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Brief report

Executive ability in relation to blood pressure in residents of homes for the elderly

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Abstract

The objective of the present study was to examine whether blood pressure (BP) relates to various executive functions in residents of homes for the elderly. Several cognitive tests measuring flexibility, fluency, inhibition, planning, and working memory were administered. Associations between these executive functions and systolic and diastolic BP (SBP and DBP) were examined. The results revealed that normal SBP (<120 mmHg) related to better fluency and flexibility performance, whereas no significant effects of DBP were noted. The present study indicates that specifically SBP might be important with regard to executive ability in residents of homes for the elderly.
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Keywords: Systolic blood pressure; Diastolic blood pressure; Executive function; Very old

1. Introduction

With the population increasing in age, an increase in the prevalence of age-related disorders can be anticipated. A common observation in aging is a decrease in cognitive functions (Parkin & Java, 1999; Rabbit & Lowe, 2000). Several cardiovascular risk factors, including high blood pressure (BP) might play an important role in this cognitive deterioration. The prevalence of high BP is known to increase with aging (e.g. Efstratopoulos et al., 2006; Jo et al., 2001; Prencipe et al., 2000). For example, among elderly people aged 65 years and older the prevalence of hypertension may be as high as 65% (e.g. Efstratopoulos et al., 2006; Prencipe et al., 2000). High BP furthermore, both at middle and old age, has been associated with a decline in cognitive ability (Harrington, Saxby, McKeith, Wesnes, & Ford, 2000; Knopman et al., 2001; Saxby, Harrington, McKeith, Wesnes, & Ford, 2003; Waldstein, Giggey, Thayer, & Zonderman, 2005). These effects have been observed in several cognitive domains, including memory, speed of information processing and executive function (Harrington et al., 2000; Knopman et al., 2001; Saxby et al., 2003; Waldstein et al., 2005). The term executive function encompasses a variety of functions, such as inhibition, flexibility, and working memory. The majority of the studies that examined the effect of high BP on executive function has focused on a single or few of these

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functions (Kuo et al., 2004; Saxby et al., 2003; Waldstein et al., 2005), whereas not all executive functions may be equally affected as a result of high BP. For example, despite that associations between hypertension or BP and executive functions such as flexibility (assessed with the trail making test) or inhibition (assessed with the Stroop test) have been established (Kuo et al., 2004; Vicario et al., 2005; Waldstein et al., 2005), results are not utterly convincing. Negative results have been reported with regard to fluency and flexibility performance (e.g. Knopman et al., 2001; Van Boxtel et al., 1997). In addition, it is unclear whether BP also relates to other executive functions such as planning or working memory, although an inverse relationship between hypertension and working memory performance has been observed (Saxby et al., 2003). It is therefore crucial to assess different executive functions together in a single study population. Furthermore, studies to date have in general focused on a relative young population of elderly people (e.g. mean age 72 years, S.D. = 4.4, range = 65–85, Kuo et al., 2004; mean age 76 years, S.D. = 4, range = 70–89, Saxby et al., 2003), whereas studies examining the association of BP with cognition in the very old (e.g. 85+) are limited and inconclusive. Those studying this age population report varying results such as inverse (Harrington et al., 2000) or positive (Guo, Fratiglioni, Winblad, & Viitanen, 1997) associations of high BP with cognition. The precise relationship between BP and executive functions in a very old population therefore requires elucidation, especially when one considers executive function as a very important predictor of functional status (Royall, Palmer, Chiodo, & Polk, 2004). Residents of homes for the elderly constitute one example of a very old population vulnerable to the detrimental effects of aging that affect functional status. Therefore, the present study focused on possible associations between BP and executive function in residents of homes for the elderly. The following executive functions were assessed: fluency, flexibility, inhibition, planning, and working memory.

2. Methods

2.1. Subjects

The recruitment of participants was accomplished in cooperation with four different homes for the elderly in Amsterdam, the Netherlands. The selection procedure of subjects was as follows: medical records of residents admitted for care at a somatic ward were screened to select those subjects free of a history of: neurodegenerative disease (e.g. dementia, Parkinson's disease), stroke, transient ischemic attack, schizophrenia, alcohol or other substance abuse, thyroid disease, and severe depression. Further patient interview was performed to assess alcohol consumption; usage > 4 units/day was reason for exclusion. Next to the exclusion of subjects with a history of dementia and cognitive decline, the mini-mental state examination (MMSE) (Folstein, Folstein, & McHugh, 1975) was used as a screening instrument to further exclude possible dementia: a score of ≥24 was required for participation (Grut, Fratiglioni, Viitanen, & Winblad, 1993).

BP was measured in upright sitting position using an aneroid Sphygmomanometer after at least 5 min of rest. Subjects were visited on two different occasions to perform BP readings, with (on average) a 4-week interval. On each occasion, BP was measured twice, resulting in four BP readings. Average systolic and diastolic BP (SBP and DBP, respectively) was calculated from these readings. The correlations between the different readings were $r = 0.60$ ($p < .001$) for SBP and $r = 0.63$ ($p < .001$) for DBP, representing strong correlations (Cohen, 1988). BP groups were classified according to Joint National Committee's report (Chobanian et al., 2003). Hence, normal SBP (<120 mmHg), medium SBP (120–139 mmHg) and high SBP (≥140 mmHg) groups were classified. DBP was categorized as follows: normal DBP (<80 mmHg), medium DBP (80–89 mmHg) and high DBP (≥90 mmHg).

Education, depressive symptoms, antihypertensive agents (e.g. thiazide diuretics, ACE inhibitors), and cardiovascular risk factors were taken into account. Education was assessed with an ordinal rating scale ranging from 1 (incomplete primary school) to 7 (university degree) (Heslinga, van den Burg, & Saan, 1983). The 7 different scores include the following: 1 = incomplete primary education; 2 = primary education; 3 = incomplete lower secondary education; 4 = lower general secondary education; 5 = upper secondary vocational education; 6 = higher general secondary education, pre-university secondary education, higher vocational education; 7 = university. Depressive symptoms were assessed using the Dutch version of the symptom checklist (SCL-90) (Arrindell & Ettema, 1986). The depression subscale consists of 16 questions, on which subjects can use a five-point scale of severity (1–5). As such, scores can vary between 16 and 80. A thorough search in the medical records was performed to deduce use of antihypertensive medication and to check for cardiovascular risk factors. These risk factors included a history of cardiac disease, diabetes mellitus, and hypertension. Smoking behavior was deduced from patient interview and scored as follows: no or former smoker (score 0) and current smoker (score 1).

Table 1
Subject characteristics of the SBP groups ($n = 76$)

Variable	SBP < 120 ($n = 14$)	SBP 120–139 ($n = 28$)	SBP ≥ 140 ($n = 34$)	p
Age (mean ± S.D.)	85.1 (4.1)	85.4 (5.7)	85.2 (4.5)	.93
Gender (% male)	50	32.1	32.4	.46
Antihypertensive agents (% users)	78.6	71.4	61.8	.50
MMSE (mean ± S.D.)	27.5 (2.0)	27.6 (1.8)	26.3 (1.2)	.013
Education (mean ± S.D.)	4.4 (1.4)	4.0 (1.8)	3.6 (1.4)	.22
Depressive symptoms (mean ± S.D.)	27.3 (9.8)	25.2 (5.7)	25.7 (10.5)	.64
Cardiac disease (%)	64.3	53.6	32.4	.08
Diabetes mellitus (%)	14.3	21.4	14.7	.72
Hypertension (%)	50	39.3	52.9	.55
Smoking behavior (%)	21.4	17.9	20.6	1.0

Chi-square of Fisher's exact tests were employed to compare gender, use of antihypertensive agents, and the prevalence of cardiac disease, hypertension, diabetes mellitus, and smoking behavior between the groups. Kruskal–Wallis tests were used for age, MMSE, education and depressive symptoms. MMSE: mini-mental state examination.

Ninety-three residents participated. Of these residents, 12 obtained an MMSE score < 24 and were excluded from the study. No subject was excluded because of excessive alcohol consumption. As such, 81 residents participated. In these participants, high DBP (≥90 mmHg) was observed only once; this participant was excluded from further analyses. Of the 80 remaining subjects, four subjects were excluded because of missing SCL-90 data. Participant characteristics of the remaining 76 subjects (mean age = 85.3 ± 4.9) are presented for both the SBP (Table 1) and the DBP (Table 2) groups. All subjects gave an informed consent. The study was approved by the local ethics committee.

2.2. Cognitive measures

The following executive functions were assessed:

2.2.1. Flexibility

The trail making test (TMT) (Reitan, 1958) was employed to assess flexibility performance. The TMT-A consists of 25 encircled numbers that are randomly distributed on a sheet of paper. The subject is required to sequentially connect these numbers. With the TMT-B, both numbers and letters are distributed. This time, the subject in instructed to alternate between the numbers and letters (e.g. 1, A, 2, B, 3, etc.). Both completion time of part B corrected for part A (TMT-B/TMT-A) and TMT-B number of errors were considered.

Table 2
Subject characteristics of the DBP groups ($n = 76$)

Variable	DBP < 80 ($n = 56$)	DBP 80–89 ($n = 20$)	p
Age (mean ± S.D.)	85.5 (5.2)	84.6 (3.9)	.39
Gender (% male)	37.5	30	.55
Antihypertensive agents (% users)	67.9	70	.86
MMSE (mean ± S.D.)	27.1 (1.7)	26.6 (1.6)	.29
Education (mean ± S.D.)	3.8 (1.6)	4.05 (1.6)	.66
Depressive symptoms (mean ± S.D.)	26.5 (9.8)	24.0 (4.9)	.55
Cardiac disease (%)	46.4	45.0	.91
Diabetes mellitus (%)	17.9	15.0	1.0
Hypertension (%)	44.6	55.0	.43
Smoking behavior (%)	21.4	15.0	.75

Chi-square of Fisher's exact tests were employed to compare gender, use of antihypertensive agents, and the prevalence of cardiac disease, hypertension, diabetes mellitus, and smoking behavior between the groups. Mann–Whitney U tests were used for age, MMSE, education and depressive symptoms. MMSE: mini-mental state examination.

2.2.2. Fluency

Both category fluency and the controlled oral word association test (COWAT) (Benton, Hamsher, & Sivan, 1983) were examined. Subjects are instructed to generate as many words as possible within 1 min. For category fluency, total number of words for both 'animal' and 'profession' categories was used. The COWAT score consisted of the total number of words beginning with a specific letter (Dutch equivalent of 'fas').

2.2.3. Inhibition

The word (*W*), color (*C*) and color/word (*C/W*) cards of the Stroop test (Stroop, 1935) were assessed. The *W* card consists of 10 rows containing 10 color names, printed in black ink, which the subject is required to read aloud as fast as possible. For the *C* card, 10 rows, with each row containing 10 colored blocks, are presented, and the subject is required to name the colors of the blocks as fast as possible. On the *C/W* card, instead of colored blocks, color names are printed in an incongruent color, and the subject is required to name the colors in which the words are printed. For all three cards, the number of (correct) items finished in 45 s was measured. As performance on the *C/W* card is directly influenced by performance on the *C* and *W* cards, an interference score was calculated with the following formula: interference = Stroop $C/W - [(WC)/(W + C)]$ (Golden, 1978). Both this interference score and the number of errors on the *C/W* card were used.

2.2.4. Planning

Stockings of Cambridge (SOC) (CANTAB), a computerized version of the Tower of London test, was used to assess planning ability. Two displays with colored balls are presented, and subjects have to adjust one display so that it matches the other one. Subjects are instructed to adjust the display in a minimal number of moves (ranging from two-step problems to five-step problems). The subject is instructed to first think about the moves to be performed before starting moving balls. A maximum number of moves (5, 7, 9, and 12 moves for two-, three-, four- and five-step problems, respectively) is allowed before the trial terminates and the next problem is introduced. The number of problems solved in minimal moves was of interest.

2.2.5. Working memory

The spatial working memory test of the CANTAB and the digit span backward test were completed to examine working memory. In the *spatial working memory* test several boxes are displayed, in one of which a blue token is hidden. Subjects have to search for this token and, once found, collect them in an empty space on the right side of the screen. Once a token is found, a new token is hidden. Subjects were instructed that once a token was found, that particular box would never be used again to hide a token. The number of 'between errors', which represents the number of times subjects re-open a box where a blue token had already been discovered in was considered. In the *digit span backward* test (Wechsler, 1987) an order of digits is orally presented. Following presentation, participants are requested to repeat the digits in the reversed order. The number of the digits presented gradually increases following successful performance. Total number of correct reproductions was of interest.

Each raw test score was transformed into a standardized *z*-score. Average *z*-score were calculated for each function within the executive domain. This resulted in a single score for each function (i.e. a flexibility, fluency, inhibition, planning and working memory score). Scores were adjusted so that a higher value always represented better performance.

2.3. Procedure

The MMSE was always administered prior to other cognitive tests, in order to include only those subjects with a score of 24 and higher. The total administration of the tests was divided between two different occasions, always in the same order, in order to prevent fatigue effects. Time interval between both test sessions was less than 2 weeks. Testing always occurred in the morning (i.e. between 10 and 12 a.m.) or the afternoon (i.e. between 2 and 4 p.m.). The first BP measurement was performed at the end of the second test session, according to the guidelines described above.

2.4. Statistical analysis

The analyses were performed using SPSS Version 11.5 (SPSS Inc., Chicago, IL). Chi-square tests, or Fisheřs exact test if appropriate, were performed to test for possible differences in gender, use of antihypertensive agents, and presence of diabetes mellitus, cardiac disease, hypertension and smoking behavior, between the BP groups. Furthermore, Kruskal–Wallis tests were performed to assess possible differences in age, education, MMSE, and depressive symptoms between the SBP groups. Finally, Mann–Whitney U tests were performed to examine possible differences in these baseline variables between the DBP groups.

Analyses of variance (ANOVA's) were conducted with the cognitive domains as dependent variables and the BP groups as predictors. Post hoc tests were performed with Bonferroni correction.

3. Results

Analysis revealed that the SBP groups did not differ in age, education, depressive symptoms, gender, use of antihypertensive agents, or presence of diabetes mellitus, cardiac disease, hypertension, and smoking behavior. The MMSE score differed significantly between groups, with the lowest performance in the high SBP group (Table 1). The DBP groups did not differ on any of the baseline characteristics examined (Table 2). When smoking behavior was re-examined in terms of never, former, or current smoker, again no group differences with regard to this variable were found. Since age, education, depressive symptoms, gender, use of antihypertensive agents, diabetes mellitus, hypertension, cardiac disease, and smoking behavior, factors that can all be considered to confound cognitive task performance, did not differ significantly between groups, these variables were not controlled for in further analyses.

3.1. Blood pressure and cognitive performance

Main effects of SBP and DBP were of interest. Significant effects of SBP were present for flexibility ($F(2,59) = 4.98$, $p < .05$, partial $\eta^2 = .14$) and fluency ($F(2,72) = 5.65$, $p < .01$, partial $\eta^2 = .14$) ability. Examination of the results revealed superior fluency and flexibility performance of the normal SBP (<120 mmHg) compared to the high SBP ($\geq$140 mmHg)

Table 3
Executive function performance in the SBP groups

Executive function	SBP (mmHg)			F	p
	Normal (<120)	Medium (120–139)	High ($\geq$140)		
Flexibility	0.61 (0.27)[b]	0.12 (0.21)	−0.38 (0.18)	4.98	.01
Fluency	0.72 (0.23)[a]	−0.14 (0.16)	−0.12 (0.15)	5.64	.005
Inhibition	0.31 (0.27)	−0.09 (0.21)	0.01 (0.18)	<1	.50
Planning	0.44 (0.30)	−0.01 (0.20)	−0.11 (0.19)	1.2	.30
Working memory	0.20 (0.20)	0.01 (0.14)	−0.07 (0.12)	<1	.55

Values represent mean z-scores (S.D.) and higher scores reflect better performance. SBP: systolic blood pressure.
  [a] Normal SBP > medium ($p < .01$) and high ($p < .05$) SBP.
  [b] Normal SBP > high SBP ($p < .01$).

Table 4
Executive function performance in the DBP groups

Executive functions	DBP (mmHg)		F	p
	Normal (60–79)	Medium (80–89)		
Flexibility	0.05 (0.16)	−0.14 (0.24)	<1	.51
Fluency	0.04 (0.12)	−0.01 (0.20)	<1	.93
Inhibition	0.06 (0.14)	−0.02 (0.23)	<1	.76
Planning	0.00 (0.15)	0.07 (0.24)	<1	.82
Working memory	0.06 (0.10)	−0.11 (0.16)	<1	.37

Values represent mean z-scores (S.D.) and higher scores reflect better performance. DBP: diastolic blood pressure.

group, and superior fluency performance of the normal SBP (<120 mmHg) compared to medium SBP (120–139 mmHg) group (Table 3). No DBP effects were noted (Table 4).

4. Discussion

The present study provides more insight into possible associations between BP and executive function performance in residents of homes for the elderly. The normal SBP group (<120 mmHg) performed superior on the fluency and flexibility tests. No other associations between BP, including DBP, and executive function were noted.

This is the first study to assess several executive functions in relation to BP in residents of homes for the elderly. Associations between BP and flexibility and fluency performance, as observed in the present study, have been reported previously (Kilander, Nyman, Boberg, & Lithell, 2000; Waldstein et al., 2005). While fluency and flexibility were significantly related to BP, no further executive functions were. One possible explanation might be related to the diverse cognitive functions assessed with certain tests. As high BP strongly affects both frontal and temporal lobe integrity (Den Heijer et al., 2005; Raz, Rodrigue, & Acker, 2003), it can be argued that tests sensitive to both frontal and temporal dysfunctioning are most strongly associated with BP. This might be crucial when examining cognitive functions in a population, such as residents of homes for the elderly, characterized by a decline in numerous cognitive domains. For both fluency and flexibility functions, evidence suggests a concomitant role of both frontal and temporal lobe involvement in test performance (Alessio et al., 2006; Leskelä et al., 1999; Zakzanis, Mraz, & Graham, 2003). The importance of temporal lobe processing in these tasks is further supported by the notion that performance on these tests might be equal or even reduced in patients with Alzheimer's disease compared to vascular dementia patients (who are typically characterized by executive dysfunctioning) (Baillon et al., 2003; Vanderploeg, Yuspeh, & Schinka, 2001). In these studies, patients were free from possible mixed types of dementia. In addition, inhibition (Stroop interference), planning, and working memory ability appear to be largely dependent on frontal and parietal functioning (Cabeza & Nyberg, 2000; Newman, Carpenter, Varma, & Just, 2003). As such, a differentiation between various functions within the executive domain is appropriate.

However, cognitive tests of the type employed here tap a variety of cognitive functions and a deficit in any function might result in reduced executive ability. This implies that the current observed decline in fluency and flexibility performance might not necessarily be related to deficits in executive function. For example, verbal ability might significantly contribute to fluency performance, whereas psychomotor speed might confound TMT-B performance. These factors may have biased the present results. Nonetheless, several possible confounders, including educational attainment, which strongly relates to verbal ability, did not differ between the BP groups. The TMT-B score used in the analysis, in addition, was corrected for TMT-A, or psychomotor speed, performance. Therefore, although some confounding effects cannot be ruled out, it is not likely that these factors fully mediate the observed association between BP and task performance.

The present study revealed a high prevalence of systolic hypertension, but not of high DBP, which was observed in a single patient only. The prevalence of isolated systolic hypertension (ISH) is known to be quite high in the old age, mediated by a decrease in DBP starting at 50 years of age with a concurrent rise in SBP (Franklin, 2004). We report similar observations in that ISH (SBP ≥ 140, DBP < 90) was present in 34 subjects (44.7%). The importance of controlled SBP in regard to cognitive functioning is stressed by the observation that normal SBP was associated with better performance on fluency and flexibility tests.

Several aspects increase the strength of the present study. First of all, several factors known to influence cognitive task performance, including depressive symptoms, education, sex, and co-morbid cardiovascular disease, were taken into consideration. Secondly, BP was measured on two different occasions. The strong correlations between both readings imply high reliability of the BP ratings in the current study.

A limitation of the present study is that no longitudinal information is available, in that the effects of midlife BP on cognitive functioning in this population are unknown. As BP changes across the lifespan, it rises approximately until the age of 75 after which it decreases, it is unclear whether current normal SBP is related to, for example, normal or high SBP in midlife. It could also be argued that several participants with normal or medium high SBP suffered from high SBP in earlier years. As such, effects of BP may be underestimated in the present study. Another drawback is that selecting a group of 'cognitive intact' elderly, expressed by an MMSE-score ≥ 24, might have affected outcomes. Examining a larger range of subjects without a diagnosis of clinical dementia (i.e. allowing subjects with an MMSE < 24 to participate) might result in additional associations between BP and executive functions. This introduces

another potential limitation of the present study, in that the MMSE was applied as an exclusion criterion. We used a previously validated score of 23 and lower (Grut et al., 1993) to exclude possible dementia. However, this cut-off score was applied to all participants without considering age and education, whereas both factors are strong predictors of MMSE performance (Bravo & Hebert, 1997). The present study may therefore contain a selection bias. Nonetheless, in an old population such as included in the present study, even highly educated subjects will have MMSE-scores around 27 (Bravo & Hebert, 1997), which is comparable to the average performance of the entire current study sample, irrespective of education. The bias that is likely to be present in the present study may therefore be the selection of residents with relatively high cognitive ability. This may have moderated the relationship between BP and executive function.

The association between BP and various executive function domains in residents of homes for the elderly was assessed in the present study. Even in such an old population, BP still predicted some functions within the executive domain. This indicates the importance of controlled BP, as well as a critical examination of the various functions that are all labeled as executive functions.

Acknowledgements

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