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Age Differences in Reaction Time and Attention in a National Telephone Sample of Adults: Education, Sex, and Task Complexity Matter

Patricia A. Tun and Margie E. Lachman
Brandeis University

This study demonstrated effects of age, education, and sex on complex reaction time in a large national sample ($N = 3,616$) with a wide range in age (32–85) and education. Participants completed speeded auditory tasks (from the MIDUS [Midlife in the U.S.] Stop and Go Switch Task) by telephone. Complexity ranged from a simple repeated task to an alternating task that involved central executive processes including attention switching and inhibitory control. Increased complexity was associated with slower responses in older adults, those with lower education, and women, even after controlling for differences in health status. Higher levels of education were associated with greater central executive efficiency across adulthood: Overall, adults with college degrees performed on complex tasks like less educated individuals who were 10 years younger, up to age 75. These findings suggest that advanced education can moderate age differences on complex speeded tasks that require central executive processes, at least up to the point in old age at which biological declines predominate. The approach demonstrates the utility of combining laboratory paradigms with survey methods to enable the study of larger, more diverse and representative samples across the lifespan.

Keywords: aging, reaction time, switching, education, sex

Among the mental abilities that show age differences across the lifespan, processing speed and central executive function are especially critical in everyday functioning. In recent years there has been a surge of interest in investigating these abilities by examining response latencies on both a reaction time (RT) test in which one task is repeated and an alternating test that involves switching between two tasks (following Rogers & Monsell, 1995). The more complex task-switching condition is presumed to involve important control functions (Baddeley, 2002; Miyake et al., 2000) that have shown age-related changes across the lifespan (Cepeda, Kramer, & Gonsalez de Sather, 2001; Reimers & Maylor, 2005), with significant declines in later adulthood (e.g., Kray & Lindenberger, 2000). Neuroimaging work has associated attentional control of task switching with function of the superior parietal cortex (Shomstein & Yantis, 2004), and older adults show more extensive frontal lobe activation than young adults during such tasks (e.g., DiGirolamo et al., 2001) as well as different patterns of event-related potentials (Goffaux, Phillips, Sinai, & Pushkar, 2008; Kray, Eppinger, & Mecklinger, 2005; West & Schwarb, 2006).

A question that remains unanswered is the extent to which these abilities may vary by factors such as formal education and sex, and how these effects vary across the adult lifespan. This is, of course, part of the larger question of which abilities are selectively maintained or negatively affected by aging, and what experiences can help maintain them—a question of theoretical importance as well as major practical significance to the increasingly large cohorts of aging adults. However, findings from previous laboratory studies in RT and task switching are often limited in the range of both age and education of the participants, who typically consist of college students and well-educated older adults (see Lachman, 2004).

Greater diversity of participants in terms of education as well as age is important in determining the generality of these previous findings, and it is here that innovations in testing methods, such as the use of the telephone in this research, can make a contribution. Higher levels of education have been associated with a reduced risk of dementia (Evans et al., 1993; Jones et al., 2006), as well as better performance on various tests of cognition (Cagney & Lauderdale, 2002; Lee, Kawachi, Berkman, & Grodstein, 2003; Lyketsos, Chen, & Anthony, 1999), including tests of executive function (Wecker, Kramer, Hallam, & Delis, 2005) and set shifting (van Hooren et al., 2007). Although education effects have been demonstrated for simple and choice RT (Deary, Der, & Ford, 2001), little is known about education differences in task-switching ability, in part because lab samples typically are homogeneous and highly educated. Recently, Reimers and Maylor (2005) carried out a large Internet study of task switching that demonstrated age-related slowing of responses consistent with previous laboratory studies, although the self-selected group comprised mainly younger and middle-aged adults aged 18–55. There was no

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Patricia A. Tun, Department of Psychology and Volen National Center for Complex Systems, Brandeis University; Margie E. Lachman, Department of Psychology, Brandeis University.

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Correspondence concerning this article should be addressed to Patricia A. Tun, Volen Center MS 013, Brandeis University, Waltham, MA 02454. E-mail: tun@brandeis.edu

evidence for education effects in this age range, perhaps because of restricted range in educational level.

Cross-sectional studies have shown higher levels of education to be associated with successful cognitive aging in later life (Albert et al., 1995; Cagney & Lauderdale, 2002; Hultsch, Hertzog, Small, & Dixon, 1999; Lindenberger & Baltes, 1997), as well as with lower risk of dementia (Jones et al., 2006). Also, longitudinal studies have shown that higher education may moderate the effects of aging on cognitive performance (see Anstey & Christensen, 2000, for a review; Lee et al., 2003; Lyketsos et al., 1999). One account for these benefits is a build-up of cognitive reserve producing greater efficiency of brain networks (Stern et al., 2005). The compensation hypothesis suggests that education and/or intellectual challenge may slow the rate of cognitive decline up to the point when basic abilities begin to deteriorate in old age, at which point individuals with higher education may show a sharper decline (Alley, Suthers, & Crimmins, 2007; Christensen et al., 1997; Hultsch et al., 1999). Alternatively, education may benefit cognitive aging through its association with higher income and cumulative advantage (Brim, Ryff, & Kessler, 2004), including greater access to resources and better health care (Alwin & Wray, 2005), or through selective effects in which higher functioning individuals go on to higher education (e.g., Salthouse, 2006). The current study is unique in including a sufficiently wide range of adult age and educational backgrounds to allow a meaningful investigation of education effects on complex RT and task switching across the adult lifespan, while controlling for effects of health status.

Our findings also extend previous work by contributing new information about sex differences in task-switching performance. Sex differences have been shown to vary across cognitive domains (Gerstorf, Herlitz, & Smith, 2006), with some evidence for sex differences in brain activity during cognitive tasks (Bell, Willson, Wilman, Dave, & Silverstone, 2006). However, the effect of sex is not well understood for central executive processes (McEwen, 2000; Wecker et al., 2005), inhibitory control (MacLeod, 1991), or processing speed (Deary & Der, 2005). Although some studies have reported a small male advantage in speed for simple and/or choice RTs (Deary & Der, 2005; Der & Deary, 2006; Fozard, Vercruysse, Reynolds, Hancock, & Quiller, 1994), others have not found this effect (Meinz & Salthouse, 1998). Few task-switching studies have assessed sex, but there is some evidence for a male advantage (Reimers & Maylor, 2005), as well as sex-specific patterns of cortical activation and neural efficiency in task switching (Grabner, Fink, Stipacek, Neuper, & Neubauer, 2004).

Finally, we also examined general and specific costs of task switching. The general cost of switching attention has been measured by the increase in response latency from a single task performed alone to a mixed-task switching condition in which one must alternate between two tasks (e.g., Kray & Lindenberger, 2000; Rogers & Monsell, 1995). There is considerable evidence for larger switch costs in older adults than in younger adults (e.g., Kray, Li, & Lindenberger, 2002; Verhaeghen & Cerella, 2002), and some evidence for differences in midlife (e.g., Cepeda et al., 2001; Kray & Lindenberger, 2000; Reimers & Maylor, 2005), although middle age is not typically included in research designs (see Lachman, 2004). Because general switch costs include differences in memory load and arousal, some have focused on specific switch costs in the mixed-task blocks, or the difference between switch trials that require a task alternation and nonswitch trials in which the task is repeated. Reports of age differences in specific switch costs depend on the methodology used, with some studies reporting an age-related increase in switch cost (e.g., Kray & Eppinger, 2006; Kray et al., 2005, 2002; Meiran, Gotler, & Perlman 2001; Van Asselen & Ridderinkhof, 2000), and others reporting finding minimal evidence for age differences in specific switch cost (e.g., Kray & Lindenberger, 2000; Mayr, 2001; Verhaeghen & Cerella, 2002). In this study we examined task switching across adulthood through old age, with a focus on effects of age, sex, and education.

Our design demonstrates how existing RT studies can be extended to larger, more diverse samples of respondents using the telephone—a form of technology that is even more readily available than the computer. We carried out such testing by telephone in a large national sample of adults ranging in age from 32 to 85, from a wide range of socioeconomic and educational backgrounds. The test included components that ranged in difficulty from a basic choice RT task to a complex task involving switching, which placed heavier demands on central executive functions. Also, an incongruent condition required inhibitory control, a function that often shows age-related changes (Hasher & Zacks, 1988).

We predicted that response latencies on these tasks would increase as a function of increased age and even after controlling for health status, higher levels of education should be associated with better RT performance, especially with increased task complexity. Although some authors have argued that education primarily benefits crystallized rather than fluid abilities (e.g., Alley et al., 2007; Christensen et al., 1997), other work suggests that education affects central executive function (van Hooren et al., 2007), and therefore effects of education should be greater with increased task complexity. If the advantage of high-ability older adults shown in other domains (e.g., Hultsch et al., 1999) extends to executive function, we hypothesized that higher education would be associated with smaller age differences in performance, at least up until the point in old age when biological age-related deterioration may prevail (Baltes, 1997). An additional question of interest was whether sex differences would be seen for these tasks, and whether we would find higher order interactions among age, sex, and education.

Method

Participants

Data were collected by telephone from a random digit dial probability sample of participants in the second wave of the National Survey of Midlife Development in the U.S. (MIDUS II). A national sample of households in the 48 contiguous states with at least one telephone was selected initially in 1995–1996 using random digit dialing (see Brim et al., 2004). The 1995 sample of 7,120 noninstitutionalized adults was stratified in advance to achieve equal sex distribution and an age distribution with the greatest number between 40 and 60. Approximately 10 years later, 70% of the original sample was recontacted and given a cognitive battery by telephone. Nonparticipants at Time 2 were slightly younger than those who did participate ($M = 45.38$ vs. 47.10, respectively), $t(7039) = 5.45$, $p < .001$, were lower in education ($M = 13.19$ vs. 14.09, respectively), $t(7085) = 13.68$, $p < .001$, and were more likely to be men (51.9% vs. 45.8% male, respectively), $\chi^2(1) = 25.25$, $p < .001$. Nonparticipants also had lower self-rated health (responding to the question “In general, would you say your physical health is excellent, very good, good, fair, or poor?” with 1 = *poor* to 5 = *excellent*; $M = 3.40$ vs. 3.62, respectively), $t(7087) = 9.48$, $p < .001$.

The Stop and Go Switch Task was administered as one component of a larger cognitive battery of tests, the Brief Test of Adult Cognition by Telephone (Lachman & Tun, 2008; Tun & Lachman, 2006). Of the 4,428 original cases, data from 183 were lost due to technical problems, experimenter error, or failure to carry out the task as instructed. We also screened 52 who did not speak English on a regular basis; 336 who self-reported a history of stroke, Parkinson’s disease, or other neurological conditions; and 241 who did not meet the accuracy criteria described below (see *Response Accuracy*). The 3,616 respondents in the final sample ranged from 32 to 85 years with a mean age of 55.06 years ($SD = 12.06$). Data are grouped into five age groups: G1 (32–44, $n = 806$); G2 (45–54, $n = 1{,}019$); G3 (55–64, $n = 939$); G4 (65–74, $n = 589$); G5 (75–85, $n = 263$). Women composed 53.7% of the sample. There were 40.5% with a 4-year college degree or higher, and the average self-rated health on a 5-point scale was 3.67 ($SD = 0.96$). Because the sample included 369 twins and 549 siblings of the primary respondent, we also conducted analyses with only one member per family; the pattern of estimates and the significance of these did not differ, showing that our findings were not due to lack of independence; thus, we present results with the full sample.

Analysis of variance with age group (5: 32–44, 45–54, 55–64, 65–74, 75–85) showed group differences in education level, $F(4, 3611) = 16.54$, $p < .001$; the three younger groups averaged more years of education than the two oldest groups, which did not differ from each other (G1 = 14.70, $SD = 2.54$; G2 = 14.61, $SD = 2.68$; G3 = 14.44, $SD = 2.72$; G4 = 13.93, $SD = 2.75$; G5 = 13.49, $SD = 2.69$). Preliminary analyses showed similar patterns of performance for participants with high school education or less and those with some college; therefore, in the following analyses we split education into high education, defined as a 4-year college degree or higher, and low education, defined as less than a college degree. The percentage of women in each group was as follows: G1 = 56.5%, G2 = 51.2%, G3 = 51.5%, G4 = 57.9%, and G5 = 52.9%, $\chi^2(4) = 10.96$, $p < .05$, for group differences.

Measures and Procedure

The assessment included a brief hearing check (in which participants listened to a series of numbers spoken and were asked to repeat each number aloud to demonstrate that they heard it) followed by 2 single-task blocks and a mixed-task block that required alternating between two tasks. Participants carried out 2 single-task blocks of 20 trials each, first following a congruent response rule (“say *stop* to *red* and *go* to *green*”), then an incongruent response rule (“say *go* to *red* and *stop* to *green*”). The mixed-task block included 14 practice trials with 5 switch trials that required alternating between the congruent and incongruent response rules each time a cue to switch was given (the word *normal* or the word *reverse* cued which response rule was required), followed by 29 test trials (6 switch, 23 nonswitch). In order to maximize sensitivity to age effects, we used an unpredictable task sequence (Van Asselen & Ridderinkhof, 2000), with cues given only on switch trials at random intervals of 2–6 trials (e.g., Baddeley, 2002; Salthouse, Fristoe, McGuthry, & Hambrick, 1998). Thus, the switch trials placed especially heavy loads on control functions because they required processing the cue as well as switching the task (e.g., Mayr, 2001). Although this task is relatively brief, pilot work showed good correlations with performance on a longer version of the task, and no significant differences between performance on the first, second, and third sections of the trial sequence, consistent with previous findings for longer trial sequences (Salthouse et al., 1998).

Testing was administered by telephone by live interviewers at a large university survey center. Computers controlled stimulus timing and recorded sound files for later scoring of latencies. In order to minimize lags in transmission, we avoided the use of cell phones and conducted interviews on landline phones. Reliability testing during development of the test showed satisfactory correlations between telephone and face-to-face testing ($r[24] = .65$, for single-task blocks, $r[24] = .62$ for mixed-task blocks), consistent with previous telephone studies (Herzog & Wallace, 1997). Test–retest reliability after a 6-month interval was $r(35) = .66$, for the single-task condition, and $r(35) = .77$, for the mixed-task condition.

Results

Response Accuracy

In order to assess response latencies and ensure that participants were performing the task as directed, we required a criterion of at least 75% accuracy in each task condition. We excluded 241 participants who did not perform at that level or were outliers in latency (>2 s on single task or >4 s on mixed task), resulting in a sample of 3,616 respondents used in the following latency analyses. Participants who did not meet these accuracy criteria were slightly older than those who did (61.28 vs. 55.64 years, respectively), $t(3384) = 7.14$, $p < .01$, and had lower levels of education (13.08 vs. 14.40 years, respectively), $t(3384) = -6.70$, $p < .001$. Accuracy rates were quite high, averaging .99 correct for single-task trials ($SD = .02$) and .98 for mixed-task trials ($SD = .04$), and greater than 94% across all age-groups in all conditions. There was no evidence of a speed–accuracy tradeoff, as faster responses were associated with greater accuracy, even after controlling for age.

Latency Analyses

Median latency for correct responses was calculated for each participant in each condition. Due to concern that general age-related slowing may produce spurious interactions between age groups and experimental conditions (Faust, Balota, Speiler, & Ferraro, 1999; Ratcliff, 1993), we conducted all analyses using log-transformed RTs (e.g., Kray & Lindenberger, 2000; Mayr, 2001). These analyses yielded similar effects unless otherwise noted.

We first performed repeated measures analysis of covariance on raw latency scores, with age (5 groups), education level (2: no college degree, college graduate), and sex (2: male, female) as between-subject variables, and self-rated health as a covariate. Within-subject factors were task type (3: single task, nonswitch mixed task, switch mixed task) and response type (2: congruent, incongruent). Post hoc tests used the Bonferroni method. Overall better performance was associated with better health, $F(1, 3595) = 35.38$, $p < .001$, $\eta_p^2 = .010$, and higher levels of education, $F(1, 3595) = 27.49$, $p < .001$,

$\eta_p^2 = .008$, as well as younger age, $F(4, 3595) = 83.68$, $p < .001$, $\eta_p^2 = .085$, and male sex, $F(1, 3595) = 15.40$, $p < .001$, $\eta_p^2 = .004$. Table 1 shows RTs for those with low and high education, and for men and women. The significant interaction between age group and sex, $F(4, 3595) = 2.98$, $p < .05$, $\eta_p^2 = .003$, suggested that the effects of sex vary across the lifespan: Bonferroni comparisons showed that men were faster than women in the 45–54, 55–64, and 75–85 age groups.

As expected, latencies were longer as the task progressed in difficulty from the simplest single-task to mixed-task nonswitch trials to switch trials (task type effect, $F[2, 7190] = 350.60$, $p < .001$, $\eta_p^2 = .089$. Figure 1 shows mean latencies for five age groups on the six experimental conditions, ranging in task complexity from single-task to mixed-task nonswitch trials to switch trials, with congruent and incongruent response rules in each task type. Interactions showed that the effect of task complexity was increased by older age (Task Type × Age, $F[8, 7190] = 22.91$, $p < .001$, $\eta_p^2 = .025$, and female sex (Task Type × Sex, $F[2, 7190] = 34.99$, $p < .001$, $\eta_p^2 = .010$). The difference between low and high education levels was significant at each level of task complexity, but the effects of education were larger as the task became more complex (Task Type × Education, $F[2, 7190] = 8.94$, $p < .001$, $\eta_p^2 = .002$). Differences between education groups were 24 ms for the single tasks, 33 ms for the nonswitch trials, and 60 ms for the switch trials.

Also as expected, RTs were longer on incongruent trials than on congruent trials, $F(1, 3595) = 147.50$, $p < .001$, $\eta_p^2 = .039$. The effect of congruency was larger with increased age for raw latencies (Congruency × Age, $F[4, 3595] = 5.02$, $p < .001$, $\eta_p^2 = .006$, but not for log-transformed scores, $F[4, 3595] = 1.84$). Women showed larger effects of congruency than men (Congruency × Sex, $F[1, 3595] = 9.66$, $p < .01$, $\eta_p^2 = .003$). Congruency effects were greater with lower education (Congruency × Education, $F[1, 3595] = 5.83$, $p < .02$, $\eta_p^2 = .002$), especially for older adults (Congruency × Age × Education, $F[4, 3595] = 2.88$, $p < .05$, $\eta_p^2 = .003$). However, these interactions did not reach significance for log-transformed scores (Congruency × Education, $F[1, 3595] = 3.29$, $p = .07$; Congruency × Education × Age, $F[4, 3595] = 2.07$, $p = .08$), suggesting that education and age effects were similar across congruency conditions, when general slowing is considered.

Figure 2 shows latencies for congruent trials (on the left) and incongruent trials (on the right); the benefits of higher education are evident, as those with college degrees were significantly faster than those with lower education up to age 75–85. As the figure shows, for all age groups except the oldest, the difference in RT between low and high education within an age group was roughly equivalent to a decade of age difference.

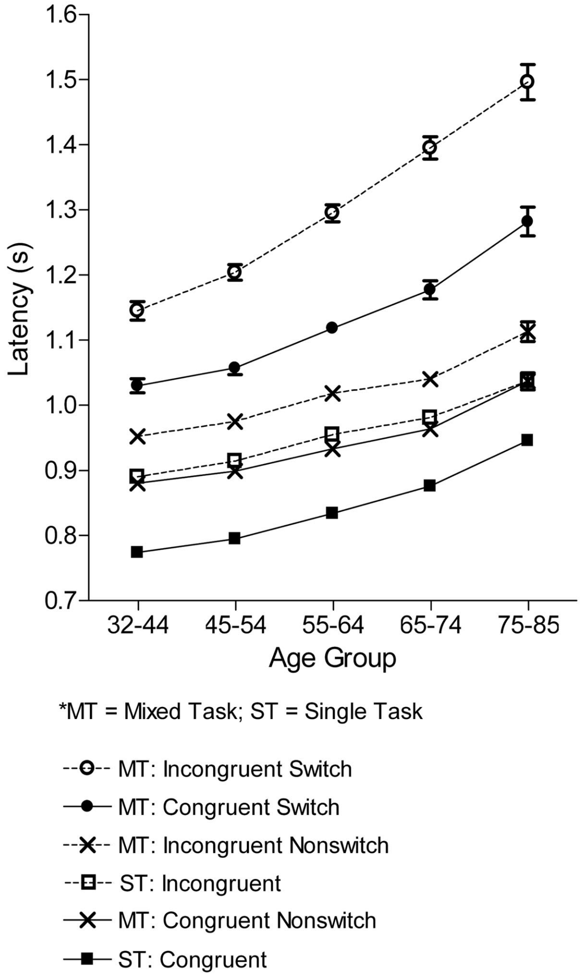

Figure 1. Mean latencies (in seconds) for five age groups on single-task, nonswitch, and switch trials (congruent and incongruent). Error bars represent standard errors of the mean.

Table 1

Latencies for Single-Task, Nonswitch, and Switch Trials (Congruent and Incongruent) by Education Level (No College Degree, College Graduate) and Sex (Men, Women)

	Single task				Nonswitch mixed task				Switch mixed task			
	Congruent		Incongruent		Congruent		Incongruent		Congruent		Incongruent	
Variable	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Education												
Low	.85	.003	.97	.004	.96	.004	1.04	.005	1.16	.008	1.34	.009
High	.84	.004	.94	.006	.93	.006	1.00	.007	1.11	.010	1.28	.013
Sex												
Men	.84	.004	.96	.005	.94	.005	1.01	.006	1.11	.009	1.26	.011
Women	.85	.004	.96	.006	.95	.005	1.03	.006	1.16	.009	1.35	.011

Note. Values shown are marginal means and standard error in seconds, adjusted for covariate self-rated health.

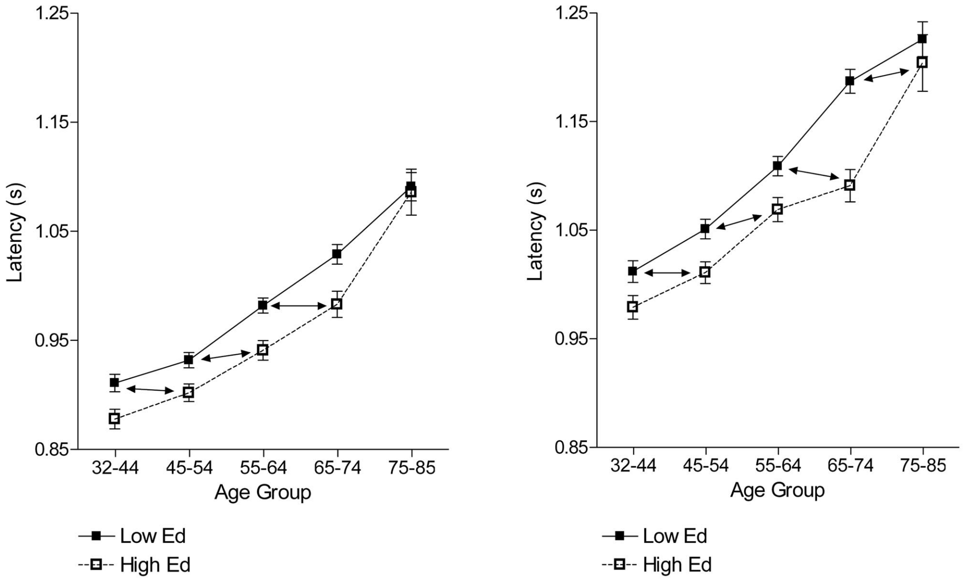

Figure 2. Mean latencies (in seconds) for high and low education levels in five age groups, on congruent trials (left panel) and incongruent trials (right panel). Error bars represent standard errors of the mean. Horizontal arrows show similar performance by high and low education groups at different ages.

A striking picture emerges when we compare participants with college degrees to those with lower education at different ages; these comparisons are depicted in the horizontal bars in Figure 2. Overall, we found that participants with college degrees performed at the same level as those with lower education levels who were 10 years younger, suggesting that higher education was associated with delayed aging effects. Planned comparisons showed that the high education group at age 45–54 did not differ significantly in RT from that of the lower education group at age 32–44. At age 55–64 the high education group resembled the low education group at age 45–54, at 65–74 the high education group resembled the low education group at age 55–64, and at 75–85 the high education group resembled the low education group at age 65–74 for the incongruent but not the simpler congruent trials. Thus, these findings suggest that the effects of education were associated with delayed age-related slowing from middle age through older adulthood, on tasks that involved central executive processes.

Finally, we found significant interactions between task and congruence: effects of task complexity were greater on incongruent trials (Task Type × Congruency, $F[2, 7190] = 7.27$, $p < .001$, $\eta_p^2 = .002$), particularly for older adults (Task Type × Congruency × Age, $F[8, 7190] = 7.27$, $p < .001$, $\eta_p^2 = .008$); thus, older adults' difficulty with the more complex conditions was not simply a consequence of generalized slowing. Analysis of raw scores suggested that women were slowed more than men on the more difficult conditions (Task Type × Congruency × Sex, $F[2, 7190] = 5.30$, $p < .01$, $\eta_p^2 = .001$), although this interaction was not significant with log-transformed scores, $F(1, 3593) = 3.18$. No other interactions were significant.

Specific Switch Costs

Specific switch costs were defined as latencies for switch trials relative to nonswitch trials in the mixed task. An analysis of covariance of raw scores including age group (5: 32–44, 45–54, 55–64, 65–74, 75–85), education (2: no college degree, college graduate), and sex (2: men, women), with self-rated health (2: low, high) as a covariate, showed significant effects of age group, $F(4, 3595) = 27.67$, $p < .001$, $\eta_p^2 = .030$, education, $F(1, 3595) = 9.25$, $p < .01$, $\eta_p^2 = .003$ (for log transforms, $F[1, 3595] = 3.558$, $p = .059$), and sex, $F(1, 3595) = 29.99$, $p < .001$, $\eta_p^2 = .008$, with no significant interactions. Specific switch costs were larger with increased age, lower education, and for women compared to men. The sex differences were relatively small in size but are consistent with the literature; for example, our overall differences of about 48 ms between men and women are consistent with previous findings (Der & Deary, 2006; Reimers & Maylor, 2005). The finding of age differences with log-transformed scores indicates that age differences were not merely an artifact of general age-related slowing.

General Switch Costs

General switch costs, defined as latency differences between single-task and mixed-task blocks, may be taken to reflect processes involved in updating internal control settings, or setting up and maintaining a clear course of action with competing mental sets (e.g., Mayr, 2001). The method of calculating general switch costs has varied across studies; in this study, age differences in these costs depend on the method used.

One method compares single-task latencies with all trials from the mixed task, including both switch and nonswitch trials (e.g., Kray & Lindenberger, 2000). Analyses using this method showed a significant age effect for raw scores, $F(4, 3595) = 10.60$, $p < .001$, $\eta_p^2 = .012$, but not log-transformed scores, $F(4, 3595) = 1.16$, *ns*. There were significant effects of sex, $F(1, 3595) = 35.91$, $p < .001$, $\eta_p^2 = .010$, education, $F(1, 3595) = 8.51$, $p < .01$, $\eta_p^2 = .002$ (for log transforms, $F[1, 3595] = 4.24$, $p < .05$), and self-rated health, $F(1, 3595) = 12.04$, $p < .001$, $\eta_p^2 = .003$. Costs were larger for women than for men and for lower compared to higher education. No interactions were significant.

A second method of calculating general switch costs compares single-task trials with nonswitch trials from the mixed-task block (e.g., Mayr, 2001). Using this method, we found significant effects of sex, $F(1, 3595) = 7.15$, $p < .01$, $\eta_p^2 = .002$, and health, $F(1, 3595) = 11.27$, $p < .01$, but not for age, $F(4, 3595) < 1.0$, or education, $F(1, 3995) < 1.0$. The age effect was significant with log-transformed RTs, $F(4, 3595) = 3.17$, $p < .02$; comparisons showed a larger cost for the 32–54 groups compared to the 65–84 groups in the congruent condition ($p < .05$), but no significant group differences in the incongruent condition. Apparently, in the congruent single-task condition the younger adults responded in a more rapid, automatic way, while older adults may have needed to continually retrieve task-set algorithms (DiGirolamo et al., 2001; Goffaux et al., 2008). Thus, the young showed proportionally more slowing than the older groups when they needed to update internal control settings on the mixed-task block.

In summary, age differences in general switch costs varied with the use of raw or log-transformed scores, suggesting that these age effects were less reliable than differences in specific switch cost and depended somewhat on differences in baseline speed.

Discussion

Our findings from the Stop and Go Switch Task are the first to demonstrate effects of adult age, sex, and education level on complex RT tasks tested by telephone in a large population-based sample of adults. Consistent with previous testing using in-person visual methods in both laboratory-based research (e.g., Cepeda et al., 2001; Fozard et al., 1994) and larger field studies (Der & Deary, 2006), we demonstrated cross-sectional age-related slowing across adulthood in choice RT on this auditory task using novel technology. In addition, age differences increased with task complexity involving central executive functions such as switching, although age differences for tasks involving inhibitory control were not significant after controlling for general slowing. These findings using telephone assessment (Lachman & Tun, 2008) are generally consistent with previous studies that have examined adult age differences in complex speeded tasks (Cepeda et al., 2001; Reimers & Maylor, 2005) and executive function (Plumet, Gil, & Gaonac'h, 2005).

Age differences were also seen in older adults' larger specific switch costs in the mixed task, showing that even after controlling for general slowing, old age was associated with longer latencies on switch trials as compared to nonswitch trials. Age differences in general switch costs were less consistent and appear to have been driven largely by general slowing. The pattern of switch costs shown in a test typically depends on methodological variables, and in the current study the use of oral responses, unpredictable task sequences, overlapping task representations, and an incongruent response mode likely contributed to our findings of significant age differences for specific switch costs. Age differences between younger and older adults in specific switch costs have been reported in previous studies that used overlapping task-set representations (Kray & Eppinger, 2006) and unpredictable task sequences (e.g., Kray et al., 2002; Mayr, 2001; Van Asselen & Ridderinkhof, 2000), while studies that have used predictable sequences have typically shown minimal age differences for specific switch costs and larger general costs (Kray & Lindenberger, 2000).

Importantly, in addition to our findings for age differences, this work extends previous work by demonstrating the relationship of formal education with performance across the adult lifespan on speeded tasks that vary in complexity. This represents the first population-based study, to our knowledge, to examine education effects on such tasks after controlling for health status. This is a necessary control, as education may be associated with cumulative advantage in terms of income, health care, and health behaviors (e.g., Alwin & Wray, 2005; Cagney & Lauderdale, 2002), which may in turn affect cognitive performance; indeed, our data confirmed that better self-reported health status was associated with better performance on these tasks.

Nevertheless, even after controlling for health status, we demonstrated that higher education (a college degree) was associated with significantly faster response latencies, especially on complex conditions that involved central executive function. Education effects increased with task complexity from the simplest two-choice test to nonswitch trials and then to switch trials in the mixed-task block. This range of conditions was designed to maximize involvement of executive control function in terms of task switching as well as cue processing, rather than to distinguish task-switching ability from other central executive abilities, as has been the focus of some studies (e.g., Mayr, 2001). This demonstration of education effects on a task involving executive function extends previous findings for tasks involving crystallized abilities such as language (Anstey & Christensen, 2000; Alley et al., 2007; Christensen et al., 1997).

The benefits of education were evident in faster speed across adulthood, as performance by individuals with college degrees was similar to those 10 years younger, who had lower levels of education. These striking results suggest that on speeded tasks requiring central executive involvement, higher education may be associated with the equivalent of being 10 years younger in terms of performance. Nevertheless, our findings suggest that educational advantages can moderate the effects of aging only up until a certain point: We found no significant benefit of higher education in the oldest group aged 75–85. Education may compensate for age differences in health and cognitive processes up to a point in the aging process, at which point deterioration of basic processes may predominate (Hultsch et al., 1999). Mortality selection and health-related changes may also be a factor here, as well as cohort differences due to the lesser educational opportunities available to older participants, which may restrict the range in those groups. Similarly, Baltes (1997) has referred to the lessened compensatory impact of cultural experience in very old age as "the incomplete architecture of human ontogeny" (p. 366). Some longitudinal studies of older adults have found that higher education afforded an advantage but did not delay declines in psychomotor speed (Christensen et al., 2001) or general cognitive performance (Singer, Verhaeghen, Ghisletta, Lindenberger, & Baltes, 2003). However, a review by Anstey and Christensen (2000) found a generally positive effect of education on cognitive aging, and there is evidence for a lower risk of dementia with higher education (Jones et al., 2006).

The inconsistency in reports of education effects on cognitive performance is due at least in part to differences in tests and sample characteristics. Our findings are consistent with previous reports of education effects on choice RT (Deary et al., 2001) and simple speeded tests (Bosma, van Boxtel, Ponds, Houx, & Jolles, 2003; Fritsch et al., 2007; Ylikowski et al.,1998). Also, a recent population-based study of older adults (van Hooren et al., 2007) found effects of education on a set-shifting task, although a younger self-selected sample did not show effects of education on task switching (Reimers & Maylor, 2005), and Ylikowski et al. (1998) reported no education effects on a Stroop switching task. Nevertheless, our findings are consistent with reported effects of education on other tests of executive function (Wecker et al., 2005), suggesting that education may be associated with a general benefit in organizing and scheduling complex responses (Plumet et al., 2005; Wecker et al., 2005). Greater mental agility and flexibility may be associated with experience with cognitively challenging tasks (Bosma et al., 2003; Schooler & Mulatu, 2001). Switching processes may be modifiable by educational experience, perhaps due to greater cognitive reserve or processing efficiency (Stern et al., 2005). Or, education may afford selective protection to different aspects of executive function, such that some processes benefit while other processes may be relatively less modifiable.

These findings are important because they help tease out the locus of the benefits of formal education, separating the cognitive experiential effects from confounding factors such as cumulative advantage related to better health status. It may be that education is associated with better performance on cognitive tasks due to selective effects, in which brighter, fitter individuals seek out higher levels of education. Nevertheless, there is substantial evidence for the plasticity of the brain throughout life (e.g., Emsley, Mitchell, Kempermann, & Macklis, 2005), including neural benefits of enriched experience in critical areas such as frontal lobes, which have been implicated in complex switching tests such as those studied here (DiGirolamo et al., 2001). Our data demonstrate that in individuals of similar health status, those with higher levels of education respond faster on speeded tests, especially tasks that involve executive functions such as switching. These findings extend the evidence for the advantage of higher education (e.g., Albert et al., 1995; Anstey & Christensen, 2000; van Hooren et al., 2007). However, within the limitations of this cross-sectional design, we found no evidence that education reduced age differences in late adulthood after age 75.

Although the effect of sex on choice RT has not been clearly established, our findings are consistent with previous reports of a male advantage (Deary & Der, 2005; Der & Deary, 2006; Fozard et al., 1994; but see also Reimers & Maylor, 2006). Few task-switching studies have assessed sex, but there is some evidence for a male advantage in switching times (Reimers & Maylor, 2005) as well as sex-specific patterns of cortical activation and neural efficiency in task switching (Bell et al., 2006; Grabner et al., 2004). Many sources of structural, developmental, and environmental sex differences in performance have been proposed (McEwen, 2000), including hormonal effects associated with the neuromodulatory effect of dopamine on executive function (Mozley, Gur, Mozley, & Gur, 2001), and sex-specific differences in stress effects on critical brain regions (Letenneur et al., 2000). The finding that the largest sex differences appeared in our oldest group might suggest that the men who survived to that age represented a select, fitter group (Perls, 1995); however, the sex difference remained after controlling for health status. These effects will require further investigation.

Novel testing methods such as the telephone afford an opportunity for convenient testing of large numbers of individuals, although one limitation is that the experimenter does not have full knowledge of the participant's circumstances. In this study we minimized problems with distractions by using live interviewers who were trained to note unusual occurrences, and testing at times selected to minimize distractions. Another potential concern in using auditory tests with older adults is the effect of hearing loss on performance; therefore, at the beginning of each interview we carried out a brief hearing screening to verify that the participant could hear the stimuli clearly. In addition, we found that self-reported hearing ratings were not significantly related to performance, and thus age differences were not due simply to hearing difficulties. Because reliability was moderate, some caution is in order in interpreting these findings.

The current work demonstrates how by combining laboratory paradigms with survey methods, innovations such as the Stop and Go Switch Task can extend laboratory findings by enabling researchers to test larger and more diverse and representative samples than have been available previously, using different modalities. The opportunity to examine differences in complex task RT associated with adult age and education contributes to a better understanding of executive control processes and of the aging process. Recently, tests of RT have shown associations with mortality (Metter, Schrager, Ferrucci, & Talbot, 2005), and executive-function tasks have shown some sensitivity in predicting functional decline and mortality (Johnson, Lui, & Yaffe, 2007), and detecting persons at risk for Alzheimer's disease (Wetter et al., 2005) as well as psychopathology (Whitmer & Banich, 2007). Even in high-functioning older adults, executive control functions are critical for successful independent functioning and in activities such as medication compliance (Carlson, Fried, Xue, Tekwe, & Brandt, 2005). The use of telephone assessment demonstrated here with the Stop and Go Switch Task holds the promise of providing a convenient means of testing important cognitive and attentional processes in middle-aged and older adults as well as those younger in the lifespan, who may not be willing or able to be tested in person.

References

Albert, M. S., Jones, K., Savage, C. R., Beckman, L., Seeman, T., Blazer, D., & Rowe, J. W. (1995). Predictors of cognitive change in older persons: MacArthur studies of successful aging. *Psychology and Aging, 10,* 578–589.

Alley, D., Suthers, K., & Crimmins, E. (2007). Education and cognitive decline in older Americans. *Research on Aging, 29,* 73–94.

Alwin, D. F., & Wray, L. A. (2005). A life-span developmental perspective on social status and health. *Journals of Gerontology, Series B: Psychological Sciences and Social Sciences, 60,* P7–P14.

Anstey, K., & Christensen, H. (2000). Education, activity, health, blood pressure and apolipoprotein E as predictors of cognitive change in old age: A review. *Gerontology, 46,* 163–177.

Baddeley, A. (2002). Fractionating the central executive. In D. T. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (pp. 246–277). New York: Oxford University Press.

Baltes, P. B. (1997). On the incomplete architecture of human ontogeny: Selection, optimatization, and compensation as foundation of developmental theory. *American Psychologist, 52,* 366–380.

Bell, E. C., Willson, M. C., Wilman, A. H., Dave, S., & Silverstone, P. H.

(2006). Males and females differ in brain activation during cognitive tasks. *NeuroImage, 30,* 529–538.

Bosma, H., van Boxtel, M. P. J., Ponds, R. W. H. M., Houx, P. J. H., & Jolles, J. (2003). Education and age-related cognitive decline: The contribution of mental workload. *Educational Gerontology, 29,* 165–173.

Brim, O., Ryff, C., & Kessler, R. (2004). *How healthy are we?: A national study of well-being at midlife*. Chicago: University of Chicago Press.

Cagney, K. A., & Lauderdale, D. S. (2002). Education, wealth, and cognitive function in later life. *Journals of Gerontology, Series B: Psychological Sciences and Social Sciences, 57,* P1201–P1214.

Carlson, M. C., Fried, L. P., Xue, Q. L., Tekwe, C., & Brandt, J. (2005). Validation of the Hopkins Medication Schedule to identify difficulties in taking medications. *Journals of Gerontology, Series A: Biological Sciences and Medical Sciences, 60,* M217–M223.

Cepeda, N. J., Kramer, A., & Gonzalez de Sather, J. C. M. (2001). Changes in executive control across the life span: Examination of task-switching performance. *Developmental Psychology, 37,* 715–770.

Christensen, H., Hofer, S. M., MacKinnon, A. J., Korten, A. E., Jorm, A. F., & Henderson, A. S. (2001). Age is no kinder to the better educated: Absence of an association investigated using latent growth techniques in a community sample. *Psychological Medicine, 31,* 15–28.

Christensen, H., Korten, A. E., Jorm, A. F., Henderson, A. S., Jacomb, P. A., & Rodgers, B. (1997). Education and decline in cognitive performance: Compensatory but not protective. *International Journal of Geriatric Psychiatry, 12,* 323–330.

Deary, I. J., & Der, G. (2005). Reaction time, age, and cognitive ability: Longitudinal findings from age 16 to 63 years in representative population samples. *Aging, Neuropsychology, and Cognition, 12,* 187–215.

Deary, I. J., Der, G., & Ford, G. (2001). Reaction times and intelligence differences: A population-based cohort study. *Intelligence, 29,* 389–398.

Der, G., & Deary, I. J. (2006). Age and sex differences in reaction time in adulthood: Results from the United Kingdom Health and Lifestyle Survey. *Psychology and Aging, 21,* 62–73.

DiGirolamo, G. J., Kramer, A. F., Barad, V., Cepeda, N. J., Weissman, D. H., Milham, M. P., et al. (2001). General and task-specific frontal lobe recruitment in older adults during executive processes: A fMRI investigation of task-switching. *NeuroReport, 12,* 2065–2071.

Emsley, J. G., Mitchell, B. D., Kempermann, G., & Macklis, J. D. (2005). Adult neurogenesis and repair of the adult CNS with neural progenitors, precursors, and stem cells. *Progress in Neurobiology, 75,* 321–341.

Evans, D. A., Beckett, L. A., Albert, M. S., Hebert, L. E., Scherr, P. A., Funkenstein, H. H., & Taylor, J. O. (1993). Level of education and change in cognitive function in a community population of older persons. *Annals of Epidemiology, 3,* 71–77.

Faust, M. E., Balota, D. A., Speiler, D. H., & Ferraro, F. R. (1999). Individual differences in information-processing rate and amount: Implications for group differences in response latency. *Psychological Bulletin, 125,* 777–799.

Fozard, J. L., Vercruysse, M., Reynolds, S. L., Hancock, P. A., & Quiller, R. E. (1994). Age differences and changes in reaction time: The Baltimore Longitudinal Study of Aging. *Journals of Gerontology, Series B: Psychological Sciences and Social Sciences, 49,* P179–P189.

Fritsch, T., McClendon, M. J., Smyth, K. A., Lerner, A. J., Friedland, R. P., & Larsen, J. D. (2007). Cognitive functioning in healthy aging: The role of reserve and lifestyle factors early in life. *The Gerontologist, 47,* 307–322.

Gerstorf, D., Herlitz, A., & Smith, J. (2006). Stability of sex differences in cognition in advanced old age: The role of education and attrition. *Journals of Gerontology, Series B: Psychological Sciences and Social Sciences, 61,* P245–P249.

Goffaux, P., Phillips, N. A., Sinai, M., & Pushkar, D. (2008). Neurophysiological measures of task-set switching: Effects of working memory and aging. *Journals of Gerontology, Series B: Psychological Science and Social Sciences, 63,* P57–P66.

Grabner, R. H., Fink, A., Stipacek, A., Neuper, C., & Neubauer, A. C. (2004). Intelligence and working memory systems: Evidence of neural efficiency in alpha band ERD. *Cognitive Brain Research, 20,* 212–225.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 22, pp. 193–225). New York: Academic Press.

Herzog, A. R., & Wallace, R. B. (1997). Measures of cognitive functioning in the AHEAD study [Special issue]. *Journals of Gerontology, Series B: Psychological Sciences and Social Sciences, 52,* P37–P48.

Hultsch, D., Hertzog, C., Small, B. J., & Dixon, R. A. (1999). Use it or lose it: Engaged lifestyle as a buffer of cognitive decline in aging? *Psychology and Aging, 14,* 245–263.

Johnson, J. K., Lui, L., & Yaffe, K. (2007). Executive function, more than global cognition, predicts functional decline and mortality in elderly women. *Journals of Gerontology, Series A: Biological Sciences and Medical Sciences, 62,* M1134–M1141.

Jones, R. N., Yang, F. M., Zhang, Y., Kiely, D. K., Marcantonio, E. R., & Inouye, S. K. (2006). Does educational attainment contribute to risk for delirium? A potential role for cognitive reserve. *Journals of Gerontology, Series A: Biological Sciences and Medical Sciences, 61,* M1307–M1311.

Kray, J., & Eppinger, B. (2006). Effects of associative learning on age differences in task-set switching. *Acta Psychologica, 123,* 187–203.

Kray, J., Eppinger, B., & Mecklinger, A. (2005). Age differences in attentional control: An event-related potential approach. *Psychophysiology, 42,* 407–416.

Kray, J., Li, K. Z. H., & Lindenberger, U. (2002). Age-related changes in task-switching components: The role of task uncertainty. *Brain & Cognition, 49,* 363–381.

Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging, 15,* 126–147.

Lachman, M. E. (2004). Development in midlife. *Annual Review of Psychology, 55,* 305–331.

Lachman, M. E., & Tun, P. A. (2008). Cognitive testing in large scale surveys. Assessment by telephone. In S. Hofer & D. Alwin (Eds.), *Handbook of cognitive aging: Interdisciplinary perspective* (pp. 506–522). Thousand Oaks, CA: Sage.

Lee, S., Kawachi, I., Berkman, L. F., & Grodstein, F. (2003). Education, other socioeconomic indicators, and cognitive function. *American Journal of Epidemiology, 157,* 712–720.

Letenneur, L., Launer, L. J., Andersen, K., Dewey, M. E., Ott, A., Copeland, J. R., et al. (2000). Education and the risk for Alzheimer's disease: Sex makes a difference. *American Journal of Epidemiology, 151,* 1064–1071.

Lindenberger, U., & Baltes, P. B. (1997). Intellectual functioning in old and very old age: Cross-sectional results from the Berlin Aging Study. *Psychology and Aging, 12,* 420–432.

Lyketsos, C. G., Chen, L., & Anthony, J. C. (1999). Cognitive decline in adulthood: An 11.5 year follow-up of the Baltimore Epidemiological Catchment Area Study. *American Journal of Psychiatry, 156,* 58–65.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109,* 163–203.

Mayr, U. (2001). Age differences in the selection of mental sets: The role of inhibition, stimulus ambiguity, and response-set overlap. *Psychology and Aging, 16,* 96–109.

McEwen, B. S. (2000). Stress, sex, and the structural and functional plasticity of the hippocampus. In M. S. Gazzaniga (Ed.), *The new cognitive neuroscience* (pp. 171–198). Cambridge, MA: MIT Press.

Meinz, E. J., & Salthouse, T. A. (1998). Is age kinder to females than to males? *Psychonomic Bulletin & Review, 5,* 56–70.

Meiran, N., Gotler, A., & Perlman, A. (2001). Old age is associated with a pattern of relatively intact and relatively impaired task-set switching abilities. *Journals of Gerontology, Series B: Psychological Sciences and Social Sciences, 56,* P88–P102.

Metter, E. J., Schrager, M., Ferrucci, L., & Talbot, L. A. (2005). Evaluation of movement speed and reaction time as predictors of all-cause mortality in men. *Journals of Gerontology, Series A: Biological Sciences and Medical Sciences, 60,* M840–M846.

Miyake, A., Friedman, M. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wagner, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49–100.

Mozley, L. H., Gur, R. C., Mozley, P. D., & Gur, R. E. (2001). Striatal dopamine transporters and cognitive functioning in healthy men and women. *American Journal of Psychiatry, 158,* 1492–1497.

Perls, T. T. (1995). The oldest old. *Scientific American, 271,* 50–55.

Plumet, J., Gil, R., & Gaonac'h, D. (2005). Neuropsychological assessment of executive functions in women: Effects of age and education. *Neuropsychology, 19,* 566–577.

Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin, 114,* 510–532.

Reimers, S., & Maylor, E. A. (2005). Task switching across the life span: Effects of age on general and specific switch costs. *Developmental Psychology, 41,* 661–671.

Reimers, S., & Maylor, E. A. (2006). Gender effects on reaction time variability and trial-to-trial performance: Reply to Deary and Der (2005). *Aging, Neuropsychology, and Cognition, 13,* 479–489.

Rogers, R. D., & Monsell, S. (1995). The cost of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124,* 207–231.

Salthouse, T. A. (2006). Mental exercise and mental aging. *Perspectives on Psychological Science, 1,* 68–87.

Salthouse, T. A., Fristoe, N., McGuthry, K. E., & Hambrick, D. Z. (1998). Relation of task switching to speed, age, and fluid intelligence. *Psychology and Aging, 13,* 445–461.

Schooler, C., & Mulatu, M. S. (2001). The reciprocal effects of leisure time activities and intellectual functioning in older people: A longitudinal analysis. *Psychology and Aging, 16,* 466–482.

Shomstein, S., & Yantis, S. (2004). Control of attention shifts between vision and audition in human cortex. *Journal of Neuroscience, 24,* 10702–10706.

Singer, T., Verhaeghen, P., Ghisletta, P., Lindenberger, U., & Baltes, P. B. (2003). The fate of cognition in very old age: Six-year longitudinal findings in the Berlin Aging Study (BASE). *Psychology and Aging, 18,* 318–331.

Stern, Y., Haback, C., Moeller, J., Scarmeas, N., Anderson, K. E. Hilton, H. J., et al. (2005). Brain networks associated with cognitive reserve in healthy young and old adults. *Cerbral Cortex, 15,* 394–402.

Tun, P. A., & Lachman, M. E. (2006). Telephone assessment of cognitive function in adulthood: The Brief Test of Adult Cognition by Telephone (BTACT). *Age and Ageing, 35,* 629–633.

Van Asselen, M., & Ridderinkhof, K. R. (2000). Shift costs of predictable and unexpected set shifting in young and older adults. *Psychologica Belgica, 40,* 259–273.

van Hooren, S. A. H., Valentijn, A. M., Bosma, H., Ponds, R. W. H. M., van Boxtel, M. P. J., & Jolles, J. (2007). Cognitive functioning in healthy older adults aged 64–81: A cohort study into the effects of age, sex, and education. *Aging, Neuropsychology, and Cognition, 14,* 40–54.

Verhaeghen, P., & Cerella, J. (2002). Aging, executive control, and attention: A review of meta-analyses. *Neuroscience and Biobehavioral Reviews, 26,* 849–857.

Wecker, N. S., Kramer, J. H., Hallam, B. J., & Delis, D. C. (2005). Mental flexibility: Age effects on switching. *Neuropsychology, 19,* 345–352.

West, R., & Schwarb, H. (2006). The influence of aging and frontal function on the neural correlates of regulative and evaluative aspects of cognitive control. *Neuropsychology, 20,* 468–481.

Wetter, S. R., Delis, D. C., Houston, W. S., Jacobson, M. W., Lansing, A., Cobell, K., et al. (2005). Deficits in inhibition and flexibility are associated with the APOE-E4 allele in nondemented older adults. *Journal of Clinical and Experimental Neuropsychology, 27,* 943–952.

Whitmer, A. J., & Banich, M. T. (2007). Inhibition versus switching deficits in different forms of rumination. *Psychological Science, 18,* 546–553.

Ylikowski, R., Ylikoski, A., Erkinjuntti, T., Sulkava, R., Keskivaara, P., Raininko, R., & Tilvis, R. (1998). Differences in neuropsychological functioning associated with age, education, neurological status, and magnetic resonance imaging findings in neurologically healthy elderly individuals. *Applied Neuropsychology, 5,* 1–14.

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