Published in final edited form as:
Psychol Aging. 2013 June ; 28(2): 495–504. doi:10.1037/a0031255.

The Impact of Age and Motivation on Cognitive Effort: Implications for Cognitive Engagement in Older Adulthood

Gilda E. Ennis, **Thomas M. Hess**, and **Brian T. Smith**
Department of Psychology, North Carolina State University, Raleigh, NC 27695-7650, (919) 515-1729, (919) 515-1716 (fax)

Abstract

We examined age differences in the effort required to perform the basic cognitive operations needed to achieve a specified objective outcome and how hypothesized increases in effort requirements in later life are related to intrinsic motivation associated with enjoyment of and participation in effortful cognitive activities. Young (*N* = 59; 20–40 years) and older (*N* = 57; 64–85 years) adults performed a memory-search task varying in difficulty across trials, with systolic blood pressure responsivity—calculated as the increase over baseline during task performance—used as a measure of effort expenditure and task engagement. Consistent with expectations, older adults exhibited greater levels of responsivity (i.e., effort) at all levels of objective task difficulty, and this increase was reflected in subjective perceptions of difficulty. Older adults also exhibited greater levels of disengagement (i.e., effort withdrawal) than younger adults at higher levels of task difficulty, conceivably reflecting the disproportionately greater effort required for successful performance in the former group. We also found that, relative to younger adults, older adults' engagement was more sensitive to the importance attached to the task (i.e., motivation to do well). Finally, we also obtained evidence that increased costs associated with cognitive engagement in later life were negatively associated with intrinsic levels of motivation to engage in effortful cognitive activity. The results support the general conclusion that the costs of cognitive activity increase with age in adulthood, and that these costs influence individuals' willingness to engage resources in support of demanding cognitive activities.

Keywords

Aging; Cognition; Motivation; Effort; Cardiovascular response; Engagement

The efficiency of controlled and effortful cognitive processes declines with increasing age in adulthood (for reviews, see Braver & West, 2008; Park & Payer, 2006). For example, relative to younger adults, older adults require greater environmental support to initiate strategic memory behaviors (Craik & Anderson, 1999), their performance is more negatively affected by cognitive loads (Verhaeghen, Steitz, Sliwinski, & Cerella, 2003), and the demands of sensory processing have a disproportionately negative impact on their cognitive functioning (Murphy, Craik, Li, & Schneider, 2000; Tun, McCoy, & Wingfield, 2009). One possible implication of these findings—and an assumption underlying much theorizing about cognitive aging—is that older adults need to exert more effort than young adults to initiate and maintain cognitive performance. Support for these ideas about aging and cognitive effort has come primarily from relatively indirect methods (e.g., inferences based on performance outcomes associated with task difficulty) or less then reliable indices of

Correspondence should be addressed to Thomas M. Hess, Department of Psychology, North Carolina State University, Raleigh, NC 27695-7801. thomas_hess@ncsu.edu.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

effort (e.g., time spent on task). Neuroimaging research has shown that older adults recruit more regions of the brain to perform at levels similar to young adults (Cabeza, 2002; Cappell, Gmeindel & Reuter-Lorenz, 2010; Mattay et al., 2006), perhaps suggestive of increased effort. Interpretation of these effects, however, is still somewhat speculative.

Hess and Ennis (2012) have suggested that age differences in cognitive effort—and its impact on behavior—might be fruitfully explored through the assessment of certain aspects of cardiovascular (CV) response, especially systolic blood pressure (SBP). SBP response, which describes a change in SBP from a resting state, has been used as a measure of effort or task engagement in a number of investigations with young adults (e.g., Gendolla & Richter, 2006; Gendolla, Richter, & Silvia, 2008; Wright, Martin & Bland, 2003; Wright et al., 2007), an application based on Wright's (1996) integration of Obrist's (1981) active coping hypothesis with Brehm's theory of motivational intensity (Brehm and Self, 1989). According to Wright's (1996) integrative approach, sympathetic nervous system influence upon the CV system is positively associated with subjective task difficulty, as long as successful performance is perceived as possible and worthwhile. Specifically, energy mobilization to meet task demands is thought to be mediated by sympathetic (beta-adrenergic) activity upon the myocardium resulting in increased myocardial contractility: a change reflected in decreases in the pre-ejection period (PEP; i.e., the period between ventricular stimulation and the opening of the aortic valve). Richter, Friedrich, and Gendolla (2008) have found that SBP response, more so than other standard measures of CV responsivity (e.g., diastolic blood pressure [DBP] and heart rate [HR]), is related to task difficulty in a manner similar to PEP. This is most likely because the influence of myocardial contractility upon SBP is more systematic than it is upon DBP, which reflects the minimal pressure between cardiac contractions. Although HR increases in response to sympathetic activity, parasympathetic dominance of this index makes it a less sensitive indicator (Berntson, Quigley, & Lozano, 2007). SBP has been shown to increase systematically with task difficulty up to the point where successful performance is perceived to be still possible; when success is seen as impossible or not worthwhile, SBP declines, reflecting task disengagement (Wright & Dill, 1993). Effort—as evinced in CV responsivity—is also related to perceived ability. Relative to individuals with high perceived ability, those with low ability perception exhibit higher SBP responses, with these responses tailing off at lower levels of task difficulty (e.g., Wright & Dill, 1993; Wright, Murray, Storey, & Williams, 1997). Thus, to the extent that perceived and actual ability overlap, this finding is consistent with expectations that low relative to high ability individuals (a) must expend greater effort to achieve a similar objective level of performance and (b) withdraw effort at lower levels of difficulty, presumably because success seems too costly or impossible (e.g., Wright & Franklin, 2004).

Unfortunately, there has been little systematic work utilizing SBP responsivity to assess cognitive effort in older adults (see Uchino, Birmingham, & Berg, 2010). In an initial study employing this index, Hess and Ennis (2012) found that older adults exerted more effort than young adults to support a fixed level of performance. Sustained cognitive activity was also shown to have greater costs for the old compared to the young. Specifically, high levels of effort devoted to initial tasks required older adults to exert even more effort to maintain performance in subsequent tasks, and older adults who demonstrated the highest levels of effort in subsequent tasks exhibited disruption of task performance. This suggests that older adults' resources may become depleted during demanding cognitive activity, in this case resulting in an increase in the effort needed to support performance. These findings provide initial support for the use of SBP as a means for studying age differences in cognitive effort and their impact on functioning.

The present study builds upon this initial work and extends it in several important ways. First, we examined the impact of task difficulty on age differences in the effort associated with cognitive activity in a more systematic fashion. Hess and Ennis used different tasks at each level of difficulty, potentially complicating interpretation of effects associated with task demands. In the present study, we used a single task but varied the demands of that task across multiple levels. We hypothesized that effort supporting performance would increase with difficulty—at least initially—across age groups, but that older adults would have to expend more effort than younger adults at each level of difficulty to achieve similar levels of objective task performance. Second, we were also interested in changes in effort expenditure where challenges to perceived ability to perform might be most evident. Whereas high levels of effort might result in increased exertion to meet task demands—as in Hess and Ennis (2012)—disengagement from the task might also occur as task demands put pressure on or exceed one's perceived ability to perform. Given the hypothesized age differences in effort requirements, we predicted that older adults would exhibit greater disengagement—as reflected in reductions in SBP response—at both the highest levels of task difficulty and over time. We assume the former effect reflects age differences in perceptions of task difficulty, with older adults reaching perceived limits of their capabilities—and thus disengaging—at an earlier point of objective task difficulty than younger adults. In contrast, disengagement over time is thought more to reflect the greater negative impact of sustained cognitive activity on older adults.

A third novel component of the present study involved the exploration of the relationship between age, effort, and motivation. Consistent with Brehm and Self's (1989) model, Wright, Dill, Geen, and Anderson (1998) observed that SBP responsivity in difficult tasks is sensitive to the meaning attached to the task by the individual. That is, as task difficulty and the associated effort required for successful performance increase, motivational factors (e.g., beliefs regarding the importance of doing well as opposed to situational responses to increases in difficulty) take on increased importance in determining task engagement. Consistent with the notion of selective engagement (e.g., Hess & Emery. 2012), we hypothesized that changes in cognitive effort with age would have two specific effects on the relationship between motivation and behavior in later life. First, the fact that older adults must exert more effort to achieve similar levels of performance relative to younger adults should disproportionately increase the salience of the task with respect to self (e.g., importance). That is, attention to the personal value of the task should increase with age in adulthood in conjunction with the costs of cognitive engagement. This, in turn, should manifest itself in a stronger relationship between effort expenditure and motivation in later life. Hess and colleagues (e.g., Germain & Hess, 2007; Hess, Germain, Swaim, & Osowski, 2009; Hess, Rosenberg, & Waters, 2001) have demonstrated such selective engagement effects on behavioral outcomes in a variety of contexts (e.g., memory, judgments). The present study attempts to demonstrate selectivity at the more fundamental level of cognitive effort, which is assumed to underlie these behavioral effects. We predicted that older adults who are motivated to do well would exert more effort at high cognitive demand levels than older adults who were less motivated. In addition, consistent with the selective engagement hypothesis, we predicted that differences in SBP responses across motivation levels would be more pronounced for older than for younger adults. This differential impact of motivation across age groups reflects the stronger linkage between perceptions of task importance and behavior in later life.

We also examined the relationship between the costs associated with cognitive engagement and the intrinsic motivation to enjoy and engage in cognitively demanding activities. Hess, Emery, and Neupert (2011) demonstrated that self-reported aging-typical declines in physical and sensory resources were related to decreases in both the motivation to engage in cognitively demanding activity and subsequent participation in such activities. Age-related changes in the costs of cognitive activity are likely partial reflections of changes in physical and sensory resources. Thus, we hypothesized that higher levels of cognitive effort required to support an objective level of task performance in later life would be associated with lower levels of intrinsic motivation to engage cognitive resources.

Finally, we also measured subjective responses regarding task difficulty and control over performance in order to address two important issues. We assessed perceptions of task difficulty in order to help establish SBP response as a valid index of age differences in effort expenditure. We expected that these subjective reports would be greater for older than for younger adults, and that these perceptions would be related to SBP responses in a similar manner as objective measures of task demand. We further examined whether perceptions of control over task performance would predict SBP responses in a similar manner as perceptions of ability described in previous work (e.g., Wright & Dill, 1993; Wright et al., 1997), and whether the linkage between control and SBP responsivity would vary with age. Older adults report lower internal and higher external control beliefs regarding cognitive ability than younger adults (Lachman, 1991). Further, a sense of low control over cognitive ability has been found to have a disproportionately greater negative effect upon the cognitive test scores of older relative to younger adults (e.g., Lachman & Andreoletti, 2006; Miller & Gagne, 2005; Miller & West, 2010; Riggs, Lachman, & Wingfield, 1997). Thus, we hypothesized that older adults with lower perceptions of control would exhibit a greater decline in SBP response, indicating more pronounced disengagement, at lower levels of task difficulty than older adults with higher perceptions of control, and that differences in SBP responsivity associated with control would be greater in older compared to young adults.

Method

Participants

Our final sample included 59 younger adults (28 women; 20–40 years of age) and 57 older adults (24 women; 64–85 years of age). Participants were community-based volunteers recruited from the NCSU Adult Development Lab’s database. Differences between the two groups in terms of health and cognitive ability are consistent with normative expectations (Table 1). Initial exclusionary criterion at recruitment was self-reported high blood pressure (i.e., SBP ≥160 mm Hg or DBP ≥ 100 mm Hg). In addition, nine participants were not tested because screening in the lab or baseline measure of SBP was ≥160 mm Hg. Participants were paid $30 for their participation. Data from one young and two older adults were also excluded due to potential cognitive impairment based on scores of 8 or higher on the Short Blessed test (Katzman, Brown, Peck, Schechter, & Schimmel, 1983).

Measures and Equipment

CV responses—The Finometer MIDI (Finapres Medical Systems, Amsterdam, Netherlands) was used to collect continuous measures of blood pressure and heart rate using a cuff that assesses finger arterial pressure. Pressure readings were obtained with each beat of the heart through the volume-clamp method of Peñáz (1973). Automated calibrations, performed throughout pressure collection, defined and maintained the correct diameter at which the finger artery was clamped. Brachial artery systolic and diastolic pressures were extrapolated from finger arterial pressure through the use of waveform filtering and level correction methods through the BeatScope software provided with the system. The technology used in the Finometer MIDI has demonstrated reliability and validity (e.g., Gerin, Pieper, & Pickering, 1993; Guelen et al., 2003)

Memory search task—A Sternberg-type (1966) memory search task was used to examine the effects of task difficulty. Randomly generated strings of consonants (i.e., memory set) were presented on a computer screen for 3 s, followed by a single target consonant. Participants used “yes” or “no” buttons on a response box to indicate whether or not the target was part of the immediately preceding memory set. Participants were presented with five different trial blocks of 30 items each, with the size of the memory set—2, 4, 6, 8, or 10 consonants—being consistent within but varying across trial blocks. Presentation order of the five trial blocks was counterbalanced across participants using five different orders such that each level of difficulty was presented a similar number of times in each serial position within age groups.

Cognitive ability—The vocabulary, digit-symbol-substitution, and letter-number-sequencing subtests from the Wechsler Adult Intelligence Scale-III (WAIS-III; Wechsler, 1997) were used to provide general assessments of ability.

Intrinsic motivation—The Need for Cognition scale (Cacioppo, Petty, & Kao, 1984) assesses the intrinsic cognitive motivation to engage in and enjoy effortful cognitive activities (Cacioppo, Petty, Feinstein, & Jarvis, 1996).

Attitude questionnaire—This instrument included five items assessing general responses to testing on a 9-point scale: (a) how challenging to complete task; (b) concerns that performance would reflect poorly on abilities; (c) nervousness induced by presence of the tester; (d) motivated to do well; and (e) importance of doing well. An additional item was included at posttest assessing perceptions of how worthwhile the task was.

Procedure

Prior to the laboratory session, participants completed the SF-36 Health Survey (Ware, 1993), the Need for Cognition scale, a demographic questionnaire that included questions about medical conditions and medication use, and some additional scales unrelated to the present study. At the laboratory, participants had their blood pressure screened using a BP-785 automatic monitor (Omron Healthcare, Inc., Kyoto, Japan). Next, a finger blood-pressure cuff was attached to the index, middle, or ring finger of the participant’s non-dominant hand. Cardiovascular baselines were established during the last 5 min of a 10-min pre-test relaxation period.[1] After baseline, participants were given five practice trials using a memory set-size of three items, and then completed the attitude questionnaire. The five trial blocks of the memory search task were presented next, with blood pressure data collected continuously during this task. At the end of each trial block, participants provided several ratings on a 9-point scale (1 = not at all; 9 = extremely), including perceived task difficulty, effort required for successful performance, and degree of control over performance. Following the search task, participants completed the attitude questionnaire again, and then were administered the cognitive ability tests. Finally, participants were debriefed and paid.

Analyses

Our primary analytic plan used multilevel modeling (MLM) to examine behavioral data, SBP responsivity, and subjective task perceptions when fully unconditional null models revealed significant between and within participant variance. In the main analyses, memory set-size—as a measure of objective task difficulty—and serial position (Level 1), age group (young = 0, old = 1; Level 2), and cross-level interaction terms were included as predictors. In addition, we included both linear and quadratic effects of the Level 1 variables, dropping the latter if not significant. Two separate sets of analyses were conducted for each dependent

[1]A between-subjects accountability manipulation was included in the original test procedure. Manipulation checks indicated that it was not successful, and thus it is not discussed.

variable (DV). The initial analysis focused on set-size and its cross-level interaction with age using serial position as a covariate, which permitted the examination of task difficulty effects while controlling for effects associated with position of the trial block in the test session. The second analysis reversed the roles played by the two Level 1 variables so that serial position effects could be examined while controlling for task difficulty. This allowed us to assess fatigue-related effects associated with sustained cognitive effort over time.

Results

Responses to Testing

Prior to our primary analyses, 2 × 2 (Age X Time) analyses of variance (ANOVA) were conducted on each of the attitude questionnaire ratings examining subjective responses to the test situation. Significant increases from pretest to posttest were observed in ratings of challenge (*M*s = 3.2 vs. 6.1), concern (*M*s = 3.0 vs. 4.7), motivation (*M*s = 7.1 vs. 7.8), and importance (*M*s = 6.4 vs. 6.9), $F(1,114) = 11.03 – 130.17$, $p \leq .001$, $\eta^2 = .09 – .53$. Significant interactions were also observed for motivation, $F(1,114) = 10.21$, $p = .002$, $\eta^2 = .08$, and importance, $F(1,114) = 4.65$, $p = .03$, $\eta^2 = .04$, due to the change over time being somewhat greater in the old than in the young group. Differences between age groups on these two measures, however, were nonsignificant at each time of test. There were no significant effects relating to concerns about the presence of the tester ($M = 1.8$). The only other age effect was due to the expected finding that older adults perceived the task as more challenging than younger adults (*M*s = 5.1 vs. 4.3), $F(1,114) = 7.17$, $p = .009$, $\eta^2 = .06$. Taken together, there was little evidence that older adults were less motivated or more affected by the testing context than were younger adults, thereby eliminating potential alternative explanations (e.g., stereotype threat) for any observed age effects. In addition, older adults rated the task as significantly more worthwhile than did the younger adults (*M*s = 6.6 vs. 5.8), $t(114) = 2.06$, $p = .001$, suggesting that any observed age differences in engagement could not be attributed to older adults' lower interest in the task.

Memory Search

Accuracy and mean response time (RT) for correct trials were assessed in the memory search task (Table 2). Age differences for RT were consistent with past research. In addition to increases in RT with age and set-size (*p*s < .003), the interaction between these two variables was also significant, $B = 33.05$, $t = 2.00$, $p = .05$, with the age difference in RT increasing as set-size increased. Age also interacted with presentation position, with RT declining faster over time for the old ($b = −39.03$, $p < .0001$) than for the young ($b = −14.63$, $p = .07$). This result replicates past research demonstrating that older adults receive more benefit from task experience (i.e., practice) than do younger adults (e.g., Fisk & Rogers, 1991). Controlling for accuracy did not alter these effects, further reinforcing this practice-based interpretation.

Accuracy scores were examined using 2 × 5 × 5 (Age X Serial position X Set-size) ANOVAs given that fully unconditional MLM null models revealed no significant within-participant variance on this variable. Accuracy declined with both age, $F(1,106) = 17.63$, $p < .001$, $\eta^2 = .14$, and set-size, $F(4,424) = 421.53$, $p < .001$, $\eta^2 = .80$, with the age difference increasing with set-size, $F(4,424) = 3.80$, $p = .005$, $\eta^2 = .04$. We found no systematic effects of serial position on accuracy when it was substituted for set-size in the above analysis.

SBP Response

We next examined SBP responsivity (SBP-R) as a measure of cognitive effort using mean response for each trial block minus baseline. Previous research (Hess & Ennis, 2012) had demonstrated high levels of reliability of this index ($\alpha = .98 – .99$) within 3 – 5 min time periods in a given task. Baseline SBP was included as a covariate. Consistent with expectations, older adults exhibited higher SBP-R than younger adults at all levels of task difficulty, $B = 8.49$, $t = 5.69$, $p < .0001$. In addition, the linear and quadratic effects associated with set-size were significant ($ps = .001$), and both interacted with age: $B_{linear} = 1.11$, $t = 2.72$, $p = .007$, $B_{quadratic} = -.14$, $t = -3.04$, $p = .003$. Although the influence of set-size was significant at each age level, the effects were much stronger for the older adults: young—$B_{linear} = .93$, $p = .001$; $B_{quadratic} = -.11$, $p = .002$; old—$B_{linear} = 2.04$, $p < .0001$; $B_{quadratic} = -.25$, $p < .0001$. As can be seen in Figure 1, SBP-R increased in both age groups initially with an increase in set-size, and then tailed off at the two highest levels of difficulty. To better characterize these effects, we examined age and set-size effects for each adjacent pair of difficulty levels. Older adults exhibited significantly (ps < .01) higher responsivity for each contrast, and significant positive slopes associated with set-size were observed for levels 2 vs. 4 ($b = .74$, $p = .02$) and levels 4 vs. 6 ($b = .82$, $p = .02$). A significant Age X Set-size interaction was also observed for the levels 2 vs. 4 comparison, $B = 1.51$, $t = 3.72$, $p = .0003$. Although significant increases in responsivity with difficulty were observed in both groups, the older adults exhibited a stronger initial increase ($b = 2.25$) than did the young ($b = .74$). The only other interaction between age and set-size was for the levels 8 vs. 10 contrast, $B = -1.15$, $t = -2.83$, $p = .006$. Older adults exhibited a significant *decrease* in responsivity as difficulty increased ($b = -1.31$, $p < .0001$), whereas younger adults responses remained relatively stable ($b = -.17$, $p = .56$). This pattern of effects is consistent with the hypothesis that older adults would exhibit greater disengagement at lower levels of task difficulty than would younger adults.

When serial position effects were examined, a significant Age X Position interaction was obtained, $B = -.72$, $t = -2.29$, $p = .02$, with the old exhibiting significant decline in responsivity over time, $b = -1.14$, $p < .0001$, but not the young, $b = -.41$, $p = .06$ (Figure 1). Controlling for RT reduced the strength of this interaction, but it still remained significant, $B = -.66$, $t = -2.05$, $p = .04$. This suggests that the age effect did not simply reflect the greater increase in efficiency— and presumed reduction in effort requirements—implied by the stronger practice effects observed for RT in the old. Indeed, RT did not mediate the impact of serial position on SBP-R: Sobel test—$t = 1.20$, $p = .23$.

A potential concern in these analyses is that prescription medications for hypertension might have moderated responsivity in the older group, where 31 participants were taking such medication as opposed to only 2 in the young group. To assess their influence, we categorized older participants by the following medication types: beta-blockers ($n = 11$), alpha-blockers ($n = 0$), and other ($n = 20$). We then examined the moderating impact of beta-blockers vs. other hypertension medication vs. no hypertension medication in the old group as an additional Level 2 variable in the foregoing analyses, and found no significant main effects or cross-level interactions involving medication. Thus, hypertension medication did not appear to have a significant impact on our findings.

Taken together, these results are consistent with expectations. Older adults exhibited higher levels of responsivity than did younger adults at all levels of task difficulty, suggestive of greater effort expenditure to support performance. They also exhibited greater decline in responsivity at the highest levels of difficulty and following sustained task performance. Both trends can be taken to represent disengagement as the task becomes too difficult or after extended periods of effort expenditure, with this disengagement effect being stronger for older than for younger adults. Notably, none of these effects were dramatically influenced when either accuracy or RT was controlled, suggesting that the observed age effects were not simply related to age differences in performance (e.g., greater error rate leading to higher levels of arousal in older adults).

DBP and HR Response

We duplicated our main analyses with similarly calculated measures of DBP and HR responsivity (i.e., *M*-level within trial blocks – baseline). For DBP-R, we found responsivity was related to age, $B = 2.31$, $t = 3.59$, $p = .0005$, and set-size, $B_{linear} = .47$, $t = 4.03$, $p < .0001$, $B_{quadratic} = -.05$, $t = -3.51$, $p = .0005$. Set-size also interacted with age: $B_{linear} = .40$, $t = 2.38$, $p = .02$, $B_{quadratic} = -.05$, $t = -2.80$, $p = .005$. No significant effects were observed for serial position. When HR-R was examined, even less systematic variability was observed. The only significant effects observed were due to set-size, $B_{linear} = .58$, $t = 4.91$, $p < .0001$, $B_{quadratic} = -.05$, $t = -4.17$, $p < .0001$, and the Age X Serial Position interaction, $B = -.39$, $t = -2.59$, $p = .01$. Whereas the effects associated with these two measures are similar in nature to those observed with SBP-R, they are somewhat weaker with less variance accounted for in our models. For example, for our primary analyses examining the effects of set-size, 35.0% of SBP-R variance was accounted for in contrast to 32.9% of DBP-R and 16.7% of HR-R variance.

Motivational Factors

We next tested our two motivation-based hypotheses. To examine age differences in the impact of situational motivation on effort, we incorporated self-reported level of motivation to do well (grand-mean centered) on the posttest questionnaire as an additional Level 2 index in our MLM analyses. A significant Age X Motivation interaction was obtained, $B = 2.30$, $t = 2.47$, $p = .02$, with the Age X Motivation X Set-size$_{linear}$ approaching significance, $B = -.52$, $t = -1.92$, $p = .057$. Examination at each level of age revealed no significant motivation effects for young adults (*p*s > .52). For older adults, motivation was positively associated with responsivity, $B = 2.11$, $t = 3.06$, $p = .003$, and significant interactions between motivation and set-size were obtained: $B_{linear} = -.40$, $t = -1.98$, $p = .05$; $B_{quadratic} = .05$, $t = 2.01$, $p = .05$. Comparing set-size effects across motivation levels (±1 *SD* from the mean), significantly higher levels of SBP-R are evident for older adults reporting high motivation at all levels of task difficulty. As seen in Figure 2, the interactions involving set-size reflect the greater initial response to task difficulty in the low motivation participants, and the stronger drop-off in these same participants at the highest levels of task difficulty. These results suggest that older adults reporting high motivation exhibited higher levels of engagement, regardless of task difficulty, and were less likely to disengage at the highest levels of difficulty relative to those reporting low motivation.

We conducted a similar analysis to examine the relationship between intrinsic motivational factors and effort required to support performance using Need for Cognition (NFC) as a Level 2 predictor. Two significant interactions emerged from this analysis: Age X NFC X Set-size$_{linear}$ ($B = -1.08$, $t = -2.28$, $p = .02$) and Age X NFC X Set-size$_{quadratic}$ ($B = .14$, $t = 2.66$, $p = .008$). Examination at each level of age revealed that the interactions between NFC and both set-size effects were significant in the old group (*p*s ≤ .01), but not in the young group (*p*s > .33). As can be seen in Figure 3, older adults reporting low levels of Need for Cognition exerted more effort and exhibited a stronger response to task difficulty than did older adults reporting high levels. This finding is consistent with the notion that, as the costs of cognitive engagement (e.g., level of effort required) in later life increase, motivation to engage in cognitive activity will decrease. Obviously, interpretation of this effect is complicated by our inability to infer causality due to the cross-sectional nature of the data. However, these effects remained when controlling for accuracy (i.e., including accuracy as a Level 1 predictor), suggesting that the differences observed across levels of motivation reflected the effort necessary to achieve a similar level of objective task performance.

Task Perceptions

Perceived task difficulty was calculated by taking the mean of the ratings for difficulty and effort requirements ($r = .79$) for each trial block. These mean ratings were then examined using MLM analyses analogous to those used to examine SBP-R. Perceived difficulty increased with age, $B = .72$, $t = 2.45$, $p = .02$, set-size (controlling for serial position), $B = .75$, $t = 9.24$, $p < .0001$, and presentation position (controlling for set-size), $B = .41$, $t = 2.92$, $p = .01$. In addition, interactions involving age and set-size were also significant: $B_{linear} = .28$, $t = 2.40$, $p = .02$; $B_{quadratic} = -.04$, $t = -3.13$, $p = .002$. These last effects are due to the differences between age groups diminishing somewhat at the highest levels of task difficulty. Similar analyses on ratings of control revealed that older adults had lower perceptions of control than did younger adults, $B = -.75$, $t = -2.55$, $p = .01$. In addition, perceptions of control declined with set-size, with this decrease becoming gradually steeper as set-size increased: $B_{linear} = -.22$, $t = -2.14$, $p = .03$; $B_{quadratic} = -.03$, $t = -2.46$, $p = .02$. Taken together, the subjective ratings were consistent with expectations. Older adults perceived the task to be more difficult than did younger adults at all levels of difficulty, and they also perceived themselves to have less control over their performance.

We next investigated the relationship between subjective responses to the task and responsivity. We first examined the extent to which perceptions of task difficulty predicted SBP-R using the previously described MLM analyses, but substituting the mean difficulty rating (grand mean centered) for set-size at Level 1. Although not as strong, the results were similar to those obtained with the more objective measure of task difficulty. Specifically, a significant quadratic effect of set-size was obtained, $B = -.14$, $t = -2.16$, $p = .03$, with age also moderating this effect, $B = -.24$, $t = -2.55$, $p = .01$. Reflecting a trend similar to that observed with set-size, this latter effect reflected the fact that the quadratic effect was stronger in the older group ($B = -.38$) than in the young group ($B = -.14$). This modulation as a function of perceived task difficulty serves as further validation of use of SBP-R as a measure of effort and engagement in older adults.

We also examined how perceptions of control interacted with task difficulty in determining responsivity. In general, we expected the relationship between control and SBP-R to increase in strength with set-size. In addition to the previously observed effects involving age and set-size, a significant interaction was observed between age, control, and the linear component of set-size, $B_{linear} = -.48$, $t = -2.27$, $p = .02$. Examination of control effects within each age group revealed no relationship between control ratings and responsivity for young adults. In contrast, for the old group, significant effects were observed for control ratings ($B = .97$, $p = .001$) and their interaction with set-size on responsivity ($B_{linear} = -.29$, $p = .03$). Specifically, higher perceptions of control were related to higher levels of responsivity, with the difference being especially strong at the lower levels of task difficulty (Figure 4).

Discussion

The present study explored the relationship between aging and the effort associated with engagement in cognitive activity. We specifically examined age differences in the effort required to perform basic cognitive operations needed to achieve a specified objective outcome as well as how effort requirements influence the relationship between age and the motivation to participate in effortful cognitive activities in everyday life.

Following up on our initial investigation using SBP as a measure of effort (Hess & Ennis, 2012), we replicated the finding that older adults exhibited higher levels of responsivity than younger adults at all levels of objective task difficulty. Importantly, the elevated responsivity in later life did not appear to simply reflect age differences in general CV reactivity to the task in that SBP responsivity was meaningfully related to varying levels of objective task difficulty. Consistent with work with young adults (e.g., Wright et al., 1998), we found that responsivity increased systematically from low to moderate levels of difficulty, and then decreased as difficulty increased. SBP responsivity was also meaningfully related to subjective perceptions of task difficulty and control. In addition, perceived task difficulty increased with age, perhaps suggesting that such perceptions are partially based in participant experiences of the physiological responses associated with effort expenditure.

Whereas the systematic relationships observed with task difficulty support the validity of SBP responsivity as a measure of cognitive effort in both young and older adults, the meaningful relationships observed between responsivity and subjective perceptions of control and task difficulty lend further support. For example, responsivity tended to be higher for participants reporting higher levels of control. In addition, this effect was stronger in older than in younger adults, consistent with other work on aging. The fact that these control effects were most evident at lower levels of task difficulty is somewhat inconsistent with expectations. This may reflect the fact that effort in those with low levels of control is primarily driven by external factors (e.g., task difficulty) whereas intrinsic factors are more dominant in those with high control.

Further support for the validity of the obtained results in terms of reflecting age differences in cognitive effort relate to the fact that the effects were stronger for SBP relative to other indices of CV response. Analyses conducted with DBP and HR responsivity produced a weaker but similar pattern of results compared to those observed with SBP-R. Importantly, however, the similarity of trends across CV indices bolsters the claim that SBP-R reflected increases in beta-adrenergic activity upon the myocardium (Obrist, Light, James, & Strogatz, 1987). This replicates findings from Hess and Ennis (2012), who also found that SBP was most sensitive to task demands in both young and older adults. Given that SBP is partially determined by myocardial contractility--which is dominated by the sympathetic nervous system (Berntson et al., 2007)—the pattern of results obtained with SBP is consistent with Obrist's (1981) proposal that sympathetic nervous system influence on CV response is proportional to level of engagement. Although data regarding SBP responsivity and aging is limited, reactivity does not appear to be suppressed in later life and has been shown to be sensitive to context in spite of a normative increase in SBP in later life (for review, see Uchino et al., 2010). This plus the systematic relationships observed here and in Hess and Ennis (2012) support the validity of SBP as a marker of mental effort in studies of aging.

Another goal of the present study was to explore the linkages between age-related variation in the costs associated with effortful cognitive activity—including effort requirements and associated fatigue/depletion effects—and both the motivation to engage and actual engagement in such activity. Similar to previous research with young adults, SBP responsivity was found to decline after extended effort expenditure and as task difficulty increased. This reduction is thought to reflect disengagement from the task as perceptions of the effort required for successful performance are assumed to be incongruent with the value placed on the task (Gendolla & Wright, 2005). The more dramatic changes associated with these effects in older adults support our hypothesis that age differences in effort requirements associated with performance are likely to lead to higher probability of disengagement at lower levels of objective task demands than found in younger adults.

Consistent with the selective engagement perspective (e.g., Hess, 2006; Hess & Emery, 2012), we found that the importance attached to the task—as reflected in self-reported motivation to do well—was a stronger predictor of effort expenditure in older adults than it was in young adults. This is consistent with the idea that greater costs associated with cognitive activity increases older adults' sensitivity to task demands and the self-implications of the task, resulting in greater selectivity in terms of engagement of resources and a generally closer linkage between behavior and motivational factors than observed in younger adults. Significantly, the present results extend previous support for this hypothesis based primarily in behavioral outcomes (e.g., Germain & Hess, 2007; Hess et al., 2001, 2009) by demonstrating such selectivity at its prime locus: effort expenditure. Although previous demonstrations of disproportionate performance enhancements (e.g., memory [Hess et al., 2009]) for older adults when motivation was high were consistent with the notion of selective engagement of cognitive resources, our finding of a similar linkage involving SBP provides stronger evidence. This is primarily due to the facts that (a) SBP responsivity is a theoretically and empirically grounded reflection of mental engagement and (b) performance outcomes may reflect other factors (e.g., efficacy) besides effort. Note that our findings are not meant to imply that motivational factors do not exert influence on the performance of younger adults. Rather, we assert that, under normal circumstances, the costs of cognitive engagement are greater for older adults, increasing the salience of such costs. In other circumstances in which the costs of cognitive activity are accentuated (e.g., fatigue), younger adults should exhibit similar responses to task importance (e.g., Webster, Richter, & Kruglanski, 1996).

We had also hypothesized that the increased costs associated with cognitive engagement in later life would make older adults less motivated to engage in effortful cognitive activities in everyday life. We found support for this hypothesis by showing that older adults reporting low levels of Need for Cognition had to exert more effort to support performance than those high on this factor to achieve the same objective level of performance (controlled for in the MLM analyses). On the surface, this relationship seems odd given that high Need for Cognition is typically associated with higher levels of engagement (see Cacioppo et al., 1996). In this case, however, our interpretation is that level of intrinsic cognitive motivation is in part based on the costs associated with engaging cognitive resources. Naturally, causal inferences regarding this relationship must be made with caution given the cross-sectional nature of our data. We note, however, that these findings are consistent with longitudinal data showing that changes in personal resources (e.g., health) are associated with changes in intrinsic motivation to engage in complex cognitive activity (Hess et al., 2012). Similarly, a recent study by Jackson, Hill, Payne, Roberts, and Stine-Morrow (2012) demonstrated that openness to experience—a personality construct correlated with Need for Cognition—increased in older adults as a consequence of cognitive training. This further suggests a casual linkage between the efficiency of cognitive skills and intrinsic characteristics associated with willingness to engage in cognitive activity.

In conclusion, the present study demonstrated the utility of using CV responsivity to assess age differences in mental effort. Consistent with much theorizing regarding cognitive aging over the years (e.g., Craik, 1986), the findings of our study and those of Hess and Ennis (2012) support the hypothesis that the mental effort required to initiate and support cognitive performance increases in later life. In addition, building on earlier theorizing regarding the impact of age-related changes in the costs associated with resource engagement (e.g., Hess, 2006; Hess & Emery, 2012), we also established an empirical linkage between age differences in mental effort and the intrinsic motivation to participate in cognitively demanding activities in everyday life. Thus, in addition to demonstrating some utility for examining basic issues regarding cognitive aging, the present study may have implications for cognitive maintenance and intervention in later life. If engagement in cognitive activities is truly beneficial to cognitive health (for review, see Hertzog, Kramer, Wilson, & Lindenberger, 2009), the motivation to reduce engagement as the effort associated with successful performance increases is potentially troubling, with those older adults in greatest need of engagement perhaps being least likely to do so. Certainly, greater exploration of such relationships is warranted.

Acknowledgments

Support for this study was provided by NIA grant R01 AG05552.

We would like to thank Logan Collins and Katie Bigelow for their assistance with various aspects of the project.

References

Berntson, GG.; Quigley, KS.; Lozano, D. Cardiovascular psychophysiology. In: Cacioppo, JT.; Tassinary, LG.; Berntson, GG., editors. Handbook of psychophysiology. 3. Cambridge, UK: Cambridge University Press; 2007. p. 182-210.

Braver, TS.; West, R. Working memory, executive control, and aging. In: Craik, FIM.; Salthouse, TA., editors. The handbook of aging and cognition. 3. New York, NY: Psychology Press; 2008. p. 311-372.

Brehm JW, Self EA. The intensity of motivation. Annual Review of Psychology. 1989; 40:109–131.10.1146/annurev.psych.40.1.109

Cabeza R. Hemispheric asymmetry reduction in older adults: The HAROLD model. Psychology and Aging. 2002; 17:85–100.10.1037/0882-7974.17.1.85 [PubMed: 11931290]

Cacioppo JT, Petty RE, Feinstein JA, Jarvis WBG. Dispositional differences in cognitive motivation: The life and times of individuals varying in need for cognition. Psychological Bulletin. 1996; 119:197–253.10.1037//0033-2909.119.2.197

Cacioppo JT, Petty RE, Kao CF. The efficient assessment of need for cognition. Journal of Personality Assessment. 1984; 48:306–307.10.1207/s15327752jpa4803_13 [PubMed: 16367530]

Cappell KA, Gmeindl L, Reuter-Lorenz PA. Age differences in prefontal recruitment during verbal working memory maintenance depend on memory load. Cortex: A Journal Devoted to the Study of the Nervous System and Behavior. 2010; 46:462–473.10.1016/j.cortex.2009.11.009 [PubMed: 20097332]

Craik, FI. A functional account of age differences in memory. In: Klix, F.; Hagendorf, H., editors. Human memory and cognitive capabilities, mechanisms, and performances. Amsterdam: Elsevier; 1986. p. 409-422.

Craik, FIM.; Anderson, ND. Applying cognitive research to problems of aging. In: Gopher, D.; Koriat, A., editors. Attention and performance: Vol. XVII. Cognitive regulation of performance: Interaction of theory and application. Cambridge, MA: MIT Press; 1999. p. 583-615.

Fisk AD, Rogers WA. Toward understanding of age-related memory and visual search effects. Journal of Experimental Psychology: General. 1991; 120:131–149.10.1037/0096-3445.120.2.131 [PubMed: 1830608]

Gendolla GHE, Richter M. Cardiovascular reactivity during performance under social observation: The moderating role of task difficulty. International Journal of Psychophysiology. 2006; 62:185–192.10.1016/j.ijpsycho.2006.04.002 [PubMed: 16750583]

Gendolla GHE, Richter M, Silvia PJ. Self-focus and task difficulty effects on effort-related cardiovascular reactivity. Psychophysiology. 2008; 45:653–662.10.1111/j.1469-8986.2008.00655.x [PubMed: 18282201]

Gendolla, GHE.; Wright, RA. Motivation in social settings: Studies of effort-related cardiovascular arousal. In: Forgas, JP.; Williams, K.; von Hippel, B., editors. Social motivation: Conscious and nonconscious processes. Cambridge University Press; 2005.

Gerin W, Pieper C, Pickering TG. Measurement reliability of cardiovascular reactivity change scores: A comparison of intermittent and continuous methods of assessment. Journal of Psychosomatic Research. 1993; 37:493–501.10.1016/0022-3999(93)90005-Z [PubMed: 8350291]

Germain CM, Hess TM. Motivational influences on controlled processing: moderating distractibility in older adults. Aging, Neuropsychology, and Cognition. 2007; 14:462–486.10.1080/13825580600611302

Guelen I, Westerhof BE, van der Sar GL, van Montfrans GA, Kiemeneij F, Wesseling KH, Bos WJW. Finometer, finger pressure measurements with the possibility to reconstruct brachial pressure. Blood Pressure Monitoring. 2003; 8:27–30.10.1097/01.mbp.0000057013.67622.97 [PubMed: 12604933]

Hertzog C, Kramer AF, Wilson RS, Lindenberger U. Enrichment effects on adult cognitive development: Can the functional capacity of older adults be preserved and enhanced? Psychological Science in the Public Interest. 2009; 9:1–65.10.1111/j.1539-6053.2009.01034.x

Hess TM. Adaptive aspects of social cognitive functioning in adulthood: age-related goal and knowledge influences. Social Cognition. 2006; 24:279–309.10.1521/soco.2006.24.3.279

Hess, TM.; Emery, L. Memory in context: The impact of age-related goals on performance. In: Naveh-Benjamin, M.; Ohta, N., editors. Memory and aging: Current issues and future directions. New York, NY: Psychology Press; 2012. p. 183-214.

Hess TM, Emery L, Neupert SD. Longitudinal relationships between resources, motivation, and functioning. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences. 2012; 67B:299–308.10.1093/geronb/gbr100

Hess TM, Ennis GE. Age differences in the effort and costs associated with cognitive activity. The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences. 2012; 67B:447–455.10.1093/geronb/gbr12

Hess TM, Germain CM, Swaim EL, Osowski NL. Aging and selective engagement: The moderating impact of motivation on older adults' resource utilization. The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences. 2009; 64B:447–456.10.1093/geronb/gbp020

Hess TM, Rosenberg DC, Waters SJ. Motivation and representational processes in adulthood: The effects of social accountability and information relevance. Psychology and Aging. 2001; 16:629–642.10.1037//0882-7974.16.4.629 [PubMed: 11766917]

Jackson JJ, Hill PL, Payne BR, Roberts BW, Stine-Morrow EAL. Can an old dog learn (and want to experience) new tricks? Cognitive training increases openness to experience in older adults. Psychology and Aging. 2012; 27:286–292.10.1037/a0025918 [PubMed: 22251379]

Katzman R, Brown T, Fuld P, Peck A, Schecter R, Shimmel H. Validation of a short orientation-memory-concentration test of cognitive impairment. American Journal of Psychiatry. 1983; 140:734–739. [PubMed: 6846631]

Lachman ME. Perceived control over memory aging: Developmental and intervention perspectives. Journal of Social Issues. 1991; 47:159–175.10.1111/j.1540-4560.1991.tb01840.x

Lachman ME, Andreoletti C. Strategy use mediates the relationship between control beliefs and memory performance for middle-aged and older adults. The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences. 2006; 61B:88–94.10.1093/geronb/61.2.P88

Mattay VS, Fera F, Tessitore A, Hariri AR, Berman KF, Das S, Weinberger DR. Neurophysiological correlates of age-related changes in working memory capacity. Neuroscience Letters. 2006; 392:32–37.10.1016/j.neulet.2005.09.025 [PubMed: 16213083]

Miller LMS, Gagne DD. Adult Age Differences in Reading and Rereading Processes Associated with Problem Solving. International Journal of Behavioral Development. 2008; 32:34–45.10.1177/0165025407084050

Miller LMS, West RL. The effects of age, control beliefs, and feedback on self-regulation of reading and problem solving. Experimental Aging Research. 2010; 36:40–63.10.1080/03610730903418380 [PubMed: 20054726]

Murphy DR, Craik FIM, Li KZH, Schneider BA. Comparing the effects of aging and background noise on short-term memory performance. Psychology and Aging. 2000; 15:323–334.10.1037//0882-7974.15.2.323 [PubMed: 10879586]

Obrist, PA. Cardiovascular psychophysiology: A perspective. New York: Plenum; 1981.

Obrist PA, Light KC, James SC, Strogatz DS. Cardiovascular responses to stress: I. Measures of myocardial response and relationship to high resting systolic pressure and parental hypertension. Psychophysiology. 1987; 24:65–78.10.1111/j.1469-8986.1987.tb01864.x [PubMed: 3575596]

Park, DC.; Payer, D. Working memory across the adult lifespan. In: Bialystok, E.; Craik, FIM., editors. Lifespan cognition: Mechanisms of change. New York: Oxford University Press; 2006. p. 128-142.

Peñáz, J. Photoelectric measurement of blood pressure volume and flow in the finger. In: Albert, A.; Vogt, W.; Hellig, W., editors. Digest of the 10th international conference on medical and biological engineering. Dresden, Germany: International Federation for Medical and Biological Engineering; 1973. p. 140

Richter M, Friedrich A, Gendolla GHE. Task difficulty effects on cardiac activity. Psychophysiology. 2008; 45:869–875.10.1111/j.1469-8986.2008.00688.x [PubMed: 18665860]

Riggs KM, Lachman ME, Wingfield A. Taking charge of remembering: Locus of control and older adults' memory for speech. Experimental Aging Research. 1997; 23:237–256.10.1080/03610739708254282 [PubMed: 9248818]

Tun PA, McCoy S, Wingfield A. Aging, hearing acuity, and the attentional costs of effortful listening. Psychology and Aging. 2009; 24:761–766.10.1037/a0014802 [PubMed: 19739934]

Uchino BN, Birmingham W, Berg CA. Are older adults less or more physiologically reactive? A meta-analysis of age-related differences in cardiovascular reactivity to laboratory tasks. The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences. 2010; 65B:154–162.10.1093/geronb/gbp127

Sternberg S. High-speed scanning in human memory. Science. 1966; 153:652–654.10.1126/science.153.3736.652 [PubMed: 5939936]

Verhaeghen P, Steitz DW, Sliwinski MJ, Cerella J. Aging and dual-task performance: A meta-analysis. Psychology and Aging. 2003; 18:443– 460.10.1037/0882-7974.18.3.443 [PubMed: 14518807]

Ware, JE. SF-36 health survey: Manual and interpretation Guide. Boston: The Health Institute, New England Medical Center; 1993.

Webster DM, Richter L, Kraglanski AW. On leaping to conclusions when feeling tired: Mental fatigue effects on impressional primacy. Journal of Experimental Social Psychology. 1996; 32:181–195.10.1006/jesp.1996.0009

Wechsler, D. Wechsler adult intelligence scale. 3. New York, NY: Psychological Corporation; 1997.

Wright, RA. Brehm's theory of motivation as a model of effort and cardiovascular response. In: Gollwitzer, PM.; Bargh, JA., editors. The psychology of action: Linking cognition and motivation to behavior. New York: Guilford; 1996. p. 424-453.

Wright RA, Dill JC. Blood pressure responses and incentive appraisals as a function of perceived ability and objective task demand. Psychophysiology. 1993; 30:152–160.10.1111/j.1469-8986.1993.tb01728.x [PubMed: 8434078]

Wright RA, Dill JC, Geen RG, Anderson CA. Social evaluation influence on cardiovascular response to a fixed behavioral challenge: Effects across a range of difficulty levels. Annals of Behavioral Medicine. 1998; 20:277–285.10.1007/BF02886377 [PubMed: 10234421]

Wright, RA.; Franklin, J. Ability perception determinants of effort-related cardiovascular response: Mood, optimism, and performance resources. In: On, RA.; Wright, J.; Greenberg, S.; Brehm, SS., editors. Motivational analysis of social behavior: Building on Jack Brehm's contributions to psychology. Mahwah, NJ: Lawrence Erlbaum; 2004. p. 187-204.

Wright RA, Junious TR, Neal C, Avello A, Graham C, Walton N. Mental fatigue influence on effort-related cardiovascular response: Difficulty effects and extension across cognitive performance domains. Motivation and Emotion. 2007; 31:219–231.10.1007/s11031-007-9066-9

Wright RA, Martin RE, Bland JL. Energy resource depletion task difficulty, and cardiovascular response to a mental arithmetic challenge. Psychophysiology. 2003; 40:98–105.10.1111/1469-8986.00010 [PubMed: 12751807]

Wright RA, Murray JB, Storey PL, Williams BJ. Ability analysis of gender relevance and sex differences in cardiovascular response. Journal of Personality and Social Psychology. 1997; 59:1250–1260.10.1037//0022-3514.73.2.405 [PubMed: 2283591]

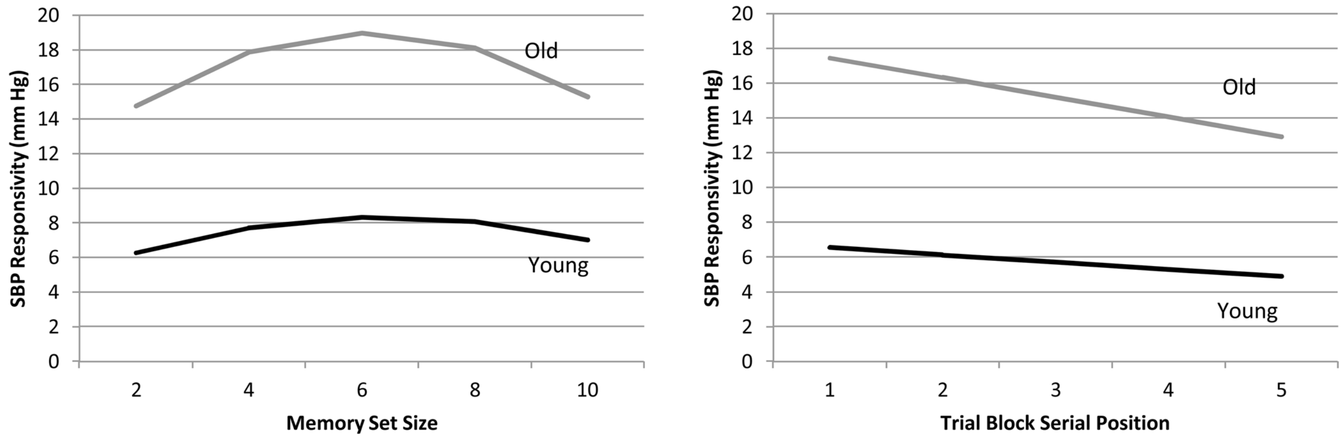

Figure 1.
Estimated SBP responsivity as a function of age and task difficulty (left) and trial block serial position (right).

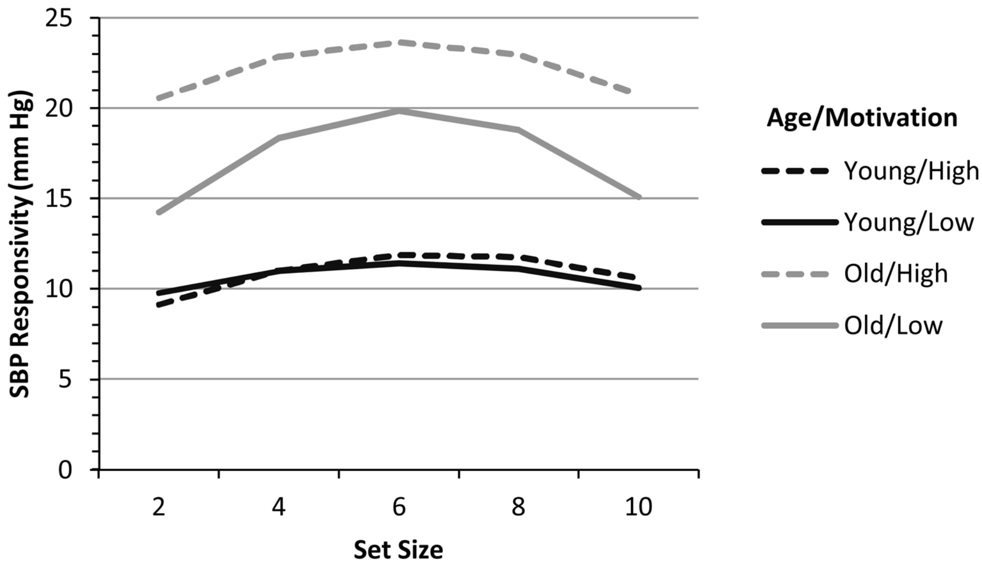

Figure 2.
Estimated SBP responsivity as a function of age, self-reported motivation (estimated at ± 1 *SD* from sample mean), and task difficulty.

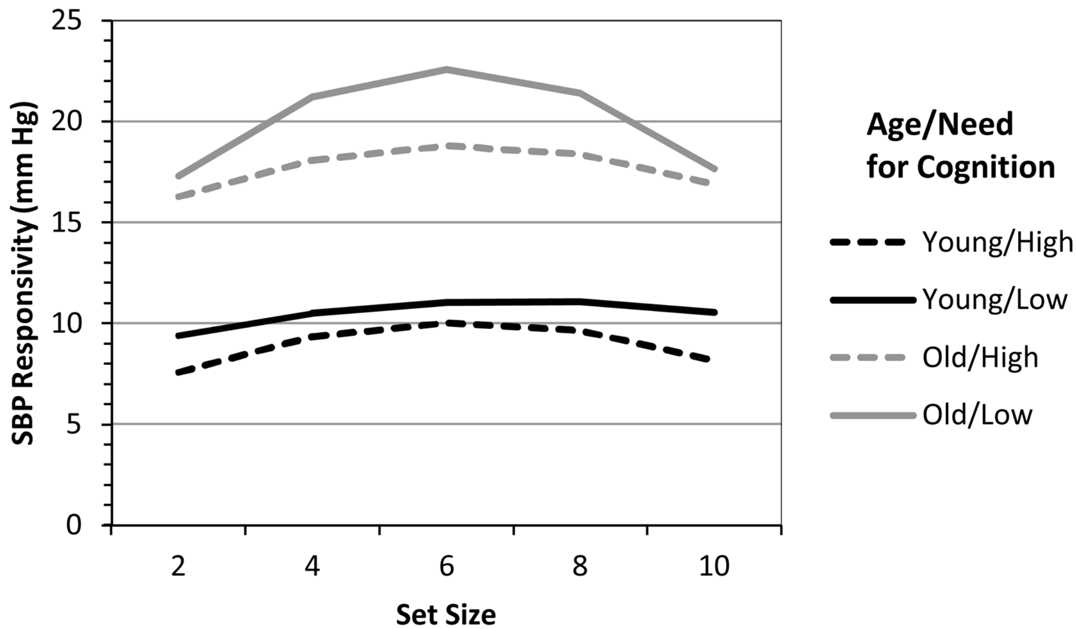

Figure 3.
Estimated SBP responsivity as a function of age, Need for Cognition (estimated at ± 1 *SD* from sample mean), and task difficulty.

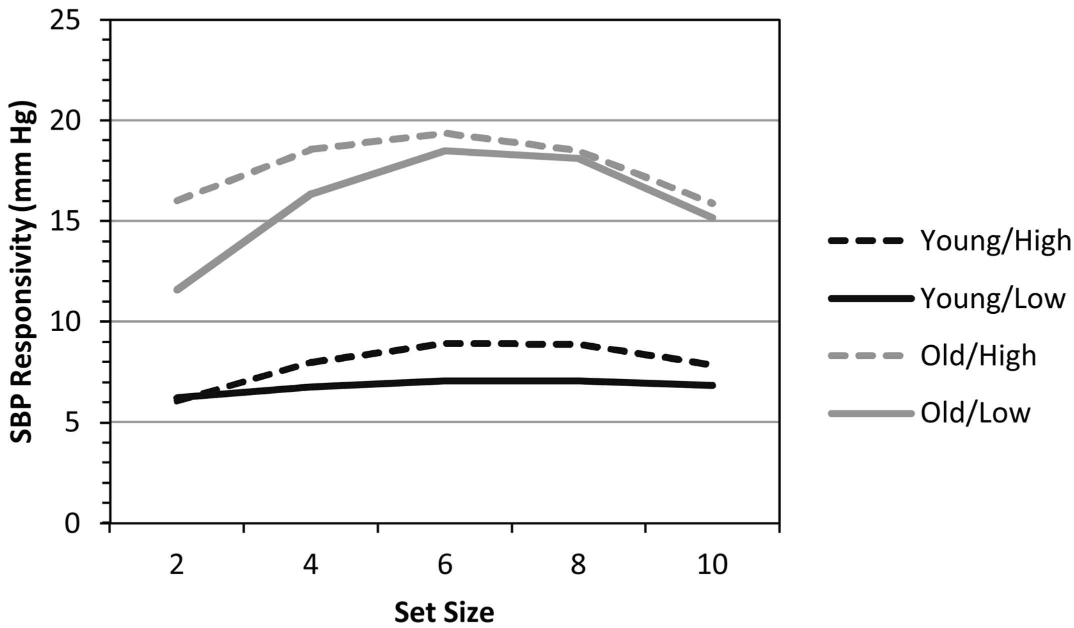

Figure 4.
Estimated SBP responsivity as a function of age and perceived control.

Table 1

Participant Characteristics

	Young Adults		Older Adults	
Measure	***M***	***SD***	***M***	***SD***
Age *	32.3	5.5	73.0	4.6
Education	16.0	1.9	16.1	2.1
SF36 Physical Health *	51.5	4.3	45.4	8.6
SF36 Mental Health *	47.2	11.9	54.8	8.3
Vocabulary	48.9	9.1	51.3	7.0
Letter-Number Sequencing *	12.0	2.7	9.9	2.5
Digit-Symbol Substitution *	86.5	18.3	64.7	12.1

*Between age group difference significant (p. < .01).

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 2

Mean Response Time (ms) and Accuracy (Proportion Correct) on Memory Search Task

	Response Time				Accuracy			
	Young		Old		Young		Old	
Set-size	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
2	938	241	1043	192	.99	.02	.98	.04
4	1064	274	1226	199	.98	.04	.96	.07
6	1188	316	1440	340	.88	.04	.83	.08
8	1189	270	1442	312	.84	.09	.79	.10
10	1258	321	1510	345	.74	.08	.68	.09