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Nonlinear Blood Pressure Effects on Cognition in Old Age: Separating Between-Person and Within-Person Associations

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Abstract

Midlife hypertension is associated with increased risk of cognitive impairment in later life. The association between blood pressure (BP) in older ages and cognition is less clear. In this study we provide estimates of between-person and within-person associations of BP and cognition in a population-based sample ($N = 382$) followed from age 70 across 12 occasions over 30 years. Between-person associations refer to how individual differences in BP relates to individual differences in cognition. Within-person associations refer to how individual and time specific changes in BP relate to variation in cognition. Hierarchical linear models were fitted to data from three cognitive measurements (verbal ability, spatial ability, and perceptual speed) while accounting for demographic and health-related covariates. We found consistent nonlinear between-person associations between diastolic BP (DBP) and cognition, such that both low (<75 mmHg) and high (>95 mmHg) pressure were associated with poorer cognition. Within-person decreases in systolic BP (SBP) and DBP were associated with decreases in perceptual speed. Notably, between-person and within-person estimates did not reveal similar associations, suggesting the need to separate the two effects in the analysis of associations between BP and cognition in old age.

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Keywords

blood pressure; cognitive function; longitudinal study; between-person; within-person associations

High midlife blood pressure (BP) has been associated with risk of late-life cognitive impairment (Elias, Wolf, D'Agostino, Cobb, & White, 1993; Launer, Masaki, Petrovitch, Foley, & Havlik, 1995) and dementia (Kivipelto et al., 2001; Launer et al., 2000). However, results from studies on the link between late-life BP and cognition are mixed. Some studies report negative associations with high BP corresponding with poorer cognitive function (Tzourio, Dufouil, Ducimetière, & Alperovitch, 1999; Waldstein, Brown, Maier, & Katzel, 2005), while others report positive associations with low BP corresponding with poorer cognitive function (Guo, Fratiglioni, Winblad, & Viitanen, 1997; Molander, Gustafson, & Lövhem, 2010; Nilsson, Read, Berg, Johansson, & Lindblad, 2007), still others report small, or nonsignificant associations (Hebert et al., 2004; Solfrizzi et al., 2004), and yet others report nonlinear associations where both high and low BP are associated with impaired cognitive function (Bohannon, Fillenbaum, Pieper, Hanlon, & Blazer, 2002; Glynn et al., 1999; Waldstein, Giggey, Thayer, & Zonderman, 2005). BP has also been found to decline over the course of dementia (Burke, Coronado, Schmitt, Gillespie, & Chung, 1994), and this decline may have onset that precedes the dementia diagnosis by several years (Petitti, Crooks, Buckwalter, & Chiu, 2005; Qiu, von Strauss, Winblad, & Fratiglioni, 2004; Skoog et al., 1996). Cognitive decline has also been shown to start long before there is evidence enough for a clinical diagnosis of dementia (Amieva et al., 2005; Thorvaldsson et al., 2011). Together these findings highlight a need for a more detailed analysis to clarify the association between changes in BP and cognition in old age.

Separating Between-Person From Within-Person Associations

Within the context of a longitudinal study, change in both BP and cognitive function are time-varying variables containing both between-person and within-person variability. That is, individuals differ from each other, but they also vary relative to their previous values over time. These two sources of variability (i.e., between-person and within-person) are likely to be affected by different influences or to a varying degree by the same factors, and can be expected to result in differences in the associations between BP and cognitive function at the between- and within-person levels of analysis. One of the challenges in analysis of associations between BP and cognitive function is to properly test differences in the associations at the two levels. If different results between levels of associations are evident, then aggregated analysis will lead to biased estimates and the two levels of associations need to be separated.

There are reasons why we may expect differences between the between-person and within-person associations across BP and cognitive functioning in old age. Long-term hypertension is associated with cerebrovascular damage and cognitive impairment (see, e.g., Kennelly, Lawlor, & Kenny, 2009). In assuming a linear association, we expect negative between-person associations because individuals with a tendency for high BP also are likely to show poorer cognitive function (see between-person effect in Figure 1a). However, longitudinal studies have also shown that within-person decline in BP is associated with brain atrophy and neuropathology (e.g., den Heijer et al., 2003; Skoog, Andreasson, Landahl, & Lernfelt, 1998). We may, therefore, expect positive within-person associations as individuals who exhibit decreases in BP are also likely to exhibit cognitive decline (see within-person effect in Figure 1a).

As shown in Figure 1a, if the between-person effect of BP on cognitive function is negative (i.e., high BP is associated with poor cognitive function) and the within-person effect is positive (i.e., decline in BP is associated with decline in cognitive function), then effects obtained in analyses not accounting for differences in between- and within-person estimates simply represent an aggregate of the two effects (see aggregated effect in Figure 1a). In addition, as individuals with hypertension or hypotension (i.e., low BP) have a tendency for poorer cognitive function compared with those within the range of normal BP, we also test between-person quadratic effects (i.e., nonlinear effects; see Figure 1b).

In this study, we conduct analyses of both between-person differences and within-person changes in order to evaluate the link between BP and cognition. The models were fitted to data obtained from a representative sample, drawn from the general Swedish population, with repeated BP measures and cognitive assessments over 30 years, or until death, from a baseline age of 70 years.

Methods

Participants

The data were drawn from the Gerontological and Geriatric Population Studies in Gothenburg, Sweden (H70). This study started in 1971 when all individuals living in Gothenburg, born between July 1, 1901 and June 30, 1902, were identified from the Swedish Population Register. All individuals born on dates ending with 2, 5, and 8 (approximately one-third of the total population of 70-years-olds; $N = 1148$) were selected and invited to participate in the study. A subsample of 460 was systematically drawn for participation in subsequent psychiatric and psychological examinations including cognitive assessments. Participation rate in this part of the study was 85%, leaving a sample of 392. In this sample, 10 individuals were already diagnosed with dementia at baseline and were excluded from the analyzed sample. Measurements and subsequent follow-ups were conducted at ages 70, 75, 79, 81, 85, 88, 90, 92, 95, 97, 99, and 100. The baseline sample was representative of the general population on various demographic and health-related variables (see Rinder, Roupe, Steen, & Svanborg, 1975; Svanborg, 1977). The nonmortality attrition rate after baseline was low at each occasion (5%–17%) and average age of death was 83.4 years ($SD = 7.50$). The study was approved by the Ethical Committee for Medical Research at the University of Gothenburg and all participants gave their written informed consent.

Cognitive Assessments

Synonyms—The Synonym test is a measure of verbal ability in which participants are instructed to match a target word with a synonym among five choices (Dureman, Kebbon, & Österberg, 1971). The maximum score is 30 and the time limit is 7 min. Words were presented in a magnified form if participants had problem reading due to visual impairment.

Block Design—The Block Design test is an indicator of spatial ability where participants are presented with blocks and asked to construct replicas of prototypes presented to the participants in colors (Wechsler, 1981). The maximum score is 42 and the time limit is 20 min.

Figure Identification—The Figure Identification test is a measure of perceptual speed in which participants are instructed to match, as fast as possible, a target figure with an identical figure placed in line among four other (Dureman et al., 1971). The maximum score is 60 and the time limit is 4 min.

The Synonym test was administered on all measurement occasions, whereas the Block Design test was omitted at age 81 and the Figure Identification test was omitted at age 81 and 100. Detailed description of the tests, scoring methods, and psychometrical properties can be found elsewhere (see Berg, 1980; Dureman et al., 1971; Thorvaldsson, Hofer, Berg, & Johansson, 2006). In order to facilitate comparisons across cognitive variables, we standardized the test scores to a distribution with a mean of 50 and standard deviation of 10 using the baseline distribution for each test. All cognitive measurements after time of diagnosis of dementia were excluded from the presented analyses.

Blood Pressure

BP was measured with a mercury sphygmomanometer in the right arm in a seated position after 5 min rest and registered to the nearest 5 mmHg. Diastolic blood pressure (DBP) was defined as Korotkoff phase 5. Both systolic blood pressure (SBP) and DBP were measured with the same procedure across measurement occasions.

Dementia Diagnosis

Diagnosis of dementia was made according to the Diagnostic and Statistical Manual of Mental Disorders (*DSM-III-R*) criteria (American Psychiatric Association, 1987) and based on information from psychiatric examinations and interviews with close informants. Prior to 1986, the diagnoses were based on information about disorientation in time and place or long-standing memory impairment, as measured by rating scales and information from case records or relatives (see Skoog, Nilsson, Palmertz, Andreasson, & Svanborg, 1993). Agreement between the two diagnostic criteria was high (Wancata, Börjesson-Hanson, Östling, Sjögren, & Skoog, 2007). All diagnoses were set by a geriatric psychiatrist without awareness of results from the cognitive test battery.

Covariates

In all subsequent analyses we used gender, education, smoking, Temperance board registration (i.e., register of individuals identified with serious alcohol problems), stroke, and antihypertensive medication as covariates (see Table 1). Education was coded as zero if the individuals had six years or less (i.e., compulsory education for this cohort) and one if they had more than six years. Smoking and Temperance board registration for alcohol abuse was coded zero if never and one if ever. Stroke and antihypertensive medication were coded as time-varying covariates taking a value of zero if never and one after the time of stroke or initiation of medication.

Statistical Analyses

To model associations between BP and cognition we fitted two hierarchical linear models (see Raudenbush & Bryk, 2002; Snijders & Bosker, 1999). In the first model, we included BP as a time-varying predictor centered at the sample mean. This is known as a grand-mean centering model and can be written as

$$\text{Cognition}_{ij} = \gamma_{00} + \gamma_{10}\text{Age}_{ij} + \gamma_{20}\text{Blood Pressure}_{ij} + u_{0i} + u_{1i}\text{Age}_{ij} + r_{ij}, \quad (1)$$

where the outcome is the cognitive performance of individual i at time j , modeled as a function of an intercept γ_{00} that can be interpreted as the estimated outcome value when other covariates in the equation have the value of zero, γ_{10} is the linear slope of chronological age (approximately identical to time-in-study as this is a single age cohort) with values varying across individuals and time, and γ_{20} is the linear slope of BP that varies across individuals and time. The u_{0i} and u_{1i} are random effects of the intercept and age slope

and interpreted as individual deviations around the respective fixed parameters. The r_{ij} is the individual and time specific residual. However, a major limitation of this modeling approach is that it does not allow us to separate the between-person association of BP and cognitive function from the within-person association. In fact, the γ_{20} parameter will be a mixture, or an aggregate, of both effects as determined by the proportion of between-person and within-person variability in the data.

To separate the between-person association from the within-person association, it is necessary to include within-person means (i.e., mean for each specific individual) as a time invariant covariate into Equation 1. This is known as group-mean centering (e.g., Raudenbush & Bryk, 2002), but as we are modeling time as nested within individuals, and not individuals nested within groups, we may refer to this approach as person-mean centering (e.g., Hoffman & Stawski, 2009). This model can be written as

$$\begin{aligned} \text{Cognition}_{ij} = & \gamma_{00} + \gamma_{10}\text{Age}_{ij} + \gamma_{20}\text{Blood Pressure}_{ij} \\ & + \gamma_{01}\text{Person Mean Blood Pressure}_i + u_{0i} \quad (2) \\ & + u_{1i}\text{Age}_{ij} + r_{ij}, \end{aligned}$$

where γ_{20} is now a linear slope of BP after accounting for between-person differences in BP and reflects the within-person association. The γ_{01} parameter, however, reflects differences in the within-person and between-person associations and provides a test of the convergence of the two. By a simple modification of this model, the BP variable is centered on the within-person mean to obtain direct estimates of both the between- and within-person associations. This model can be written as

$$\begin{aligned} \text{Cognition}_{ij} = & \gamma_{00} + \gamma_{10}\text{Age}_{ij} + \gamma_{20}(\text{Blood Pressure}_{ij} \\ & - \text{Person Mean Blood Pressure}_i) \\ & + \gamma_{01}\text{Person Mean Blood Pressure}_i + u_{0i} \quad (3) \\ & + u_{1i}\text{Age}_{ij} + r_{ij}, \end{aligned}$$

and provides an equivalent fit to the model presented in Equation 2. Now, γ_{20} refers to the within-person association, as before, but γ_{01} refers directly to the between-person effect. A quadratic (i.e., nonlinear) between-person effect (see Figure 1b) can then be added to this model by inclusion of additional fixed parameter defined as $\gamma_{02}\text{Person Mean Blood Pressure}_i * \text{Person Mean Blood Pressure}_i$.

In all the presented models we used a full maximum-likelihood function to estimate the parameters and compared nested models with a likelihood-ratio chi-square test and a Wald test. These two methods lead to the same final models. All individuals were born within one year and measured at approximately the same age (within a one-year interval). Between-person differences in age are, therefore, not confounded with the model estimates (see, e.g., Sliwinski, Hoffman, & Hofer, 2010).

Results

We first calculated the intraclass correlation coefficients (ICC) for the BP and cognitive variables to determine the proportion of between-person and within-person variability in the data (see, e.g., Snijders & Bosker, 1999). The proportion of the total variability attributed to within-person variation ($1 - \text{ICC}$) was 56% in SBP, 66% in DBP, 34% in verbal ability, 48% in spatial ability, and 58% in perceptual speed.

Estimates from the fitted linear models are shown in Table 2. All models include age (both fixed and random effects), antihypertensive medication, stroke, gender, education, smoking,

and Temperance board registration of alcohol abuse as covariates. We conducted separate analyses using data obtained from the total sample, only individuals that remained nondemented until death (noncases), and only incident dementia cases with data after time of diagnoses omitted from the analyses. As there were only minor differences in the findings after stratifying the sample according to subsequent dementia status, we report results for the total sample in Table 2 and for noncases and dementia cases as found online in supplemental material S1. The upper part of Table 2 shows the SBP estimates and the lower part the DBP estimates.

Grand Mean Centering Models

Estimates of the aggregated associations of BP and cognitive function from the grand mean centering models (see discussion of Equation 1 in the analytical section) were small and nonsignificant (ranging from -0.01 to 0.01 for SBP and -0.01 to 0.03 for DBP). These estimates were similar to the hypothesized aggregated effect plotted in Figure 1a and can be presented by approximately a flat line. Note that these models treat BP as an aggregated variable of between-person and within-person effects.

Group Mean Centering Models

Within-person effects—Based on estimates from the group mean centering models (see Equations 2 and 3), the within-person effects of SBP and DBP were significant and positive for perceptual speed but nonsignificant for verbal ability and spatial ability. These estimates indicate that changes in BP are associated with changes in perceptual speed after accounting for individual differences in level of BP, age, and the other covariates. These associations were more apparent for DBP (total sample = 0.09 , noncases = 0.10 , cases = 0.08) as compared with SBP (total sample = 0.03 , noncases = 0.02 , cases = 0.06). Based on estimates from the model fitted to the total sample, a decline in DBP by 10 mmHg was associated with decline in perceptual speed by 0.9 standardized units (i.e., 9% of the baseline between-person standard deviation). Note, according to estimates from unconditional random linear models (not shown), 78% and 93% of the population was estimated to show decline on SBP and DBP, respectively.

Between-person effects—The between-person effects (see Equation 3) of DBP were significant and negative for all three cognitive measures (ranging from -0.10 to -0.12), indicating that individuals with high DBP tend to exhibit lower cognitive performance. As an example, if an individual has a 10 mmHg higher average value on DBP as compared with the population mean value, she/he is estimated to score 1.0 standardized unit below the population mean on verbal ability and perceptual speed, and 1.2 units below the mean on spatial ability. The between-person SBP effects were nonsignificant on all cognitive outcomes (ranging from -0.03 to -0.01).

Convergence between effects—Differences among the between-person and within-person effects were consistently significant in the DBP models. In the SBP models there was a significant difference on perceptual speed. These parameters provide a test of the convergence of the two types of associations (see Equation 2). To provide demonstration of the divergence of the two effects, we have in Figure 2 plotted the between-person and within-person effects of DBP on perceptual speed. This figure demonstrates that the between-person association is negative and the within-person association is positive and that the two effects do, therefore, not converge on a similar estimate. The between-person association indicates that those individuals who on average have higher DBP as compared with others in the sample, also tend to score poorer on the perceptual speed test (i.e., negative association). The within-person associations, however, indicate that when individuals deviate from their own average level they also tend to vary in the same direction

on the speed test. Most individuals in this sample show a decline in BP, and this decline is associated with decline on the perceptual speed test. In estimation of the between- and within-person trends, we account for the effects of chronological age and other covariates.

Nonlinear effects—A quadratic between-person slope term was added into the models (i.e., Equation 3) in order to estimate a nonlinear trend. Estimates from these models fitted to the total sample are shown in Table 3, and stratified analyses for noncases and subsequent dementia cases are found online in supplemental material S2. These analyses revealed a significant quadratic between-person effect of SBP on spatial ability, and a close to significant nonlinear effect on verbal ability ($p = .075$). The nonlinear between-person effect of DBP was significant for both verbal ability and perceptual speed, and close to significant for spatial ability ($p = .057$). These effects were more apparent for the DBP compared with the nonlinear SBP effects. The between-person effects from these models are plotted in Figure 3 and demonstrate nonlinear association where both low and high (approximately <75 and >95 mmHg) DBP is associated with poorer cognitive function. Nonlinear within-person BP effects were also estimated and found nonsignificant in all models.

Stratified analyses according to antihypertensive medical treatment—Lastly, we fit the final quadratic models to the data after stratifying the sample according to treatment of antihypertensive medications. Estimates from these models are shown in Table 4 and demonstrate a stronger between-person effect among the nontreated. This is most evident in the DBP models where both the linear and quadratic components were larger among the nontreated on all cognitive outcomes. The within-person SBP and DBP effects on the perceptual speed measure were, however, more evident among the treated (SBP = 0.05, $p = .01$; DBP = 0.13, $p < .001$) as compared with the nontreated individuals (SBP = 0.01, $p = .48$; DBP = 0.03, $p = .41$). The within-person SBP effect on verbal ability was additionally positive and significant among the treated but not among the nontreated individuals.

Discussion

In this study we estimated the associations between BP and cognition in a sample systematically drawn from the population in the city of Gothenburg in 1971, first examined at age 70, and subsequently followed over 30 years or until death. Our analyses revealed three main findings. First, between-person associations between BP and cognition were nonlinear. That is, the association was an inverted U shaped where low and high BP was related to worse cognitive performance. Second, within-person association between BP and perceptual speed was linear and positive, such that individual and time-specific decline in BP was related to decline in perceptual speed. Third, between-person and within-person associations between BP and cognition did not converge on a similar estimate (i.e., they differed).

Nonlinear association between BP and cognition has been previously reported (e.g., Bohannon et al., 2002; Glynn et al., 1999; Waldstein, Giggey, et al., 2005). Others have shown that both hypertension (e.g., Tzourio et al., 1999; Waldstein, Brown et al., 2005) and hypotension (e.g., Guo et al., 1997; Molander et al., 2010; Nilsson et al., 2007; Ruitenberg et al., 2001) in old age are associated with cognitive impairment and risk of dementia. Long-term hypertension is associated with atherosclerosis and arteriosclerosis, which may lead to impaired blood circulation in the brain, ischemia, stroke, and cognitive impairment (see, e.g., Kennelly et al., 2009). Hypotension may additionally lead to low blood circulation in the brain, but may also be caused by Alzheimer-related neuropathology in the BP regulating areas (e.g., hypothalamus, medial prefrontal cortex, and amygdala) (see, e.g., Skoog & Gustafson, 2006).

The estimated associations were more apparent for DBP than for SBP. Higher DBP has been associated with the thickening of vessel walls in small brain arterioles and white-matter lesions (e.g., Guo et al., 2009), which also may lead to cognitive impairment (e.g., Skoog, Berg, Johansson, Palmertz, & Andreasson, 1996). Interestingly, the associations were stronger among individuals not treated with antihypertensives. Others have found similar results (Launer et al., 2000; Stewart et al., 2009). This may reflect a protective effect of the treatment, or that the treatment reduces the mediating associations of a third variable (e.g., cardiovascular risk factor). Our findings do not support the view that high BP in old age is protective of cognitive impairment. Rather, the findings suggest that the optimal DBP in old age, in terms of its association with cognition, is between 75 and 95 mmHg. These values should be considered an approximation based on average population values and not necessarily generalizable to an individual case.

Within-person decline in SBP and DBP was linearly associated with the decline in perceptual speed after accounting for individual differences in BP and other covariates. Alzheimer's disease-related neuropathology (see, e.g., Blennow, de Leon, & Zetterberg, 2006) may account for these findings as it may affect brain areas that are important for BP regulation and perceptual-motor execution. In previous studies, we have shown that this measure of perceptual speed is particularly sensitive to the identification of individuals in the phase of preclinical dementia and subsequent mortality many years prior to the clinical diagnosis (Thorvaldsson et al., 2011) and death (Thorvaldsson et al., 2008). White matter lesions also present a potential mediator of the association. This claim is supported by the fact that the association was more evident for DBP than for SBP. These associations were also more profound among individuals treated with antihypertensives. The reason for these findings is unclear but may relate to the fact that individuals in the antihypertensive group are more likely to have a longer history of vascular burden (see Skoog & Gustafson, 2006), which may interfere with their abilities to compensate for pathology in the BP regulation areas. Another potential explanation may be that individuals in the antihypertensive group need higher BP to maintain adequate cerebral perfusion and cognition (Ruitenberg et al., 2001), so when BP declines it is accompanied by cognitive decline.

Most importantly from an analytical standpoint, our findings demonstrate that between-person and within-person associations between BP and cognitive function differ (i.e., they do not converge on a similar estimate). The associations were in fact in the opposite direction on measurements of perceptual speed where the between-person association was negative and the within-person association positive. If the BP variable is simply treated as an aggregated effect, as was done in our grand mean centering model (Equation 1), there is a high risk of false conclusions (i.e., inferential fallacy) concerning the association between BP and cognition. This is because the estimated BP effects will then be a mixture of between-person and within-person effects weighted by the proportion of the between-person and within-person variability in the analyzed data (e.g., Raudenbush & Bryk, 2002). Note, for example, that our estimates from the grand mean centering models were always small and nonsignificant. A recommended approach is to first test the convergence of the between-person and within-person effects, as was done in the person mean centering model (Equation 2) (Snijders & Bosker, 1999). If the difference turns out to be nonsignificant, only then are aggregated analyses legitimized. If the difference is significant, then aggregated analysis is not warranted and a simple extension of the person mean model (Equation 3) will provide the separated estimates.

Another methodological issue that should be considered is that a single measurement at each wave of data collection with presumably short-time fluctuations (Gamaldo, Weatherbee, & Allaire, 2008) implies unknown measurement errors both in BP and cognitive measurements. This may lead to underestimation of the association between BP and

cognition. We, therefore, consider the reported associations to be on the lower boundary of the true associations in the general population.

Although nonmortality attrition is low in the analyzed cohort, ranging from 5% to 17% across occasions, it may be a source of bias if the attrition is missing not at random (Little & Rubin, 1987). This type of bias is, however, unlikely to be large in the present analyses given the number and types of covariates included into the models (see, e.g., Schafer & Graham, 2002). Also, previous reports of attrition comparisons from the cohort indicate that the initial sample was representative of the general population on demographic and health-related variables (Rinder et al., 1975) and retained its representativeness over the time of the study (Thorvaldsson et al., 2006). Other potential shortcomings are the small sample size, which may limit statistical power and inhibit stratified analyses (i.e., type of dementia), and that the models were fitted to data from only one birth cohort that was measured on three cognitive abilities, which may limit the generalizability of the findings. We, therefore, encourage replications of these analyses in studies including larger samples, birth cohort comparisons, and other cognitive abilities. Nevertheless, and despite the aforementioned limitations, we would like to emphasize the strength of our analytical approach and that the models were fitted to data drawn from the general population with multiple follow-ups after accounting for relevant covariates, stratifying the analyses according to dementia status, and omitting data measurements after dementia diagnosis.

Our findings imply a nonlinear between-person association between BP and cognition among nondemented older individuals. The association was particularly evident for DBP among individuals not treated with antihypertensive medication. This suggests that factors related to small vessel disease may be important as mediating factors of the association between BP and cognition. Within-person decline in BP was associated with the decline in perceptual speed. Future analyses of the mediating and moderating effects of the association between BP and cognition in old age should consider a separated hypothesis testing procedure for the between-person and within-person associations. The two sources of covariability are unlikely to be affected equally by the same pathology, and clinical implications drawn from data analyses may differ accordingly.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Hypothesized between-person and within-person associations between BP and cognition in old age.

Figure 2.

Linear between-person and within-person effects of DBP on perceptual speed (total sample $N = 382$). The between-person effects refer to association between individual differences in DBP and perceptual speed and the within-person effects refer to association between individual changes in DBP with changes in perceptual speed.

Figure 3. Nonlinear between-person effects of DBP on verbal ability, spatial ability, and perceptual speed (total sample $N = 382$).

Table 1Baseline Descriptive From the H70 Sample, Birth Cohort 1901–1902 ($N = 382$)

Variable	% or M (SD)
Gender (females)	57.9
Education > 6 years ^a	29.8
Smoker	44.8
Temperance board registration ^b	6.3
Stroke	0.8
Antihypertensive medication	24.6
SBP	167.68 (25.47)
DBP	96.99 (13.55)
Verbal ability (Synonyms)	17.10 (6.35)
Spatial ability (Block Design)	13.01 (6.97)
Speed (Figure Identification)	16.10 (8.63)

^aCompulsory education for this cohort.^bRegister of individuals identified with serious alcohol problems.

Table 2

Estimates of Within-Person and Between-Person Linear Effects of SBP and DBP on Cognitive Function in Old Age (Total Sample N = 382)

Cognitive ability	Verbal		Spatial		Speed	
Parameter^a	Estimate	SE	Estimate	SE	Estimate	SE
Grand mean centering ^b						
SBP aggregated effect	0.01	0.01	-0.01	0.01	0.01	0.01
Group mean centering (person mean centering) ^c						
SBP within-person effect	0.02	0.01	-0.008	0.01	0.03 [*]	0.01
SBP between-person effect	-0.01	0.02	-0.03	0.03	-0.03	0.02
Difference ^d	-0.03	0.03	-0.02	0.03	-0.06 [*]	0.02
Grand mean centering						
DBP aggregated effect	-0.005	0.02	-0.02	0.02	0.03	0.02
Group mean centering (person mean centering)						
DBP within-person effect	0.013	0.02	0.005	0.02	0.09 ^{***}	0.02
DBP between-person effect	-0.10 [*]	0.04	-0.12 ^{**}	0.04	-0.10 ^{**}	0.04
Difference	-0.11 ^{**}	0.05	-0.13 [*]	0.05	-0.18 ^{***}	0.04

^a Age, antihypertensive medication, stroke, gender, education, smoking, and Temperance board registration for alcohol abuse are included as covariates in all the models. Data after time of diagnosis of dementia were omitted from the analyses.

^b Equation 1 in the analytical section.

^c Equation 2 and 3.

^d Estimated differences between the between-person and within-person effect of BP on cognition.

^{*} $p < .05$.

^{**} $p < .01$.

^{***} $p < .001$.

Table 3

Estimates of Within-Person Linear and Between-Person Nonlinear Effects of SBP and DBP on Cognitive Function in Old Age (Total Sample N = 382)

Cognitive ability	Verbal		Spatial		Speed	
	Estimate	SE	Estimate	SE	Estimate	SE
SBP						
Within-person effect	0.02	0.01	−0.008	0.01	0.03 [*]	0.01
Between-person effect	−0.004	0.02	−0.02	0.03	−0.02	0.02
Quadratic between-person effect	−0.001	0.0007	−0.002 [*]	0.0009	−0.001	0.006
DBP						
Within-person effect	0.01	0.02	0.003	0.02	0.08 ^{***}	0.02
Between-person effect	−0.10 [*]	0.04	−0.12 ^{**}	0.04	−0.11 ^{**}	0.04
Quadratic between-person effect	−0.006 ^{**}	0.002	−0.004	0.002	−0.005 ^{**}	0.002

^a Age, antihypertensive medication, stroke, gender, education, smoking, and Temperance board registration for alcohol abuse are included as covariates in all the models. Data after time of diagnosis of dementia were omitted from the analyses.

^{*} $p < .05$.

^{**} $p < .01$.

^{***} $p < .001$.

Table 4

Estimates of Within-Person Linear and Between-Person Nonlinear Effects of SBP and DBP on Cognitive Function in Old Age After Stratifying the Sample According to Antihypertensive Medical Treatment (Nontreated $n = 231$, Treated $n = 151$)

Sample	Nontreated			Treated with antihypertensive medication		
	Verbal		Speed	Verbal		Speed
	Estimate	SE	Estimate	SE	Estimate	SE
Cognitive ability						
Parameter^a						
SBP						
Within-person effect	-0.02	0.01	-0.002	0.01	0.04***	0.01
Between-person effect	-0.02	0.03	-0.03	0.04	0.027	0.06
Quadratic between-person effect	-0.002	0.0009	-0.002	0.002	-0.002*	0.002
DBP						
Within-person effect	-0.02	0.03	-0.01	0.05	0.03	0.03
Between-person effect	-0.18**	0.06	-0.16*	0.07	-0.09	0.06
Quadratic between-person effect	-0.01***	0.003	-0.006	0.003	-0.006*	0.003

^a Age, stroke, gender, education, smoking, and Temperance board registration for alcohol abuse are included as covariates in all the models. Data after time of diagnosis of dementia were omitted from the analyses.

* $p < .05$.

** $p < .01$.

*** $p < .001$.