance in cognitive ability beyond the effects of age and blood pressure alone (i.e., does blood pressure moderate the relationship between age and cognitive performance)?; and (4) If blood pressure and age do not interact in adults aged 50 and over, does blood pressure mediate the relationship between age and cognitive performance?

Regarding the first and second research questions, we predicted that elevated SBP, DBP, and PP at the time of assessment would be associated with poorer EPS and traditional cognitive ability beyond the effects of age and other demographic covariates. We predicted that SBP, DBP, and PP as continuous variables would uniquely account for variance in cognitive ability even after accounting for anti-hypertensive medication use. Regarding the third question, we hypothesized that an interaction between age and blood pressure may account for a proportion of variance in cognitive ability beyond the effects of anti-hypertensive medications use, age or blood pressure alone. Specifically, while elevated blood pressure may predict worse EPS ability in younger seniors, this relationship may change with age, where lower blood pressure predicts worse EPS ability in older seniors (Brady et al., 2005; Elias et al., 2004). In the absence of an age X blood pressure interaction, we considered the possibility that blood pressure at the time of assessment would mediate the relationship between age

and cognitive performance. Elevated SBP, DBP, and PP were expected to account for a proportion of age-related variance in cognitive abilities.

METHODS

Participants

Women aged 50 and above within metro Vancouver ($N = 78$) were sought through advertisements posted at recreational facilities, commercial centres, churches, grocery stores, free online volunteer postings, and an online recruitment web survey. Participants were also recruited through aging seminars hosted by Dr. Wendy Thornton at senior activity centres. To participate in the study, the following inclusion criteria were met: (a) self-reported adequate hearing and vision (corrected or uncorrected) to ensure that sensory problems did not impede neuropsychological performance, (b) English fluency as screened by an acculturation measure, and (c) a minimum grade 6 education to certify that reading level was adequate for questionnaire completion. Exclusionary criteria included a self-reported diagnosis of dementia by a physician, diagnosis of a major psychotic illness (e.g., schizophrenia, bipolar disorder), concurrent terminal illness known to affect the CNS, neurological illness (e.g., Parkinson's disease, Huntington's disease, Multiple Sclerosis, epilepsy), history of stroke, significant head injury (defined by a loss of consciousness > 5 minutes), unresolved organ failure, or alcohol consumption of more than 3 units/day (1 unit = 1 ounce), as these variables may hinder cognitive performance and mask effects attributed to blood pressure. No participants received a score less than 24 on the Mini Mental Status Examination (MMSE; Folstein, Folstein, & McHugh, 1975), which is a

common cut-off used for screening dementia (Brady et al., 2005; Oosterman, de Vries, & Scherder, 2007; Paran et al., 2003). To ensure adequate vision for the completion of certain tasks, participants were screened for visual acuity, with a set lower limit of 20/50 in both eyes (corrected or uncorrected). Data from three participants were excluded due to visual impairments (limit above 20/50). One participant was excluded after indicating that she was diagnosed with a concurrent terminal illness, leaving the final sample at $N = 74$.

Measures and Procedure

Participants underwent a battery of physiological and neuropsychological tests to assess blood pressure, traditional cognitive and EPS functioning. All testing was conducted individually and lasted approximately 2 hours. A package of questionnaires including a demographic and health questionnaire and consent form was mailed out prior to each participant's assessment date to be completed and brought to their appointment. Participants were asked to bring in a list of current medications or when possible, the pill bottles of the medication they were presently taking to confirm self-reported medical diagnoses. Participants were compensated \$15 for time and travel expenses. Testing occurred at various senior community centres or at the Simon Fraser University Cognitive Aging lab. Screening of inclusion and exclusion criteria was performed over the phone prior to any set appointment. The following questionnaires and cognitive measures were administered and scored by trained research assistants following manualized procedures. All study protocol was approved by the SFU research ethics board.

Demographics and Health. A health questionnaire addressing current demographics, possible diagnosed medical illnesses and severity, and methods for controlling illnesses was given. Information on hypertensive diagnosis, history, and anti-hypertensive medication use was obtained.

Depressive Symptoms. To address potential associations between depressive symptoms and cognition discussed in previous aging research (Lichtenberg, Ross, Millis, & Manning, 1995; Yaffe et al., 1999), the Centre for Epidemiological Studies Depression Scale (CES-D; Radloff, 1977) was given to assess self-rated depressive symptoms. The CES-D has very satisfactory sensitivity and specificity for identifying depressive symptomatology in older adults (Beekman et al., 1997; Irwin, Artin, & Oxman, 1999) with high internal consistency of responses ($\alpha = 0.85$; Radloff, 1977). The scale consisted of 20 items inquiring about symptoms of sad mood, sleep and appetite disturbances, and feelings of hopelessness over the past two weeks. Respondents rated the severity of each symptom on a 4-point Likert scale (0 = rarely or none of the time, 3 = most or all of the time). Total scores were tabulated out of 60, with higher scores indicating higher severity of depressive symptoms. In our sample, internal consistency of responses on the CES-D was good ($\alpha = 0.86$) and comparable to Radloff's (1977) initial reported Cronbach's alpha.

Blood Pressure. Four separate blood pressure readings were taken on the right arm unless contraindicated. Blood pressure was measured using a standard upper arm blood pressure monitor (Model A&D UA-774 medium and large cuffs) validated by the British Hypertension Society (DABL Educational

Trust Ltd, 2008). Participants were asked to sit quietly with their feet flat on the floor. One reading was initially taken to familiarize the participant with the procedure. After a 5-minute rest period, three readings were taken with one-minute intervals between each reading. Three readings given in this manner should be sufficient according to general standards of blood pressure assessment in research (Campbell et al., 2005). Administrators were instructed to turn away from the machine as the reading was being taken to minimize observer-subject interactions. The average of the last three readings was used as the outcome measure for systolic and diastolic measurements, respectively. Pulse pressure (PP) was calculated by subtracting the average DBP from the average SBP.

Global Mental Status. For descriptive purposes, the MMSE (Folstein et al., 1975) was used to assess global mental status. The MMSE tested five cognitive domains including orientation, registration, attention and calculation, recall, and language. Scores ranged between 0 and 30, where scores below 24 reflected impaired cognitive function consistent with dementia. The MMSE has demonstrated reliability and validity of responses in geriatric and medical populations (Kurlowicz & Wallace, 1999), with adequate internal consistency of responses in community based populations ($\alpha = 0.77$; Holzer, Tischler, Leaf, & Myers, 1984).

Executive Functioning. The Trail Making subtest taken from the Delis-Kaplan Executive Functioning System (D-KEFS; Delis, Kaplan, & Kramer, 2001) was used to measure the mental set shifting and flexibility aspect of executive

functioning. Trail Making test B (letter-number sequencing) consists of numbers and letters randomly scattered on two attached pages. Participants were instructed to connect letters and numbers in their consecutive order, alternating from letter to number (e.g., A-1-B-2-C-3). The latency to complete the task in seconds was used as an outcome measure. The Colour-Word Interference subtest was used to measure response inhibition. Participants were instructed to name the colour of printed words, while suppressing their automatic verbal response of reading the non-corresponding colour word. The latency to perform this task in seconds was used as the outcome. The Trail Making Test has demonstrated ecological (Mitchell & Miller, 2008) and construct validity of responses in community-dwelling older adults (Sanchez-Cubillo et al., 2009). The Colour-Word Interference subtest has adequate internal consistency ($\alpha = 0.75$; Delis et al., 2001) and validity of responses in detecting executive dysfunction in both experimental and clinical populations (Homack, Lee, & Riccio, 2005).

Perceptual Speed. The Wechsler Adult Intelligence Scale-III Digit Symbol Coding task (DSC; Wechsler, 1991) was used to measure perceptual speed. The DSC has been used frequently in cognitive aging research of chronic illness (Elias et al., 2004; Fontbonne, Berr, Ducimetiere, & Alperovitch, 2001; Hassing et al., 2004), and has very high internal consistency ($\alpha >.90$; Wechsler, 1991) and demonstrated validity of responses as a measure of speed across the lifespan (Joy, Kaplan, & Fein, 2004). Participants were provided with a coding key of nine numbers, each paired to a distinct symbol. Participants were given 120 seconds

to fill empty rows of numbered boxes with the corresponding symbols. The score was the total number of correctly matched items.

Episodic and Verbal Memory. The California Verbal Learning Test-2 (CVLT-II; Delis, Kramer, Kaplan & Ober, 2000) was used as a measure of episodic and verbal memory. The CVLT-II consisted of an immediate free recall of a list of 16 words over five trials. The sum of words recalled across Trials 1-5 was used as the outcome measure of memory for items learned over repeated trials. The CVLT has very high internal consistency ($\alpha = .94$; Delis et al., 2000) and demonstrated validity of responses in older adults across age and sex (Paolo, Tröster, & Ryan, 1997).

Everyday Problem Solving (EPS). The EPS test consisted of eight paper and pencil vignettes of an interpersonal nature that were derived from previous literature (Artistico, Cervone, & Pezzuti, 2003; Denney & Palmer, 1981; Denney & Pearce, 1989). Similar tasks have been used in EPS studies with older adults (Allaire & Marsiske, 2002; Allaire & Willis, 2006; Thornton, Deria et al., 2007; Thornton, Paterson, Yeung, & Kubik, submitted). Two versions of the problem sets were created and assigned randomly to participants, where Version 2 presented the latter half of the problem set first. Participants were given one problem per page (e.g., a person who lives alone wants to see her/his children and grandchildren more frequently. What should she/he do?). They were then asked to write down as many solutions as that they could think of even if the solution was not something they would implement themselves. Responses were not timed. The EPS protocol and scoring criteria were derived from extant

literature (Allaire & Marsiske, 2002; Denney & Pearce, 1989; Marsiske & Willis, 1995), and adapted to acknowledge both quantity and quality of the individual's solutions (Marsiske & Willis, 1995). Each solution was judged by its ability to: 1) deal with the direct problem, 2) maintain safety of all individuals, and 3) be effective in resolving consequences of the problem (Thornton, Deria et al., 2007). Inter-rater reliability based on psychology undergraduate and older participants was determined to be very high ($r = 0.85$). Internal consistency of responses in our sample as measured by Cronbach's alpha was also satisfactory ($\alpha = 0.85$). To eliminate ceiling effects, the absolute number of safe and effective solutions was used as the outcome measure (Denney & Pearce, 1989).

STATISTICAL ANALYSES

Initial Analyses

For descriptive purposes, select demographic, health, and cognitive characteristics known to influence either cognitive function or blood pressure (Burton et al., 2006; Lichtenberg et al., 1995; Paran et al., 2003; Ruitenberg et al., 2001; Tzourio et al., 1999; Whitfield et al., 2004; Yaffe et al., 1999) were examined for the entire sample, and are provided in Table 1. Participants were then divided into preliminary groups to determine differences between these variables based on a hypertensive diagnosis (see Table 2). Following previously used research guidelines (Campbell et al., 2005), the hypertensive group ($n = 23$) included individuals with a self-reported physician's diagnosis of hypertension who were taking anti-hypertensive medication. Non-hypertensive individuals included those who were not taking anti-hypertensive medication ($n = 51$). Group differences were analyzed by examining effect sizes using *phi* coefficients (ϕ) from Chi-Squared analyses for categorical variables (small = .10; medium = .30; large = .50; Gravetter & Wallnau, 2008), and Cohen's *d* for continuous variables (small = .20-.30; medium = .50; large = .80; Cohen, 1988). Categorical variables considered included ethnicity (Caucasian/Non-Caucasian) and cardiovascular risks including history of type 2 diabetes, high cholesterol, cardiovascular disease, previous heart attack, and smoking status (yes/no for each risk factor). Continuous variables examined included age, years of education, self-rated

depressive symptoms as measured by the CES-D (Radloff, 1977), and global cognition using the MMSE (Folstein et al., 1975).

Table 1. Demographic, Health and Cognitive Characteristics of All Participants.

Characteristics	Participants (<i>N</i> = 74)
Age	66.20 (8.44)
Range	51-91
Ethnicity (% Caucasian)	91.9
Education	14.66 (2.66)
CES-D	7.18 (7.20)
MMSE	28.66 (1.37)
SBP (mmHg)	120.36 (17.17)
Range	96-174
DBP (mmHg)	75.10 (11.02)
Range	52-107
PP (mmHg)	45.18 (12.47)
Range	24-80
Cardiovascular risks (% diagnosed)	
Type 2 Diabetes	12.2
High cholesterol	37.8
Cardiovascular disease	9.5
Previous heart attack	0
Smoking status (current %)	6.8

Note. Means and standard deviations are presented as *M (SD)*. Age and education are presented in years. CES-D = Centre for Epidemiological Studies-Depression Scale; MMSE = Mini Mental Status Examination; SBP = systolic blood pressure; DBP = diastolic blood pressure; PP = pulse pressure.

Table 2. Demographic, Health and Cognitive Characteristics of Hypertensive and Non-Hypertensive Participants.

Characteristics	Participant		Cohen's <i>d</i>	Phi coefficient ϕ
	Hypertensive <i>n</i> = 23	Non-Hypertensive <i>n</i> = 51		
Age	69.17 (8.67)	64.86 (8.06)	.53	
Range	56-88	51-91		
Ethnicity (% Caucasian)	82.6	96.1		.23
Education	13.83 (2.42)	15.04 (2.70)	.47	
CES-D	8.09 (8.06)	6.76 (6.82)	.19	
MMSE	28.48 (1.50)	28.75 (1.31)	.20	
SBP (mmHg)	125.59 (17.10)	118.01 (16.85)	.45	
Range	103-162	96-174		
DBP (mmHg)	75.43 (9.85)	74.82 (11.60)	.06	
Range	61-97	52-107		
PP (mmHg)	49.83 (13.12)	43.08 (11.70)	.56	
Range	33-80	24-79		
Cardiovascular risks (% diagnosed)				
Type 2 Diabetes	26.1	5.9		.29
High cholesterol	60.9	28.0		.31
Cardiovascular disease	18.2	6.0		.19
Previous heart attack	0	0	-	-
Smoking status (current %)	0	9.8		.18

Note. Means and standard deviations are presented as *M* (*SD*). Age and education are presented in years. CES-D = Centre for Epidemiological Studies-Depression Scale; MMSE = Mini Mental Status Examination; SBP = systolic blood pressure; DBP = diastolic blood pressure; PP = pulse pressure. Hypertensive group includes individuals with a self-reported diagnosis of hypertension by a physician and taking anti-hypertensive medication; Non-hypertensive group includes individuals who are not taking anti-hypertensive medication.

Next, bivariate Pearson correlations were performed to determine which blood pressure predictors in our sample were significantly correlated with traditional cognitive measures supported in the literature as being sensitive to blood pressure (i.e., executive functioning, perceptual speed, episodic memory; see Table 3). Other potential demographic predictors with established relationships with cognition (i.e., age, self-reported depressive symptoms and education), and use of anti-hypertensive medications were also examined to provide a basic correlation between these predictors and the cognitive variables of interest prior to the main regression analyses. Since detailed neuropsychological performance on each selective cognitive domain was not the purpose of this study, measures that were moderately correlated with any of the blood pressure predictors were used to determine a single outcome measure for traditional cognitive ability. By doing so, data from multiple outcome variables are reduced in a meaningful way to increase reliability (Wahlin et al., 2006) and to assist in interpretation of analyses by reducing the number of dependent variables (Paran et al., 2003; Saxby et al., 2003). Three test scores were significantly correlated with DBP and included in the averaged outcome measure of traditional cognitive ability: Trail Making B ($r = -.34, p < .01$), Colour-Word ($r = -.33, p < .01$), and DSC ($r = .35, p < .01$). These scores were converted to z-scores and summed to create a composite z-score (Edgington, 1995). The composite z-score was used as a dependent variable for executive functioning and perceptual speed (EF/Speed). The total EPS score was analysed as a dependent variable in separate analyses.

Table 3. Intercorrelations among Demographic, Blood Pressure and Cognitive Variables of Interest.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Age	-												
2. Education	-.16	-											
3. CES-D	.05	-.28	-										
4. Anti-hypertensive drugs	.19	-.14	.04	-									
5. SBP	.16	-.00	-.11	.39**	-								
6. DBP	-.23	.12	-.13	.22	.65**	-							
7. PP	.41**	-.09	-.05	.34*	.76**	.01	-						
8. EPS	-.45**	.39**	-.21	-.11	.11	.17	.01	-					
9. EF/Speed composite	-.63**	.08	-.10	-.09	.11	.44**	-.24*	.44**	-				
10. Trail Making	.46**	-.01	.09	.05	-.13	-.34**	.15	-.34**	-.78**	-			
11. Colour- Word	.49**	-.12	.09	.00	-.09	-.33**	.17	-.33**	-.83**	.41**	-		
12. DSC	-.60**	.19	-.18	-.12	.06	.35**	-.21	.35**	.88**	-.52**	-.70**	-	
13. CVLT-II recall	-.20	-.04	-.15	.03	-.08	.12	-.18	.12	.23*	-.13	-.27*	.25*	-

Note. CES-D = Centre for Epidemiological Studies-Depression Scale; SBP = systolic blood pressure; DBP = diastolic blood pressure; PP = pulse pressure; EPS = everyday problem solving; EF/Speed composite = composite z-score of trail making, colour-word, and DSC; DSC = WAIS digit symbol coding; CVLT-II = California Verbal Learning Test. * $p < .05$, ** $p < .01$.

Regression Analyses

Initial Regression Analyses. A series of hierarchical multiple linear regression analyses were conducted separately using EPS total score and EF/Speed composite z-score as dependent variables. Age, SBP, DBP, PP, and their interactions (age*SBP), (age*DBP), and (age*PP) were examined as continuous independent variables. Use of anti-hypertensive medications was also considered as an independent dichotomous variable to address the impact of a hypertensive diagnosis and medication treatment effects on cognitive function. All continuous predictors and interactions were centred to reduce non-essential collinearity between independent variables (Cohen, Cohen, West, & Aiken, 2003). We considered self-rated depression and education to take into account the effects of potential covariates that may influence cognitive performance (Burton et al., 2006; Lichtenberg et al., 1995). To attenuate the reduction in statistical power that would occur by including excessive covariates, only demographic variables that were significantly associated with cognitive performance at $p < .05$ were included in the final analyses (Davis et al., 2003; see Table 3). Refer to Appendix D for details of descriptive analyses and assumption checking.

Age and education were entered in the first step to determine the proportion of variance in EPS performance that each demographic predictor accounted for while controlling for one another. Use of anti-hypertensive medications was entered in the second step to see if blood pressure treatment and a physician's diagnosis of hypertension accounted for a significant proportion

of variance in cognitive performance. SBP and DBP were entered as continuous predictors in the third step to see whether both measures of blood pressure differentially accounted for a proportion of variance in cognitive ability above and beyond age, education, and use of anti-hypertensive medications. The change in R^2 (ΔR^2) between steps and their corresponding F-tests were examined to ascertain the predictive utility of additional variables. Regression coefficients of SBP, DBP, and use of anti-hypertensive medications were considered to determine the directionality and strength of the relationship between blood pressure and cognitive performance. Pulse pressure (PP) was analyzed separately as a predictor of cognitive performance following the same hierarchical regression entry of covariates, replacing SBP and DBP on the third step. Similar analyses were then repeated with EF/Speed performance as the dependent variable. Variables were deemed significant at an alpha level of 0.05.

Moderation Analyses. For blood pressure variables that predicted a significant proportion of variance in either EPS or traditional cognitive performance in the initial regression analyses, we performed a moderation analysis to clarify potential interactions between age and blood pressure on cognitive ability. The cognitive score (i.e., EPS or EF/Speed score) that the blood pressure variable at hand was significantly associated with in the initial regression analysis was used as the dependent variable. Following the same steps as the initial regression analysis, an interaction term between age and the blood pressure predictor (e.g., age*SBP) was entered in the fourth step, following the entry of the blood pressure predictor in the third step. If a significant ΔR^2 was

found from step 3 to 4, an interaction between age and that blood pressure variable would account for a substantial proportion of variance in cognitive performance.

Mediation Analyses. In the case where no interaction between age and the blood pressure predictor at hand accounted for significant variance in cognitive performance, mediation analyses were performed to examine the blood pressure variable of interest as a mediator of age and cognitive ability. Mediation may be established if: (1) changes in the independent variable (i.e., age) significantly account for changes in the proposed mediator (i.e., blood pressure), (2) changes in the mediator significantly account for variation in the dependent variable (i.e., EPS or EF/Speed score), and (3) a previously significant relationship between age and cognitive performance is reduced in strength when changes in blood pressure are controlled (Baron & Kenny, 1986; MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002). Sobel's (1982) test was conducted to quantify the degree of mediation associated with the blood pressure variable. This test determines whether the indirect effect of age on cognitive performance via the proposed mediator is significantly different from zero. Analyses were conducted using SPSS 16 software (SPSS Inc. Chicago, IL).

RESULTS

Demographic and Health Characteristics

Information pertaining to demographic and health characteristics of the entire sample is presented in Table 1. Comparison of select characteristics between diagnosed hypertensive participants and non-hypertensive participants are presented in Table 2. Interpretation of effect sizes were determined by Cohen's criteria for Cohen's d (small $\approx .20$ -.30; medium $\approx .50$; large $\approx .80$; Cohen, 1988) and phi coefficients (small $\approx .10$; medium $\approx .30$; large $\approx .50$; Gravetter & Wallnau, 2008). Medium to large effect sizes were considered as significant differences between groups. Small effect sizes revealed minimal group differences with regards to ethnicity, self-reported depressive symptoms as measured by the CES-D, and global cognitive performance as represented by scores on the MMSE. Overall high means from the MMSE (Hypertensive $M = 28.48$, $S.D. = 1.50$; Non-hypertensive $M = 28.75$, $S.D. = 1.31$) indicated that the sample as a whole demonstrated high global cognition. Regarding blood pressure differences, medium effect sizes were obtained for SBP and PP, indicating that medicated hypertensive participants had higher SBP and PP compared to non-hypertensive participants. No significant group differences were apparent for DBP, as demonstrated by a minimal effect size.

Regarding cardiovascular risks, the hypertensive group had a greater proportion of individuals with high cholesterol ($\chi^2 [1, n = 73] = 7.20, p = .007$),

and type 2 diabetes ($\chi^2 [1, n = 74] = 6.06, p = .022$), confirmed by medium effect sizes. Small effect sizes indicated no significant group differences regarding diagnosis of cardiovascular disease, previous heart attack, or current smoking status, though these analyses were subject to limited power as a result of few cases within the entire sample.

Correlations and Hierarchical Regression Analyses assessing Age, Blood Pressure, and Cognitive Performance

Bivariate Pearson correlations were computed among the variables of interest to determine the relationships between demographic variables, elevated blood pressure, EPS, and traditional cognitive performance (see Table 3). Age was negatively correlated with performance on all cognitive measures of interest including EPS and the executive functioning/ perceptual speed composite score (EF/Speed). Education was significantly associated with better performance on all EPS measures, but was not significantly correlated with performance on any traditional cognitive domains of interest. Therefore, education was included as a covariate for all EPS analyses, but dropped from EF/Speed analyses. A self-reported depressive symptom rating as measured by the CES-D was also examined. Eleven participants attained a score of 16 points or above, which met the cut-off for potentially clinical depressive symptomatology (Radloff, 1977). However, reported CES-D scores did not correlate with any blood pressure predictors or cognitive scores, and was not considered as a covariate in the main analyses. Unexpectedly, none of the blood pressure measures (SBP, DBP, PP) taken at the time of assessment were significantly correlated with any EPS

measure. Lower DBP was strongly associated with poorer performance on both tasks of executive functioning (Trail Making and Colour-Word) and perceptual speed (DSC) that were used in the EF/Speed composite z-score. A task of episodic memory (CVLT-II) did not correlate with any demographic or cognitive measure. In addition, correlation analyses indicated that SBP was positively correlated with DBP and PP, while DBP was not correlated with PP.

A series of hierarchical regression analyses were performed with EPS score and EF/Speed as a separate dependent variable. Age was a significant predictor in all cognitive tasks examined, and was retained for all hierarchical regression analyses. Education explained a significant proportion of variance in EPS performance, and was retained in step 1 of the EPS model. The use of anti-hypertensive medication was not significantly predictive of any cognitive variable after age and education were controlled for, and thus was dropped from all final models.

Regarding EPS ability, increased age and lower education significantly predicted lower performance on the EPS task (see Table 4). While DBP did not predict a substantial amount of variance in EPS performance, decreased SBP significantly predicted worse EPS scores (95% C.I. = .012-.398). Specifically, a 10mmHg decrease in SBP was associated with a 2.05-point decrease in EPS score (EPS Sample $M=34.83$, $S.D. = 11.84$). The addition of SBP and DBP to the model predicted a 4.4% increase in variance of EPS performance beyond the effects of age and education, but this increase did not reach statistical

significance. Together, 35.2% of the variance in EPS performance was accounted for by age, education, SBP, and DBP when included simultaneously.

Similar to bivariate Pearson correlations, increased age predicted poorer traditional cognitive performance as measured by executive functioning/perceptual speed (EF/Speed; see Table 5). Decreased DBP was significantly associated with poorer EF/Speed performance (95% C.I. = .016-.128), where a 10mmHg decrease in DBP was associated with a decrease in EF/Speed performance by 0.71 z-score units. SBP did not add a significant amount of variance in predicting this measure. The addition of SBP and DBP to the model predicted a 9.5% increase in variance of traditional cognitive performance as measured by EF/Speed above and beyond the effects of age and education ($\Delta R^2 = .10$, $F [2, 67] = 6.20$, $p < .01$). Together, 48.8% of variance in traditional cognitive performance as measured by the EF/Speed composite was accounted for by the full model ($R^2 = 0.49$, $F [4, 67] = 16.00$, $p < 0.001$).

Table 4. Hierarchical Multiple Regressions Examining Main and Interaction Effects of Age, Education, Blood Pressure, and EPS.

Predictor	B	S.E.	β	p	ΔR^2
<i>Block 1</i>					
Age	-.559	.140	-.398	<.001+	
Education	1.46	.445	.328	<.01**	.307+
<i>Systolic & diastolic BP</i>					
<i>Block 2</i>					
SBP	.205	.097	.298	<.05*	
DBP	-.180	.153	-.168	.244	.044
<i>Block 3</i>					
Age X SBP			.002	.987	.000
<i>Pulse Pressure</i>					
<i>Block 2</i>					
PP	.231	.100	.243	<.05*	.049*
<i>Block 3</i>					
Age X PP	-.011	.011	-.108	.313	.010

Note. Use of anti-hypertensive medications was initially entered after block one in all analyses, but did not significantly predict variance in any cognitive variable and was removed from final analyses. SBP = systolic blood pressure; DBP = diastolic blood pressure; PP = pulse pressure. Significant *p*-values are indicated for the change in R^2 after the entry of each block of variables in the equation. + $p < .01$, * $p < .05$.

Table 5. Hierarchical Multiple Regressions Examining Main and Interaction Effects of Age, Blood Pressure, and Traditional Cognitive Abilities.

Predictor	B	S.E.	β	p	ΔR^2
<i>Block 1</i>					
Age	-.179	.027	-.627	<.001+	.394+
<i>Systolic & diastolic BP</i>					
<i>Block 2</i>					
SBP	-.003	.018	-.019	.883	
DBP	.071	.028	.328	<.01**	.094**
<i>Block 3</i>					
Age X DBP	.000	.002	-.033	.723	.001
<i>Pulse Pressure</i>					
<i>Block 2</i>					
PP	.004	.020	.022	.828	.000

Note. Education and use of anti-hypertensive medications were initially entered in all analyses, but did not significantly predict variance in any cognitive variable and were removed from final analyses. SBP = systolic blood pressure; DBP = diastolic blood pressure; PP = pulse pressure. Significant p-values are indicated for the change in R^2 after the entry of each block of variables in the equation. + p < .001, ** p < .01.

In a series of separate regression analyses, pulse pressure (PP) was examined as a predictor of cognitive performance. Regarding the relationship between PP and EPS, decreased PP significantly predicted lower EPS performance, consistent with SBP (95% C.I. = .013-.430; see Table 4). Specifically, a 10mmHg decrease in PP was associated with a 2.31-point decrease in EPS score. The addition of PP to the model significantly accounted for a 4.9% increase in variance of EPS ability above and beyond age and education ($\Delta R^2 = .05$, $\Delta F [1, 70] = 5.33$, $p < .05$). The full model including age, education, and PP predicted 35.6% of variance in EPS performance ($R^2 = 0.36$, $F [3, 70] = 12.91$, $p < 0.001$). When examining traditional cognitive performance as a dependent variable (EF/Speed), no significant relationship between PP and EF/Speed was observed after accounting for age and education (see Table 5).

To further define the relationship between low blood pressure and decreased cognition, we calculated the number of individuals below the cognitive mean score whom also were below the mean sample blood pressure, which closely matched clinical guidelines for what is considered normotensive (120/80mmHg; NIH, 2004). As a measure of performance, we examined standardized residuals for the cognitive variables of interest, which allowed us to remove variance attributed to demographic covariates (e.g., age, education) from our initial regression models. For those below the sample SBP ($M = 120\text{mmHg}$, $S.D. = 17.17$) and PP mean ($M = 45\text{mmHg}$, $S.D. = 12.47$), 76% and 70.3% of individuals, respectively, performed below the mean EPS score. Regarding traditional cognitive abilities, 61% of individuals below the sample DBP mean (M

= 75mmHg, *S.D.* = 11.02) performed below the mean EF/Speed score. These findings revealed that the weight of the relationship between low blood pressure and decreased cognitive function was predominantly carried by participants who had blood pressure below what is considered “normal.”

Finally, potential curvilinear relationships between blood pressure and cognition were considered by adding quadratic and cubic forms of the blood pressure predictors to the initial regression equations. However, higher-order variables did not add significant predictive utility to the model, and a linear fit was sufficient in detecting the relationships between blood pressure and cognition.

Moderators and Mediators of the Relationship among Age, Blood Pressure, and Cognitive Performance

Based on previous research where elevated blood pressure exhibited different relationships in young and older age groups, we considered whether an interaction between age and blood pressure existed that may account for additional variance in cognitive ability. Because SBP and PP significantly predicted EPS ability, we examined both blood pressure variables as potential moderators in separate analyses (see Table 4). Following the steps of the previous model with age and education on the first step, and SBP and DBP on the second step, age*SBP was added on the third regression step. The addition of the interaction variable did not predict a substantial proportion of variance in EPS ability. In a separate analysis examining PP, an interaction term (age*PP) was entered on the third step following the entry of PP on the second step. No interaction accounted for significant variance in any EPS measure. Therefore,

both SBP and PP maintained similar positive relationships with EPS performance across the age range of the sample. Because DBP did not significantly predict EPS performance after accounting for other covariates and SBP in the initial hierarchical linear regression model (see Table 4), DBP was not examined in moderation analyses using EPS as a dependent variable.

Next, we considered interactions between DBP and age on traditional cognitive performance (EF/Speed). Moderation analyses for EF/Speed are presented in Table 5. Age was entered on the first step, followed by SBP and DBP on the second step, and finally, the interaction term (age*DBP) was entered on the third step. No significant interaction was found, indicating that the positive relationship between DBP and traditional cognitive performance remained consistent across ages.

After establishing that blood pressure did not interact with age in our sample, we addressed whether blood pressure mediated the relationship between age and EPS ability. Reasons for these analyses were to examine whether any blood pressure variable of interest represented a potential mechanism through which age affected EPS ability (Baron & Kenny, 1986). Since initial regression analyses confirmed that age, SBP and PP were significantly associated with EPS performance, a second series of regression analyses were conducted to examine SBP and PP as potential mediators. To test for mediation, the first proposed mediator (SBP) was regressed on the independent variable (age). However, age was not significantly correlated with

SBP; therefore, the first condition of mediation was not met (Baron & Kenny, 1986), and SBP was not further examined as a proposed mediator.

Next, we examined PP as a proposed mediator between age and EPS performance. Two MLR equations were performed with EPS performance as the dependent variable. The 1st equation regressed the proposed mediator (i.e., PP) on the independent variable (i.e., age) to determine whether PP and age were correlated. In the 2nd hierarchical equation, the dependent variable (i.e., EPS performance) was regressed on the independent variable (i.e., age) in the first step. In the second step, EPS performance was regressed on the proposed mediator (i.e., PP) to determine an association between PP and EPS after accounting for the effects of the independent variable (i.e., age). The conditions to establish mediation held, as age was significantly associated with PP ($R^2 = 0.17$, $F [1, 72] = 14.56$, $p < 0.001$), age was significantly associated with EPS performance ($R^2 = 0.20$, $F [1, 72] = 18.26$, $p < 0.001$), and PP was significantly associated with EPS performance when age was controlled for ($\Delta R^2 = 0.25$, $F [1, 71] = 4.26$, $p < 0.05$). However, after conducting Sobel's (1982) test to quantify the degree of mediation, PP did not mediate the relationship between age and EPS to a significant degree (Sobel's $Z = 1.816$, n.s.).

Finally, we tested the hypothesis that DBP mediated the relationship between age and traditional cognitive performance following the same steps of mediation with EF/Speed score as the dependent variable. The first condition of mediation was not met, as DBP was not significantly associated with age, and was not further examined as a proposed mediator.

DISCUSSION

We explored the relationships among age, blood pressure at the time of assessment, and cognitive performance in community-dwelling, non-demented women, while taking into account anti-hypertensive treatment effects. Our first two research questions investigated whether blood pressure at the time of assessment predicted traditional and everyday cognitive performance beyond a hypertensive diagnosis/use of anti-hypertensive medications. Contrary to our initial predictions, increased blood pressure did not predict worse cognitive performance. Rather, decreased systolic blood pressure (SBP) and decreased pulse pressure (PP) significantly predicted worse EPS ability after statistically controlling for age and education. Similarly, decreased diastolic blood pressure (DBP) was associated with poorer traditional cognitive performance represented by executive functioning and perceptual speed after statistically controlling for age. All findings were found after considering the effects of potential confounds including self-rated depressive symptoms and use of anti-hypertensive medications.

The findings from this work extend that of previous work by demonstrating an association between low blood pressure and decreased traditional and everyday cognitive performance in both middle-aged and older women. As previously suggested, adults in the later stages of life may require a higher level of blood pressure to maintain adequate cerebral perfusion (Paran et al., 2003;

Qui et al., 2005; Skoog et al., 1996). Very low blood pressure could lead to reduced cerebral blood flow and consequently, impaired cognitive performance. A previous study found that blood pressure below 130/70mmHg was related to reduced activities of daily living and lower MMSE scores (Guo, Viitanen, Fratiglioni, & Winblad, 1997) even after controlling for age, sex, education, use of anti-hypertensive medication, and cardiovascular risks (Guo, Fratiglioni, Winblad, & Viitanen, 1997). The authors postulated that an SBP of at least 130mmHg is important for maintaining cognitive performance in very old adults. Considering that the average blood pressure of our sample was 120/75mmHg, a large proportion of participants were well below this cut off (55 out of 74 participants) including 15 individuals taking anti-hypertensive medications. These findings support the possibility that blood pressure below a certain threshold, whether controlled by anti-hypertensive medication or not, may hinder cognitive function.

The mean blood pressure of our sample was roughly equivalent to what is considered clinically “normal” (NIH, 2004). To ascertain whether the relationship between low blood pressure and decreased cognition was consistent throughout the sample, we determined the proportion of individuals below the cognitive mean score whom also were below the mean blood pressure. After accounting for age and education, the majority of individuals below the SBP and PP mean performed below the mean EPS score. Similarly, 61% of individuals below the sample DBP mean performed below the mean EF/Speed score. In summary, these findings support the contention that individuals with blood pressure below what is considered “normotensive” were at greater risk for decreased cognitive

performance than those above the blood pressure mean. Epidemiological studies demonstrate that lower blood pressure reduces stroke risk in older adults, but these findings have not yet been generalized to individuals with a blood pressure below 115/75mmHg (Aiyagari & Gorelick, 2009). Furthermore, it has not been established whether decreased stroke risk parallels decreased risks to cognitive performance. Future research would benefit from exploring whether blood pressure below what is considered normal continues to reduce stroke risk and whether cognitive performance follows similar or distinct patterns.

Low Blood Pressure and Decreased Cognitive Performance

It is intriguing that decreased SBP and PP predicted lower EPS ability, and decreased DBP predicted lower traditional cognitive ability even in adults who could be classified as middle-aged (between ages 50 and 60). Previous research presenting similar relationships had samples of adults typically over age 75 (Guo, Fratiglioni, et al., 1997; Guo, Viitanen, et al., 1997; Qui, Winblad, et al., 2003). Though we tested for the possibility of a curvilinear relationship where higher and lower blood pressure would predict lower cognitive performance compared to mid-range blood pressure, higher-order variables did not add predictive utility to the model. Notably, many studies linking high blood pressure to worse cognitive function tended to examine individuals with more severe hypertension compared to our sample (Cerhan et al., 1998; Elias et al., 2004; Harrington, Saxby, McKeith, Wesnes, & Ford, 2000; Kivipelto et al., 2001; Li et al., 2007). In a review of the literature, all nine studies reporting harmful effects of hypertension on cognitive performance used cut-offs of at least > 160/95mmHg

to define hypertension (Qui et al., 2005), which is approximately 40/20mmHg higher than the current sample's average blood pressure, and 20/5mmHg higher than the current diagnostic criteria for hypertension (NIH, 2004). A possible explanation for our findings is that our sample may not have included enough cases of severe hypertension to demonstrate the link between extreme hypertension and poorer cognitive performance. Cognitive measures may be more sensitive to changes attributed to high blood pressure if extreme hypertensive cases suffer from greater decrements to cognitive performance. Furthermore, given our limited sample size, it is possible that curvilinear relationships may be found in a larger cohort including a wider range of hypotensive, prehypertensive, and severe hypertensive individuals. Nonetheless, our findings are unique in that a subset of community-dwelling women was identified that consisted primarily of individuals with low blood pressure to mild hypertension, where lower blood pressure did not provide the best conditions for optimal cognitive performance.

Detrimental cognitive effects associated with low blood pressure in our sample can potentially be explained by inefficient cerebral blood flow regulation. Cerebral autoregulation is responsible for maintaining a relatively constant cerebral blood flow across a wide range of cerebral perfusion pressures by reflexively constricting and dilating cerebral arterioles in response to pressure change. This mechanism becomes dysfunctional at very high and low blood pressure ranges (Urrutia & Wityk, 2008), and consequently, may affect cognitive function. Moreover, atherosclerotic blood flow resistance increases as the

arteries harden with age. It is possible that the older adults in this study who had low blood pressure exhibited inefficient cerebral autoregulation; as such, they may instead require mildly elevated blood pressure to maintain cerebral perfusion pressure (Knecht et al., 2009) and preserve cognitive function. Consistent with the findings of this work, another study found that prehypertensive individuals between ages 75-79 exhibited the best cognitive performance compared to normotensive or hypertensive adults (Obisesan et al., 2008). Future research is required to more thoroughly explore the effects of cerebral autoregulation on cognitive performance in older adults across blood pressure and age groups. Such studies may help clarify whether there is a level where lower blood pressure is no longer advantageous to cognitive function.

Finally, our study draws attention to potential sex differences that may exist between males and females regarding blood pressure and cognition. It is possible that sex effects influenced the positive relationship we found regarding blood pressure and cognitive performance. In a review by Qui and colleagues (2005), only one examined study used a sample composed of solely females (Petitti, Buckwalter, Crooks, & Chiu, 2002). The authors found that in females aged 75 and over, self-reported hypertension was linked to a lower prevalence of dementia. Although their results were based on self-reported high blood pressure, they are generally consistent with our findings where decreased blood pressure was associated with decreased cognitive performance. In contrast, five of the seven articles examining midlife hypertension and cognition that reported the opposite relationship (i.e., high blood pressure was related to decreased

cognition) were based only on men (See Qui et al., 2005 for review). Though we cannot assert that the relationship between low blood pressure and decreased cognition was attributed to sex effects, the potential for sex differences provides impetus for female-only replication studies that examine both severe hypotension and hypertension.

Pulse Pressure and Cognition

Consistent with the relationship among SBP and EPS, decreased PP also predicted lower EPS ability. While some studies have demonstrated the opposite pattern where higher PP predicted worse cognitive performance (Waldstein et al., 2008), those studies tended to include individuals with more severe pulse pressures. In a non-demented older sample, lower PP (< 70mmHg) was associated with greater risk of AD and dementia, while higher PP (i.e., > 85mmHg) was associated with the same risks (Qui, Winblad, et al., 2003). Notably, these relationships were greater in women. In our female sample, no individual had a PP greater than 85mmHg, and the majority were in the lower range below 70mmHg (94.5%; $n = 70$), thus supporting previous findings where lower PP is predictive of poorer cognitive performance. Very low PP also correlates with decreased stroke volume (i.e., the amount of blood ejected with each heart contraction; Obisesan et al., 2008) and cerebral blood flow (Chae et al., 1999). Moreover, cerebrovascular lesions and poor blood pressure regulation resulting from atherosclerosis may lead to low PP and dementia (Qui, Winblad, et al., 2003). Similar to decreased SBP and DBP, it is possible that very low PP could signal dysfunctional cerebral blood pressure regulation and contribute to

cognitive impairment. Because our sample was comprised primarily of individuals with low to normal PP, we cannot speculate on how individuals with more severe pulse pressures would perform cognitively. Additional research on such populations is required.

Possible explanations for why there were differences among SBP, DBP, and PP as predictors of selective cognitive domains are uncertain. The significant correlation between SBP and PP explains similar results found between both variables in predicting EPS ability. This correlation was expected considering that SBP increases more rapidly than DBP in older age (Hense et al., 2002), which directly increases PP. However, the question remains as to why SBP and PP were not predictive of traditional cognitive performance and why DBP was not predictive of EPS ability. We considered whether non-significant relationships between certain blood pressure predictors and cognitive variables may have been due to limited sample size, which restricted our power to detect small and medium effects for certain analyses. As such, it is possible that chance of a type 2 error would increase, masking potential associations between our blood pressure variables and other cognitive domains. Notably, in cases where blood pressure variables did not predict performance on certain cognitive measures, their regression coefficients were negligible. The fact that there are multiple mechanisms through which blood pressure and hypertension affect the brain (Birns & Kalra, 2009) supports the likelihood of finding unique associations between blood pressure variables and specific cognitive domains. Analyzing SBP, DBP, and PP as distinct predictors may be particularly important in aging

studies considering that these variables naturally follow different patterns of elevation compared to younger adults, particularly in the sixth decade of life (Qui, Winblad, et al., 2003). Furthermore, future studies should acquire a larger sample size to accommodate additional blood pressure variables and ensure sufficient power to detect significant relationships.

A viable reason for the relatively lower blood pressure and PP readings in our sample may partially be due to selection strategies. A large proportion of our sample was selected from community centres (37%), where health awareness was emphasized; those who were interested and more conscious of their health may have been more likely to volunteer. We also recruited participants through Internet surveys, which may have attracted a cohort of healthier, technologically informed and functionally independent older adults (38.4%). In light of the fact that a great deal of intra-individual cognitive variability exists among older adults (Hultsch et al., 1998), sampling methods, especially for community-based samples, are likely to have considerable implications when interpreting findings in health-related studies. This study adds to the current research base by providing a homogeneous, community-dwelling female sample with blood pressure in the lower spectrum. The observation that blood pressure at the time of assessment was associated with cognitive performance in older women implies that blood pressure may be an important predictor of cerebrovascular health and cognitive aptitude, even in a less severe hypertensive population. Whether our selection strategies lead to similar relationships among age, blood pressure, and cognitive performance in men warrants further exploration.

Blood Pressure: Moderation and Mediation

To elucidate the relationships among age, blood pressure, EPS and traditional cognitive ability, we performed a series of moderation and mediation analyses. Moderation analyses addressed our third research question by examining whether an interaction between age and blood pressure existed that would account for a significant proportion of variance in cognitive ability. No interactions between age and blood pressure (i.e., no changes in the relationship between blood pressure and cognition across different ages) were found. As such, the direction and strength of the relationship between blood pressure and cognition as measured by EPS and executive functioning/perceptual speed tasks was consistent across middle-aged and older women. In our sample, no matter the age, lower blood pressure predicted worse cognitive performance. The possibility that lower blood pressure does not necessarily predict optimal cognitive function may be generalized to both middle-aged and older women.

Since no interaction was found between age and blood pressure, we tested our fourth research question, where we hypothesized that blood pressure may mediate the relationship between age and cognitive performance. None of the blood pressure variables significantly mediated the relationship between age and EPS performance, and blood pressure was not considered an influential mechanism through which age was associated with cognitive performance. The lack of a mediating relationship implies that SBP, DBP, PP, and age are important and separate contributors to cognitive variance. However, this finding does not preclude the possibility of blood pressure as a mediator in other diverse

samples that may have more severe hypertension. Reasons for non-significant mediation may be because our sample had very well controlled blood pressure regardless of age. As a result, we did not find a significant correlation between SBP/DBP and age. As it is well known that blood pressure naturally increases with age (NIH, 2004), samples that include individuals with less controlled blood pressure may be more prone to finding stronger associations between age and blood pressure, and potential mediating effects between age and cognitive performance.

Everyday Problem Solving

Consistent with previous findings, increasing age was related to decreased performance on all cognitive variables including EPS (Thornton, Deria et al., 2007; Thornton & Dumke, 2005; Allaire & Marsiske, 1999). The impact of age on EPS was considerable, accounting for 22% of the variance alone in EPS performance. Age effects on problem solving ability may be a result of decreased basic neuropsychological abilities (i.e., attention, memory) that naturally decline with age, which are important determinants of EPS performance (Burton et al., 2006). Another possibility could be that adults use qualitatively different problem solving strategies. For example, as individuals grow older, they may be more selective of solutions that have worked in the past, and/or are less likely to write solutions that are less successful (Thornton, Deria et al., 2007). In any case, it appears that EPS measures are sensitive to age effects, providing impetus for EPS tests as a potentially useful measure of everyday cognition and real-world problem solving ability in older adults.

This is the first known study to go beyond a diagnosis of hypertension and report relationships between blood pressure at the time of assessment and EPS ability. It is also the first to report a relationship where decreased blood pressure predicted lower EPS performance. An examination of blood pressure as a continuous variable may better identify cognitive relationships in individuals with chronic conditions, particularly in a community sample where some individuals have better awareness and control over their health. Lower blood pressure was associated with a decreased ability to solve real-world problems, and may consequently impact functioning in one's personal environment. Other common measures of everyday functioning such as instrumental activities of daily living are often prone to ceiling effects, particularly in community-dwelling individuals who generally lead an independent lifestyle (Marsiske & Margrett, 2006 in Thornton, Deria et al., 2007). An EPS measure may provide a more subtle indicator of how health factors influence everyday cognition in older adults. The utility of blood pressure as a predictor of real-world functioning and cognitive ability in adults with severe hypertension should be investigated in future research.

Traditional Cognitive Abilities

Regarding traditional cognitive abilities, the observation that decreased DBP significantly predicted worse performance on executive functioning and perceptual speed supports existing research that has indicated that tests reflective of subcortical functioning may be particularly sensitive to uncontrolled blood pressure. As previously suggested (Birns & Kalra, 2009; Davis, et al.,

2003), episodic or sustained low blood pressure may affect subcortical matter of the frontal lobe that is more vulnerable to ischemia and anoxia, leading to impaired perceptual processing, attention, and executive function. In this study, both executive functioning and perceptual speed were sensitive to low DBP. Furthermore, these tasks had a timed component, suggesting that speeded tasks are more sensitive to health effects on cognition. The slowing of cognitive performance is established in normal ageing, and accelerated slowing may be indicative of early cognitive impairment (Dixon et al., 2007). Similarly, related vascular illnesses where hypertension is prevalent such as type 2 diabetes have been associated with cognitive slowing, specifically in executive functioning and speed in middle-aged and older adults (Fischer, de Frias, Yeung, & Dixon, in press; Yeung, Fischer, & Dixon, 2009). Replication and exploratory studies examining other types of speeded executive functioning tasks and timed EPS tasks would be useful to corroborate current findings.

A note regarding episodic memory and blood pressure is merited. Although previous studies have found links between memory and hypertension (Moss & Jonak, 2007), episodic memory was not accounted for by blood pressure at the time of the assessment or hypertensive status in this study. This finding is particularly puzzling since our episodic memory task (i.e., CVLT) was not correlated with either age or education. Future research using multiple tasks of episodic and verbal memory with timed components may be useful to detect age and health effects, particularly in a non-demented community-dwelling population.

Health-related Confounds

A common issue with health studies is the possibility that comorbid vascular chronic illnesses may mask the true associations between blood pressure and cognitive performance. In our study, this is unlikely given that few individuals met criteria for some of the major risk factors examined such as cardiovascular disease, previous heart attack, and smoking status. In addition, these factors were not significantly different between those diagnosed as hypertensive and those who were normotensive (See Table 2). Diagnoses of high cholesterol and type 2 diabetes were elevated in those who were hypertensive, which is consistent with the known literature regarding hypertension (Rosendorff et al., 2007). There is evidence that high cholesterol and type 2 diabetes can be detrimental to cognitive performance (Moss & Jonak, 2007; Olomon et al., 2009). However, a diagnosis of either risk factor was not associated with any cognitive measure after accounting for demographic variables in our sample, and was not likely a significant influencing factor in the relationship between blood pressure and cognition. Taking into account the relatively stringent health exclusion criteria and the low proportion of individuals with severe comorbid vascular illnesses, we were able to more selectively examine blood pressure effects and reduce the influences of other health risk factors to cognition that would otherwise be found in clinical samples.

It is important to note that unlike previous findings (Thornton, Deria et al., 2007), a physician's diagnosis of hypertension and use of anti-hypertensive medications did not significantly predict performance on any cognitive measure

after age was taken into account. An examination of hypertension as a dichotomous variable based solely on a physician's diagnosis and use of anti-hypertensive medication may not be sensitive enough to capture differences in cognitive performance. Given that all individuals diagnosed with hypertension were medically treated, the effects of medication likely mitigated any potentially negative effects hypertension would have contributed to cognitive ability. Our results indicate that while an individual may suffer from health complications such as hypertension, they are not necessarily impaired on traditional or everyday cognitive tasks that are reflective of real-life functioning, particularly if their blood pressure is well controlled. Furthermore, an analysis of blood pressure continuously provides additional information beyond a hypertensive diagnosis regarding the relationship between blood pressure and cognitive function.

Overall, our interpretation emphasizes four main considerations regarding age, blood pressure, and cognitive performance in older women. First, blood pressure at the time of assessment measured continuously is a sensitive and distinct predictor of cognitive ability beyond a dichotomous hypertensive diagnosis. Decreased blood pressure is not necessarily protective of cognitive function if too low, and may signal inadequate cerebral blood flow. Second, different aspects of blood pressure (i.e., SBP, DBP, and PP) should be assessed independently, as they may have distinct relationships with specific cognitive domains. Third, blood pressure control may have significant implications regarding everyday cognition. Everyday cognition assessed by an EPS task may be sensitive to age-related changes and decreased blood pressure. Future

research is required to determine whether observed relationships alter depending on the severity of hypertension. Finally, sample selection methods of community-based populations are likely to have critical implications when assessing the influence of chronic health conditions, age effects, and their utility as predictors of cognitive performance.

Limitations and Future Directions

The findings from this work should be considered with respect to certain limitations. First, due to the cross-sectional nature of this study, longitudinal data including changes in blood pressure and cognitive performance over time were not available. Therefore, the present data cannot determine whether people with decreased blood pressure suffer from accelerated decline in cognitive function. These concerns may be addressed through longitudinal studies that document changes in cognition over time in hypertensive and non-hypertensive adults. Second, blood pressure was assessed on only one occasion, which reduces the reliability of the measurement compared to a 24-hour ambulatory measurement (Campbell et al., 2005). However, multiple measurements were taken during the assessment, and the current procedure mirrors similar methods described in extant literature (Glynn et al., 1999; Knecht et al., 2008; Knecht et al., in press; Li et al., 2007; Qui, von Strauss et al., 2003; Qui, Winblad, et al., 2003; Paran et al., 2003). Furthermore, specific precautions were taken by test administrators in order to reduce the possibility of participant reactivity or white-coat hypertension. Third, participants were asked to self-report a diagnosis of a chronic illness only if told by a physician, and self-reported medication was confirmed by objective

medication data. Although past studies have supported the accuracy of self-report measures regarding major chronic illnesses (Kriegsman, Penninx, van Eijk, Boeke, & Deeg, 1996; Midthjell, Holmen, Bjørndal, & Lund-Larsen, 1992), diagnostic accuracy may have been further improved with access to medical records. Fourth, the generalizability of the data is restricted to relatively healthy community-dwelling individuals. While the current findings are unique in the inclusion of a group of women with low to mildly hypertensive blood pressure, our sample's homogeneity also limits the generalizability of our findings to severe hypertensive samples. A more diverse community sample would likely include individuals with both hypotension and severe hypertension, as well as higher percentages of comorbid vascular illnesses, which may exacerbate the effect of blood pressure on cognitive performance. As such, it would be of great interest to see if different relationships among age, blood pressure, and cognition may be found, where lower blood pressure is beneficial or even necessary in order to maintain cognition.

Regarding sample composition, our sample was restricted to women, and future studies should examine sex effects. It is likely that relationships between blood pressure and EPS display sex differences, particularly since men and women may experience different types of problems in older age and apply diverse skills in solving problems. Nonetheless, considering that middle-aged and older women are relatively understudied compared to men (see Qui et al., 2005 for review), the study supplements the current literature by providing one of the few homogenous female samples. Finally, as previously mentioned, our power

for certain analyses was limited by our sample size (Faul, Erdfelder, Buchner, & Lang, in press). Limited power may have contributed to increased Type 2 error, which diminished our chances of finding significant relationships, both regarding main effects between blood pressure and cognition, as well as interaction and curvilinear effects. Future replication studies would benefit from larger sample sizes.

Although there are established benefits to lowering blood pressure in order to reduce cardiovascular risk factors (NIH, 2004), findings from our study indicate that lower blood pressure is not necessarily predictive of better cognitive performance in community-dwelling older women. It is uncertain whether low blood pressure for all ages promotes optimal cognitive performance (Anson & Paran, 2005). Prospective studies should place greater attention on hypotensive and prehypertensive older adults, as different patterns between blood pressure and cognitive performance may emerge when compared to more severe hypertensive patients across the life span. Such research may assist medical professionals in understanding and setting proper blood pressure goals for specific age groups in order to maintain everyday cognition, and thereby prolonging functional independence and quality of life.

APPENDICES

Appendix A

Hypertensive Treatment Effects

An area of discrepancy pertains to the way in which studies control for treatment effects of hypertension on cognition. The use of anti-hypertensive medication is often accounted for by using newly diagnosed samples that are not on medication, or by removing the use of medications briefly prior to assessment (Brady et al., 2005). Unfortunately, these methods may not be externally valid considering that only 56% of hypertensive patients are being treated, and a notable proportion of those individuals still do not have their blood pressure controlled within an acceptable range (Brady et al., 2005). Moreover, brief discontinuation of medication does not preclude the long-term effects of anti-hypertensive medication use on cerebrovascular integrity. Differences in cognitive performance may exist between hypertensive patients that are untreated, treated, and uncontrolled (Birns et al., 2006; Brady et al., 2005; Paran et al., 2003; Poon, 2008), suggesting that anti-hypertensive medication use affects cognition. While some randomized controlled studies provide evidence that blood pressure reduction enhances cognitive function (Poon, 2008), others postulate that excessive anti-hypertensive treatment may reduce cerebral perfusion, thus, putting cognitive performance at risk (Qui et al., 2005). It is also possible that these medications may not only alter cognitive performance by

reducing blood pressure, but they may also affect cognitive function independently. For example, cognitive ability may be influenced by the chemical make-up of the drug (e.g., calcium channel blockers used to treat hypertension may affect the calcium influx on neuronal cells; Poon, 2008). Previous literature is mixed regarding the direction and magnitude of cognitive differences between individuals with medically controlled and uncontrolled blood pressure. These studies highlight the importance of accounting for anti-hypertensive medication use when evaluating the effects of hypertension.

Appendix B

Hypertension and Women

The current study focuses on blood pressure and everyday cognition in a strictly female cohort of community-dwelling adults spanning middle and older age. Women endure a longer lifespan, and therefore, are more likely to confront specific age-related everyday problems such as caregiving or dealing with a spousal death. Caregiving in women is associated with health problems including elevated blood pressure, lower perceived health status, and increased risk of mortality (Lee, Colditz, Berkman, & Kawachi, 2003). Women are also more likely to endure chronic illnesses such as hypertension for a longer time than men (Fu, Vongpatanasin, & Levine, 2008). There are many potential contributing factors to this sex discrepancy including different aging effects, hormonal markers, and greater blood pressure reactivity in women (Fu et al., 2008). In light of the potential biological and cognitive differences between sexes, we focused rigorously on examining blood pressure in women in the context of EPS and other traditional cognitive abilities.

Appendix C

Everyday Problem Solving

Age and EPS. The premise for examining EPS ability in older adults stems from the hypothesis that traditional neuropsychological measures may be biased towards school-aged or younger adults (Allaire & Marsiske, 1999). A reason for this bias may be that traditional tasks often involve academic skills similar to those required in school environments. Several authors propose that older adults who have not attended school for a prolonged period may not perform as well on traditional tasks (Allaire & Marsiske, 1999; Schaie, 1978; Willis & Schaie, 1986), although their everyday functioning may be adequate. Conflicting literature has arisen regarding whether age effects are found in EPS. Some studies find no declines in EPS in old age and suggest that older adults may rely on a growing body of accumulated knowledge that is more robust to aging effects in order to solve problems (Baltes, 1993; Cornelius & Caspi, 1987). However, others propose that EPS tasks may rely on basic cognitive abilities required for performing traditional cognitive tasks, and thus, EPS ability should decline with age. Cross-sectional age differences and longitudinal mean reductions in EPS have been observed (see Allaire & Marsiske, 1999 for review). Furthermore, a recent meta-analysis examining 28 studies of EPS and decision-making effectiveness supports this aging effect, revealing that a reliable reduction in EPS ability using several different scoring criteria was found as individuals aged (Thornton & Dumke, 2005). It may be useful to examine EPS alongside traditional cognitive tasks, particularly in an older population that has

been removed from school and whose EPS ability may be indicative of their functional independence.

Structure of the EPS test. Discrepancies that exist regarding the relationship between EPS and age may partially be due to the multiple ways that EPS is measured (Allaire & Marsiske, 1999) and because these measures do not necessarily relate well to one another (Marsiske & Willis, 1995). On a broad scope, EPS tests are divided by having a well-defined or ill-defined structure (Allaire & Marsiske, 2002). Well-structured problems describe a specific situation, one means to solve the problem, or a desired outcome. Ill-structured problems tend to be open-ended questions that leave room for multiple solutions. Ill-structured problems are frequently encountered in the real world, where problems can often be solved in a number of ways (Allaire & Marsiske, 2002). In this study, the EPS task employed ill-structured problems, where participants were asked to derive multiple solutions to everyday obstacles that may be encountered.

Appendix D

Descriptive Analyses and MLR Assumption Checking

Descriptive statistics were analysed for each independent variable to determine the central tendency of the data (i.e., mean and median), variability (i.e., standard deviation and range), and data shape (i.e., skew and kurtosis). Extreme outliers on blood pressure and cognitive measures (i.e., more than three interquartile ranges from the remaining values) were altered to less extreme values by adding one to the highest non-outlying score, thus maintaining rank order of the data (Tabachnick & Fidell, 2001). Following outlier transformation, mean data values of relevant variables were compared with the 5% trimmed means to ensure influential outlying data points were attenuated (Pallant, 2007). No individuals had missing data points on blood pressure measures. Individuals with missing data on the examined demographic questions or cognitive tasks were eliminated from analyses using pairwise deletion. To check for potential multicollinearity between predictors, Variable Inflation Indices (VIF) and tolerance values were examined. The assumptions of Multiple Linear Regression (MLR) for main analyses were considered, including (1) a linear relationship between the independent variables and dependent variables, (2) homoscedasticity, (3) independence of residuals, and (4) normality of residuals (Cohen et al., 2003). These assumptions were met and confirmed following analysis of Q-Q plots and residual scatterplots. Finally, we attempted to reduce measurement error in the independent variables by using multiple blood pressure readings with a validated blood pressure monitor, discarding the first reading to increase reliability.

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