

Effects of Healthy Aging and Early Stage Dementia of the Alzheimer's Type on Components of Response Time Distributions in Three Attention Tasks

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Objective: The characteristics of response time (RT) distributions beyond measures of central tendency were explored in 3 attention tasks across groups of young adults, healthy older adults, and individuals with very mild dementia of the Alzheimer's type (DAT). **Method:** Participants were administered computerized Stroop, Simon, and switching tasks, along with psychometric tasks that tap various cognitive abilities and a standard personality inventory (NEO-FFI). Ex-Gaussian (and Vincentile) analyses were used to capture the characteristics of the RT distributions for each participant across the 3 tasks, which afforded 3 components: μ and σ (mean and standard deviation of the modal portion of the distribution) and τ (the positive tail of the distribution). **Results:** The results indicated that across all 3 attention tasks, healthy aging produced large changes in the central tendency μ parameter of the distribution along with some change in σ and τ (mean $\eta_p^2 = .17, .08, \text{ and } .04$, respectively). In contrast, early stage DAT primarily produced an increase in the τ component (mean $\eta_p^2 = .06$). τ was also correlated with the psychometric measures of episodic/semantic memory, working memory, and processing speed, and with the personality traits of neuroticism and conscientiousness. Structural equation modeling indicated a unique relation between a latent τ construct ($-.90$), as opposed to σ ($-.09$) and μ constructs ($.24$), with working memory measures. **Conclusions:** The results suggest a critical role of attentional control systems in discriminating healthy aging from early stage DAT and the utility of RT distribution analyses to better specify the nature of such change.

Keywords: aging, Alzheimer's disease, attention, ex-Gaussian response time distribution, working memory

There has been considerable interest in the cognitive performance of individuals who are in the earliest stage of dementia of the Alzheimer's type (hereafter referred to as *very mild DAT individuals*).

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Studies have demonstrated that the pathological processes of the disease are present in the brain for years before the appearance of symptoms (e.g., Bennett et al., 2006; Morris et al., 1996; Petersen, 2004; Price et al., 2009; Rubin et al., 1998; Storandt, 2008), indicating that preclinical markers of the disease are likely to be present in some older adults who appear to be clinically "normal." This highlights the need to reliably identify potential behavioral changes that could serve as additional early and antecedent markers for DAT. Although episodic memory has been regarded as the primary predictor of the onset of dementia (e.g., Albert, Moss, Blacker, Tanzi, & McArdle, 2007; Storandt, Grant, Miller, & Morris, 2006), there is accumulating evidence for a breakdown in processes related to attention in healthy older adults and, to a greater extent, in very mild DAT individuals across aspects of visual attention (Faust & Balota, 1997), divided attention (Baddeley, Chincotta, & Adlam, 2001; Duchek & Balota, 2005), task switching (Belleville, Bherer, Lepage, Chertkow, & Gauthier, 2008), and selective attention (Balota & Duchek, 1991; Castel, Balota, Hutchison, Logan, & Yap, 2007; Spieler et al., 1996).

Consider, for example, the Stroop task, a prototypical measure of attentional control (MacLeod, 1992). To successfully name the color on an incongruent trial (e.g., the word *red* printed in blue), individuals have to maintain the task goals (naming the ink color instead of the word *red*) throughout the task, activate the task-relevant information

(the ink color blue), and control the highly active but irrelevant information (the word *red*). As noted, there are clear increases in the size of the Stroop effect both in healthy older adults and in early stage DAT. In addition, Balota et al. (in press) showed that the errors on incongruent trials were the best discriminator of those who convert versus those who do not convert to DAT over a 14-year period. Of course, breakdowns in attention are not localized but also influence other cognitive functions. For example, it is widely acknowledged that there is an intimate connection between attention and memory (e.g., Craik & Lockhart, 1972; Hasher & Zacks, 1988; Jacoby, 1991). In fact, there is accumulating evidence that breakdowns in attentional control systems contribute to memory loss in both healthy aging and early stage Alzheimer's disease (e.g., Baddeley et al., 2001; Balota et al., 1999; Balota, Burgess, Cortese, & Adams, 2002; Perry & Hodges, 1999; Sommers & Huff, 2003; Tse, Balota, Moynan, Duchek, & Jacoby, 2010).

In most attention tasks, mean response time (RT) and error rate are the standard measures. There has been an increasing interest in measures of performance above and beyond the central tendency of RTs. For example, there is evidence for changes in variability across trials as a function of healthy aging and mild DAT (Hultsch, MacDonald, & Dixon, 2002; see Hultsch, Strauss, Hunter, & MacDonald, 2008, for a review). Hultsch et al. (2002) found that RT variability was a better discriminator between healthy aging and mild DAT than mean RT performance. More recently, Duchek et al. (2009) reported that individual trial-by-trial RT variability (as reflected by the coefficient of variation, the standard deviation divided by the mean of the distribution) in three attention tasks (Stroop, Simon, and switching) was higher for very mild DAT individuals than that for healthy older adults which in turn was higher than the young adults. Duchek et al. argued that one possible cause for the increase in variability across age and DAT in these attention tasks was due to changes in the ability to maintain appropriate task sets across time. Of course, simple increases in RT variability across individuals can be produced by various changes in the underlying RT distributions. For example, the variance of the entire RT distribution could be increased in a multiplicative manner. Accounts that attribute age-related changes to general slowing (see, e.g., Myerson, Hale, Wagstaff, Poon, & Smith, 1990) would suggest that older adults' performance is simply a multiplicative function of young adults' performance. This predicts that all components of the RT distribution change at the same rate across age groups. Alternatively, it is possible that some components may change more than others. For instance, the increase in variance could be primarily attributed to an increase in the slow end of the RT distribution, which is consistent with the evidence of increases in variability above and beyond mean performance (e.g., Duchek et al.; Hultsch et al., 2002). Hence, it is important to pinpoint the change in specific components of the RT distribution that contribute to the observed changes in the overall RT variability.

The present study explored the influence of healthy aging and the earliest detectable form of DAT on components of RT distributions in three standard attention tasks (Stroop, Simon, and switching). To capture the components of an individual's RT distribution, we fit raw RTs of each participant to an ex-Gaussian distribution and estimated parameters that reflect whether the age-related and DAT-related changes in mean RT were due to shifting (μ), increases in variability in the modal portion (σ),

and/or an increased tail (τ) of the RT distribution (see Balota, Yap, Cortese, & Watson, 2008, for a discussion). This approach allows one to specify whether the change in intraindividual variability as a function of age or DAT (Duchek et al., 2009; Hultsch et al., 2002; Hultsch, MacDonald, Hunter, Levy-Bencheton, & Strauss, 2000) is due to general slowing, which is reflected by changes in *all* parameters, or more specific changes in Gaussian or exponential components of the distribution. We now turn to a brief description of RT distributional analyses.

RT Distribution Analyses

The characteristics of a RT distribution have been shown to capture important aspects of human cognition (Luce, 1986), including selective attention (e.g., Castel et al., 2007; Heathcote, Popiel, & Mewhort, 1991; Spieler et al., 1996, 2000), episodic memory (e.g., Hockley, 1984; Rohrer & Wixted, 1994), word recognition (e.g., Andrews & Heathcote, 2001; Balota & Spieler, 1999; Plourde & Besner, 1997; Yap & Balota, 2007; Yap, Balota, Cortese, & Watson, 2006), semantic priming (e.g., Balota et al., 2008; Lyons, Kellas, & Martin, 1995), and individual differences in cognition (Bub, Masson, & Lalonde, 2006; McAuley, Yap, Christ, & White, 2006; Yap, Tse, & Balota, 2009). In the current research, distributional analyses were carried out both by (a) fitting individual raw RTs to a theoretical ex-Gaussian distribution and (b) averaging RT distributions across participants via Vincentile analyses. The ex-Gaussian distribution is a convolution of a Gaussian (normal) and an exponential distribution that closely approximates the empirical RT distribution (Ratcliff, 1979). The distribution is operationally defined by a three-parameter function. μ and σ parameters reflect the mean and standard deviation, respectively, of the Gaussian component, and the τ parameter reflects any additional exponential contribution to the observed fit of the RT distribution. A change in μ reflects the shifting of the RT distribution, whereas a change in τ is more reflective of the tail of the RT distribution. Because the algebraic sum of μ and τ is constrained to closely approximate the empirical distribution, one can partition the individual mean RT for a particular condition into distributional shifting or changes in the tail of the distribution. It is important to note that, even though two conditions may produce the same *mean* RT, the underlying RT distributions could be different because of counteracting effects of μ and τ (see Balota et al., 2008, for a discussion). This highlights the importance of conducting these fine-grained analyses on RT distributions.

Apart from the ex-Gaussian analyses, which assume that the empirical distribution can be captured by an ex-Gaussian distribution, we conducted Vincentile analyses to obtain converging evidence regarding the shape of the RT distributions. In Vincentile analyses, one first rank orders all of the RTs within a participant and then bins the rank-ordered data into a set of equal number of observations. For instance, to obtain eight Vincentiles, the RT data for a participant are first sorted (from fastest to slowest responses). The first 12.5% of the data is then averaged, followed by the second 12.5%, and so on. Individual Vincentiles are then averaged across participants. Unlike ex-Gaussian fitting, Vincentizing reflects the average shape of the RT distributions without a strong assumption regarding the theoretical shapes of the RT distribution. Hence, it is important to demonstrate convergence across the two techniques.

RT Distribution, Attentional Control, and Cognition

According to the worst performance rule (Coyle, 2003; Larson & Alderton, 1990), the slower portion of participants' RTs in cognitive tasks accounts for a larger proportion of variance of general intelligence than the faster portion of their RTs. In attention tasks, given that individuals with impaired attentional control systems are less likely to maintain the task goal and to suppress irrelevant information, these individuals may be more likely to experience losses of control across time (*goal neglect*; Duncan, Emslie, Williams, Johnson, & Freer, 1996) and produce slower RTs and more errors than those who have more intact attentional control systems. Thus, deficits in attentional control may lead to a larger tail of the RT distribution (i.e., larger τ). This would not be revealed if only central tendency measures, such as RT and errors instead of the characteristics of the RT distribution, were considered. A longer RT in one group of participants could be due to a shift, rather than an increase in the size of the tail of their RT distribution, relative to other groups. The ex-Gaussian parameters have been used to differentiate groups of individuals who are high versus low in attentional control abilities in developmental and aging research (e.g., Leth-Steensen, King Elbaz, & Douglas, 2000; McAuley et al., 2006; Spieler et al., 1996; West, Murphy, Armilio, Craik, & Stuss, 2002). Similarly, the individual-difference approach used by Schmiedek, Oberauer, Wilhelm, Süß, and Wittmann (2007) involved estimating the ex-Gaussian parameters in eight choice RT tasks. They showed that τ , but not μ or σ , for young adults was strongly related to working memory capacity, providing more direct evidence for the relationship between τ and attentional control that had only been assumed in previous studies (e.g., Spieler et al., 1996). In the present study, we used three attention tasks that induce stronger response competition between relevant pathways and hence more directly tap attentional control than the choice RT tasks of Schmiedek et al. The sensitivity of a task to one's attentional control is critical in the current study because the deficit in attentional control can be quite subtle for individuals who are in the earliest stages of DAT.

RT Distribution

Personality has recently been found to serve as a noncognitive indicator of early onset DAT (Duchek, Balota, Storandt, & Larsen, 2007; Wilson et al., 2003; Wilson, Schneider, Arnold, Bienias, & Bennett, 2007). For example, Duchek et al. (2007) found that very mild DAT individuals were higher in neuroticism and lower in conscientiousness than healthy older adults, even after taking into account the performance of psychometric tests. Also, Wilson et al. (2007) found that healthy older adults high in conscientiousness, compared with those low in conscientiousness, were less likely to later develop DAT in a longitudinal study. Indeed, Wilson et al. pointed out, "Conscientiousness refers to an individual's tendency to control impulses and be goal directed" (p. 1204), suggesting that individuals who are high in conscientiousness are more able to stay tuned to the task goal in the face of irrelevant information. An interesting finding by Duchek, Balota, Fagan, and Holtzman (2008) was that high scores in neuroticism and low scores in conscientiousness for healthy older adults were associated with increased intraindividual variability in their RT performance in three attention tasks (see also Robinson & Tamir, 2005, for further evidence of a relationship between neuroticism and RT variability in the Stroop task for young adults). However, as noted above, variability can reflect different components of the RT distribution, so it is important to examine specifically which

aspects of the RT distribution change as a function of conscientiousness and neuroticism in both healthy aging and early stage DAT. A priori, one would expect a negative correlation between conscientiousness and τ (i.e., the tail of the RT distribution) because individuals who are less conscientious experience more difficulty staying tuned to the task, such that they need to reinstate the task set more frequently and hence show a larger tail of their RT distribution. On the other hand, one might expect a positive correlation between neuroticism and τ because individuals who are more neurotic are more sensitive to non-goal-oriented environmental stressors, such that they need to suppress the distracting information more frequently and hence show a larger tail in their RT distribution. Thus, the intriguing prediction is that one might expect correlations between τ and both conscientiousness and neuroticism, but in opposite directions.

Present Research

The Clinical Dementia Rating scale (CDR) was used in the present study to identify individuals at the earliest stages of DAT; CDR ratings are derived independently without considering psychometric test performance (Morris, 1993; Storandt et al., 2006) and have been shown to be highly predictive of pathology consistent with Alzheimer's disease based on autopsy (Berg et al., 1998; Storandt et al., 2006). This well-characterized sample of very mild DAT individuals can provide a more refined examination of the components of RT distributions as an early marker for the onset of DAT. It is noteworthy that the very mild DAT individuals in the current sample (CDR = 0.5) are high functioning, as reflected by their relatively high Mini-Mental State Examination (MMSE) scores (29.0 for healthy controls and 26.6 for the CDR 0.5s).

There are four main predictions that highlight the role of attentional control in healthy aging and early stage DAT. First, the age- and DAT-related differences in the Stroop effect and Simon effect should be found, replicating the findings of previous studies (e.g., Castel et al., 2007; Spieler et al., 1996). For the switching task, we predicted a null age-related effect in local switch cost, as reported in previous studies (e.g., Kray & Lindenberger, 2000). However, for the DAT-related effect, one might expect a smaller local switch cost in RTs yet a larger local switch cost in errors for very mild DAT individuals, relative to healthy older adults, because of a deficit in their attentional control system. Specifically, because switching across two different task sets (odd-even vs. consonant-vowel) requires a well-tuned attentional control system that can activate one task set while suppressing the other throughout the task, individuals with a deficit in this system may be less likely to suppress the irrelevant task set across trials. The resultant simultaneous activation of both task sets should reduce the local switch cost in RT while, at the same time, it may increase the local switch cost in errors because responses should be more error-prone when the activation of the irrelevant task set is not successfully suppressed.

Second, very mild DAT individuals should show a larger τ than healthy older adults in all three attention tasks. An absence of the DAT-related effect in μ and σ would suggest that the RT difference between healthy older adults and very mild DAT individuals can be attributed primarily to the latter group showing a larger number of relatively slow RT trials.

Third, the correlation analyses for the ex-Gaussian parameters and composite scores extracted from scores in the psychometric battery (see below) should produce a robust negative correlation between τ and other

aspects of cognition that depend on attentional control systems, such as working memory and episodic memory (see McCabe, Roediger, McDaniel, Balota, & Hambrick, in press). In addition, we attempted to replicate the intriguing finding by Schmiedek et al. (2007), indicating a specific relationship between a τ construct and a working memory construct, via structural equation modeling.

Fourth, conscientiousness and neuroticism should be associated with τ because of their possible relationship with one's attentional control abilities, but interestingly in opposite directions.

Method

Participants

A total of 352 individuals participated in this study, with 246 nondemented (CDR = 0) healthy older adults and 74 very mild DAT (CDR = 0.5) individuals recruited from the Washington University Alzheimer's Disease Research Center (ADRC) and 32 healthy young adults recruited from the Washington University undergraduate participant pool (see Table 1). Although part of this data set was recently reported in Duchek et al. (2009), the current article includes new analytic procedures and a larger sample of participants. Because not all of the participants did all of the attention tasks, the sample sizes varied across tasks. There was a significant age difference between healthy older adults and very mild DAT individuals (see Table 1); hence, we controlled for this variable in all of the following analyses that involved only these two groups. All ADRC participants were screened for depression, untreated hypertension, reversible dementia, and other disorders that could potentially produce cognitive impairment. The inclusion and exclusion criteria for DAT are consistent with the criteria for "probable AD" of the National Institute of Neurological and Communications Disorders and Stroke—Alzheimer's

Disease and Related Disorders Association (McKhann et al., 1984). The presence of dementia was assessed according to the Washington University CDR scale (Morris, 1993; Morris, McKeel, Fulling, Torack, & Berg, 1988), with CDR 0, 0.5, 1, 2, and 3 representing no dementia, very mild dementia, mild dementia, moderate dementia, and severe dementia, respectively. The CDR is based on a 90-min clinical interview that assesses the participants and obtains information from close collateral sources (e.g., family members). This interview assesses potential changes in participants' cognitive and functional abilities in memory, orientation, home and hobbies, judgment and problem solving, community affairs, and personal care relative to previous behavior. The determination of a CDR status for each participant at baseline and at each annual assessment thereafter is made without reference to the psychometric performance of the individual. The recruitment and assessment methods permit the diagnosis of DAT in individuals who elsewhere may be characterized as having mild cognitive impairment (MCI; Berg et al., 1998; Morris et al., 2001; see http://alzheimer.wustl.edu/cdr/PDFs/CDR_OverviewTranscript-Revised.pdf for an online summary). Both the reliability of the CDR (Burke et al., 1988) and the validity of the diagnosis based on autopsy by this research team have been excellent (93% accuracy), including those diagnosed with very mild DAT (Berg et al., 1998; Storandt et al., 2006). This study was approved by the Institutional Review Board at Washington University School of Medicine, and all participants provided their informed consents at the beginning of the study.

Design and Procedure

Psychometric testing. Each ADRC participant was administered a 2-hr psychometric battery in a separate testing session by an examiner who was unaware of the participant's CDR status. The

Table 1
Psychometric, Span, and Personality Measure Statistics as a Function of Group

Variable/test	Young			Healthy old (CDR = 0)			Very mild DAT (CDR = 0.5)		
	<i>M</i>	<i>n</i>	<i>SD</i>	<i>M</i>	<i>n</i>	<i>SD</i>	<i>M</i>	<i>n</i>	<i>SD</i>
Age (years)	20.31 _a	32	1.12	71.77 _b	246	7.71	75.82 _c	74	7.81
Education (years)	14.62 _a	32	1.01	15.28 _a	246	2.71	14.70 _a	74	2.93
Mini-Mental State Exam	—	—	—	28.99 _a	246	1.36	26.58 _b	74	2.78
Logical Memory	—	—	—	13.28 _a	230	5.17	8.45 _b	74	4.76
WMS Associate Recall	—	—	—	14.71 _a	230	3.78	10.42 _b	73	4.14
WAIS Information	—	—	—	21.48 _a	231	4.59	18.16 _b	74	4.67
Animal Fluency	—	—	—	20.54 _a	246	5.82	15.66 _b	74	5.14
Reading Span	8.70 _a	30	1.91	7.58 _b	245	1.86	5.49 _c	73	2.08
Rotation Span	11.80 _a	30	3.07	8.94 _b	240	3.33	5.53 _c	66	3.59
Computational Span	12.73 _a	30	4.04	8.72 _b	244	3.66	5.97 _c	70	3.15
Word Fluency <i>S-P</i>	—	—	—	31.46 _a	224	10.81	26.42 _b	74	10.71
WAIS Digit Symbol	—	—	—	49.51 _a	223	10.79	37.59 _b	73	12.34
Trail Making A	—	—	—	33.59 _a	246	12.34	43.61 _b	74	23.21
Trail Making B	—	—	—	85.09 _a	245	34.61	127.92 _b	74	52.56
Forward Digit Span	—	—	—	6.53 _a	224	1.23	6.35 _a	74	1.15
Backward Digit Span	—	—	—	4.80 _a	224	1.28	4.19 _b	74	1.09
Boston Naming	—	—	—	49.73 _a	224	12.16	43.32 _b	74	13.39
Crossing Off	—	—	—	168.31 _a	224	58.77	144.97 _b	74	36.73
Conscientiousness	—	—	—	34.45 _a	228	5.59	31.57 _b	70	4.94
Neuroticism	—	—	—	14.16 _a	228	6.39	17.53 _b	70	7.34

Note. CDR = Clinical Dementia Rating scale; DAT = Dementia of the Alzheimer's type; WMS = Wechsler Memory Scale; WAIS = Wechsler Adult Intelligence Scale. The values within each row with different subscripts are significantly different from each other ($p < .05$, two-tailed). The analyses for healthy older adults versus very mild DAT individuals were controlled for age.

battery included the MMSE (Folstein, Folstein, & McHugh, 1975), forward and backward digit spans, Logical Memory, and Associate Memory subtests in Wechsler Memory Scale (WMS; Wechsler & Stone, 1973), Information and Digit Symbol subtests in Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1955), Crossing Off (Botwinick & Storandt, 1973), Trail Making A and B (Armitage, 1946), Boston Naming Test (Goodglass & Kaplan, 1983), Animal Naming Test (Goodglass & Kaplan, 1983), and Word Fluency Test *S-P* (Thurstone & Thurstone, 1949). In addition, all participants received three working memory span tasks (reading, rotation, and computation span; Engle, Tuholski, Laughlin, & Conway, 1999) in the same session in which the attention tasks were conducted. The group means and standard deviations for all of these measures are presented in Table 1. As expected, very mild DAT individuals performed worse than healthy older adults on most tests. Because young adults were not recruited via the ADRC, they did not receive the psychometric battery, although they did complete the three working memory span tasks. As shown in Table 1, their working memory performance was better than healthy older adults and very mild DAT individuals, as typically found in the literature (e.g., White & Murphy, 1998).

Personality testing. The NEO Five-Factor Inventory (NEO-FFI; Costa & McCrae, 1992) was completed by 228 of 246 healthy older adults and 70 of 74 CDR 0.5 individuals. The NEO-FFI is a shortened version of the Revised NEO Personality Inventory (NEO-PI-R) that measures the five factors of Neuroticism, Openness, Extraversion, Agreeableness, and Conscientiousness. There are 60 items rated on a 5-point scale from *strongly agree* to *strongly disagree*. Administration of the scale takes about 10–15 min. This shortened scale has correlations of .77 to .92 with the five-factor scales from the NEO-PI-R, and internal consistency values range from .68 to .86 (Costa & McCrae, 1992). The participants filled out the form after they finished the three attention tasks. If they were unable to fill out the form on their own, a trained research assistant orally administered the questionnaire. Because previous studies reported that Conscientiousness and Neuroticism are most relevant to attentional control and affected by DAT (e.g., Duchek et al., 2007; Wilson et al., 2003, 2007), we report only these factors in the current article. As shown in Table 1, we replicated the findings that very mild DAT individuals yielded lower Conscientiousness and higher Neuroticism scores than healthy older adults.

Stroop task. This task involved four color names (red, blue, green, and yellow) and four neutral words (*bad*, *poor*, *deep*, and *legal*). In the 36 congruent trials, each of the four color names appeared 9 times in its corresponding color. In the 36 incongruent trials, each of the four color names appeared 3 times in each of the three nonmatching colors. In the 32 neutral trials, each of the four neutral words appeared twice in each of the four colors. These trial types were randomly intermixed for each participant. To familiarize the participants with the task and screen out any potential color-blind individuals, they were first presented with examples of colors and words to be used in the task. Prior to the actual trials, participants were presented with a block of 16 practice trials. Each trial began with a fixation stimulus (+++) displayed for 700 ms, following by a 50-ms blank-screen interstimulus interval. The word then appeared on a black background and remained on the screen until the participant read aloud its color. Once the voice-operated relay was triggered, the experimenter coded the response as correct, nonintrusion error (i.e.,

stutters, false starts, or other noises), or intrusion error (i.e., participant named the word or other color names).

Simon task. The stimulus display in this task consisted of a white central fixation (+) and a white arrow (measuring approximately 4 cm in length and 2 cm in height) presented on a black background. The peripheral locations of the arrow (left and right) were situated 5° on the horizontal plane from the central fixation. Participants were told that they would be presented with an arrow pointing to either the left or right on the screen and the arrow would appear on the left half, right half, or center of the screen. They were told to ignore the arrow location on the screen and respond according to its direction by pressing a key on either the left (*q* key) or right side (*p* key) of the keyboard when the arrow was pointing left or right, respectively. In the 40 congruent trials, the arrow direction corresponded to the arrow location (e.g., left-pointing arrow on the left half of the screen). In the 40 incongruent trials, the arrow direction was opposite the arrow location (e.g., left-pointing arrow on the right half of the screen). In the 40 neutral trials, the arrow appeared at the center of the screen. These trials were included to ensure that participants would keep their fixation on the center of the screen. These trial types were randomly intermixed for each participant. Prior to the actual trials, participants were presented with a block of 12 practice trials. Each trial began with a 500-ms central fixation, followed by the onset of an arrow, which stayed on the screen until the participant made a response or until 5 s had elapsed. Once a response was made, the screen cleared and accuracy feedback was presented for 400 ms. The next trial began 2 s after feedback. Both RT and accuracy were recorded.

Switching task. In this task (modified from Minear & Shah, 2008), participants engaged in two different tasks across trials. On each trial, a letter–number pair (e.g., *A 3*) appeared at the center of the screen with a cue appearing at the top of the screen indicating if it is a letter or number trial. On a letter trial, participants were told to decide whether the letter was a consonant or vowel (CV). On a number trial, they were told to decide whether the number was odd or even (OE). Participants pressed the *d* key when responding consonant or odd and the *k* key when responding vowel or even. They first received 10 practice trials with feedback, and then a block of 60 switch/nonswitch trials in an alternate runs sequence, CV, CV, OE, OE, CV, CV, OE, OE and so forth in which a given task (e.g., consonant–vowel decisions) was performed on successive trials, but then switched to a different task (e.g., odd–even decisions). Hence, there were 30 switch trials (e.g., CV trial followed by OE trial) and 30 nonswitch trials (e.g., CV trial followed by CV trial). Feedback was not given on these trials. The letter–number pair remained on the screen until participants made a response and then the next pair appeared immediately. Participants were instructed to respond as quickly and as accurately as possible and keep track of the order of the trials rather than rely on the cues at the top of the screen.¹

¹ In our switching task, we also had participants perform two other pure blocks in which all trials were consonant–vowel trials in one block and odd–even trials in the other block. We did not consider the performance in these trials in our subsequent analyses because they are more similar to the typical choice–RT tasks, which are less likely to tap the attentional control system to the same degree as the Stroop task, the Simon task, and the mixed block in the switching task (i.e., the one reported here) do. Hence, to ensure that our data are comparable across the Stroop, Simon, and switching tasks, we only considered the data of the mixed block in all of our analyses involving the switching task.

Results

We first present the mean RT and error data as a function of group and condition to ensure that we replicated the typical findings reported in Stroop, Simon, and switching studies. We also followed Faust, Balota, Ferraro, and Spieler's (1999) recommendation and performed z -transformed RT analyses to determine whether the observed effects within condition were due to general slowing. The overall patterns of the z RT data were similar to those of the RT data. Hence, we report only the RT and error data here for the sake of brevity.

For the RT analyses, trials with incorrect responses and trials with correct-response RTs that were shorter than 200 ms and those that were above or below 3 standard deviations of each participant's mean RT were all removed, resulting in an elimination of 2–3% of correct-response trials for each group in each task. We included only the trials with correct responses in all of our RT analyses. The effect sizes of F statistics are represented by η_p^2 . For each of the three tasks, we obtained the ex-Gaussian parameters for each participant for all trials within a task using quantile maximum likelihood estimation procedure in QMPE 2.18 (Cousineau, Brown, & Heathcote, 2004; Heathcote, Brown, & Mewhort, 2002). This procedure provides unbiased parameter estimates and has been shown to be more effective than continuous maximum likelihood estimation for small samples (Heathcote & Brown, 2004; Speckman & Rouder, 2004). All fits successfully converged within 500 iterations. Mean Vincentiles for the data were plotted, providing a graphical complement to the ex-Gaussian fits. As noted earlier, Vincentizing averages RT distributions across participants to produce the RT distribution profile of a group of participants (Ratcliff, 1979).

RT and Errors

For the Stroop and Simon tasks, participants' means were submitted to a 3 (group) \times 3 (condition: congruent, neutral, or incongruent) mixed-factor analysis of variance (ANOVA). For the switching task, participants' means were submitted to a 3 (group) \times 2 (condition: switch or nonswitch) mixed-factor ANOVA. For the Stroop task, we separately report the mean overall, intrusion, and nonintrusion error rates. Figure 1 summarizes the mean RTs and errors by conditions in these three tasks. The statistics from these ANOVAs are listed in Table 2.

For the Stroop task, the main effects of group and condition and the Group \times Condition interaction were all significant. Follow-up tests revealed that the Stroop effect (incongruent–congruent) was larger for very mild DAT individuals than for healthy older adults after controlling for age (RT: $p < .001$, $\eta_p^2 = .12$; overall errors: $p < .001$, $\eta_p^2 = .09$; intrusion errors: $p < .001$, $\eta_p^2 = .06$; nonintrusion errors: $p < .001$, $\eta_p^2 = .04$) and larger for healthy older adults than for young adults in RT ($p < .001$, $\eta_p^2 = .05$), but not in overall errors ($p = .50$, $\eta_p^2 = .002$), intrusion errors ($p = .20$, $\eta_p^2 = .006$), or nonintrusion errors ($p = .11$, $\eta_p^2 = .009$).

For the Simon task, the main effects of group and condition and the Group \times Condition interaction were all significant. Follow-up tests revealed that the Simon effect (incongruent–congruent) was larger for very mild DAT individuals than for healthy older adults, after controlling for age (RT: $p < .001$, $\eta_p^2 = .05$; errors: $p < .001$, $\eta_p^2 = .03$), and larger for healthy older adults than for young adults in RT ($p < .005$, $\eta_p^2 = .04$), but not in errors ($p = .87$, $\eta_p^2 = .00$).

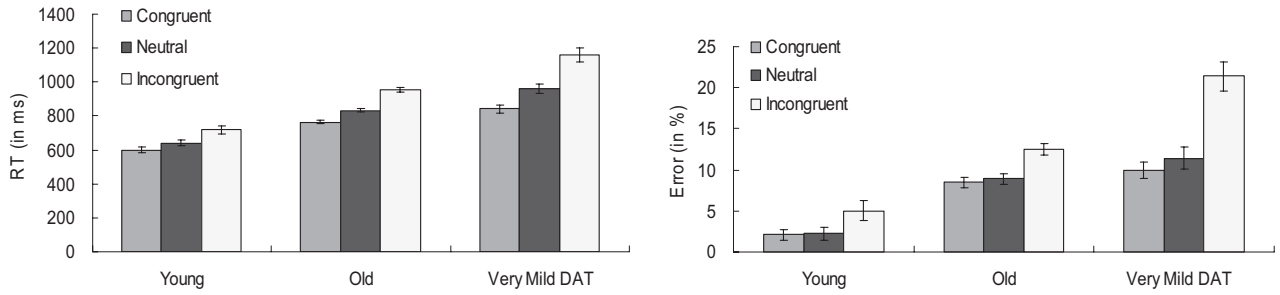
For the switching task, the main effects of group and condition in both RT and errors and the Group \times Condition interaction in RTs

were all significant, but the interaction in errors was not. Follow-up tests revealed that the local switch cost (switch–nonswitch) in RT was smaller for very mild DAT individuals than for healthy older adults, after controlling for age ($p < .001$, $\eta_p^2 = .05$). The local switch cost in error rates was larger, albeit marginally so, for very mild DAT individuals than it was for healthy older adults, after controlling for age ($p = .09$, $\eta_p^2 = .01$). The cost did not differ for young and healthy older adults in RT ($p = .18$, $\eta_p^2 = .01$) or errors ($p = .38$, $\eta_p^2 = .003$), consistent with previous studies in task switching (e.g., Kray & Lindenberger, 2000). The smaller local switch cost in very mild DAT individuals was also in line with our prediction. That is, the deficit in attentional control system for these individuals made it less likely for them to suppress one of the task sets across trials in the switching task. The activation of both task sets reduced the local switch cost in RT but at the same time increased, albeit marginally, the local switch cost in errors as responses were more error-prone when the activation of the irrelevant task set was not successfully suppressed.²

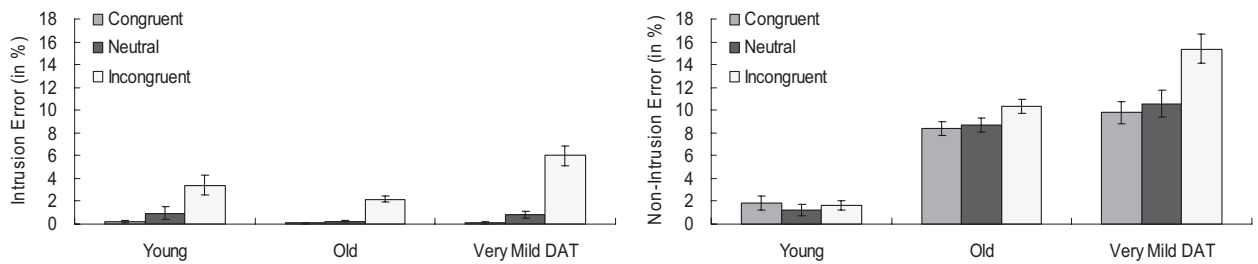
The DAT-related reduction in local switch cost at first glance appears to be incompatible with the findings reported in previous studies examining individuals with DAT (e.g., Belleville et al., 2008) or with other attentional control problems (e.g., children with attention-deficit/hyperactivity disorder [ADHD] in Cepeda, Cepeda, & Kramer, 2000). However, it should be noted that the methodological differences between these studies and the present study likely make direct comparisons problematic. For example, Belleville et al. (2008) did not find any differences in local switch cost between their MCI individuals and their controls; however, their switching task involved a random intermixing of switch and nonswitch trials, as opposed to the AABBA ordering used here. Hence, healthy controls may have been less tuned to the task constraints before hand in Belleville et al., thus producing greater switch costs. In addition, Cepeda et al. (2000) used a numerical Stroop switching task and observed larger switch costs in their ADHD children, compared with the control sample. It is possible that the selection based on the numerical Stroop task produced the increased difficulty for the ADHD participants. In fact, we have recently found that a Stroop switching task does indeed produce a much higher error rate in DAT individuals compared with healthy controls (Hutchison, Balota, & Duchek, in press). Clearly, there are many characteristics of switching tasks that can influence between-

² To further investigate the role of attentional control in task switching performance, we divided the trials into congruent (e.g., *E 04*, both vowel and even responses require participants to press the same key) or incongruent (e.g., *J 04*, both consonant and even responses require participants to press different keys) and performed the same set of RT and error analyses reported above by including response congruency as a variable. One may expect that participants would be slower for the incongruent trials because it takes time to overcome the response conflict between the digits and letters. Consistent with this idea, we obtained a Response Congruency \times Group interaction in RT, $F(2, 326) = 11.75$, $MSE = 231149$, $p < .001$, $\eta_p^2 = .07$. Although the interaction was not significant in errors, $F(2, 326) = 1.14$, $MSE = 25.82$, $p = .32$, $\eta_p^2 = .01$, the overall pattern was in the same direction as that of RTs. The response congruency effect (i.e., incongruent–congruent) was stronger for very mild DAT individuals (125 ms, 13.6%) than for healthy older adults (37 ms, 3.6%), and in turn for young adults (24 ms, –0.5%). Neither of these interactions was modulated by the condition (i.e., switch vs. nonswitch) in the switching task ($F_s < 2.35$, $p_s > .09$). Hence, these data indicate that the responses for the switch and nonswitch trials were equally affected by whether the responses were in concert or in conflict between the digit and letter.

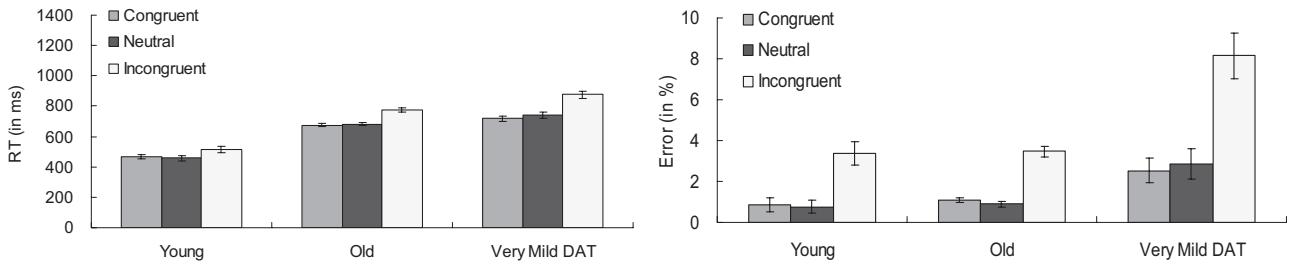
Stroop RTs and overall errors



Stroop intrusion and non-intrusion errors



Simon RTs and errors



Switching RTs and errors

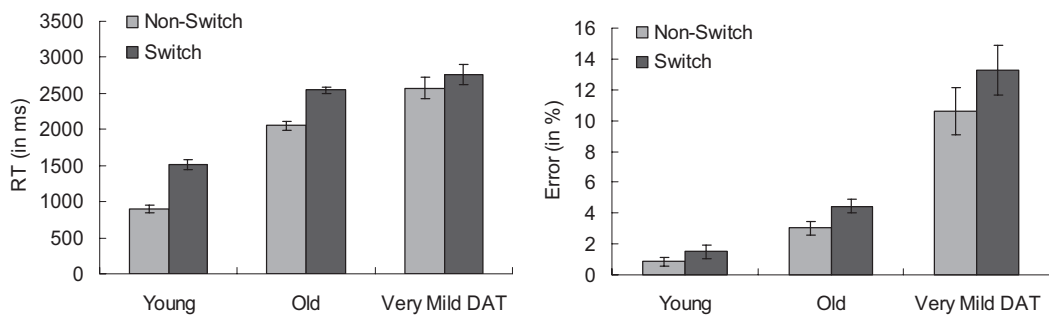


Figure 1. Mean reaction times (RTs) and percentage errors in Stroop, Simon, and switching tasks as a function of condition and group. Error bars indicate standard errors of means.

Table 2

Analysis of Variance for Reaction Time (RT), Error, and Ex-Gaussian Parameters in Stroop, Simon, and Switching Tasks

Measure	Variable	df	F	MSE	p	η_p^2
For Stroop RT	Main effect of group	2, 346	44.03	85254	<.001	.20
	Main effect of condition	2, 692	309.07	6221	<.001	.47
	Group \times Condition	4, 692	24.78	6221	<.001	.13
For Stroop error	Main effect of group	2, 346	16.13	248.98	<.001	.09
	Main effect of condition	2, 692	60.92	32.29	<.001	.15
	Group \times Condition	4, 692	15.06	32.29	<.001	.08
For Stroop intrusion error	Main effect of group	2, 346	13.52	14.20	<.001	.07
	Main effect of condition	2, 692	81.96	8.54	<.001	.19
	Group \times Condition	4, 692	13.86	8.54	<.001	.07
For Stroop nonintrusion error	Main effect of group	2, 346	15.71	212.99	<.001	.08
	Main effect of condition	2, 692	13.40	24.05	<.001	.04
	Group \times Condition	4, 692	5.93	24.05	<.001	.03
For Stroop μ	Effect of group	2, 346	17.82	14097	<.001	.09
For Stroop σ	Effect of group	2, 346	16.51	2679	<.001	.09
For Stroop τ	Effect of group	2, 346	30.02	15925	<.001	.15
For Simon RT	Main effect of group	2, 343	32.28	69318	<.001	.18
	Main effect of condition	2, 686	145.40	3586	<.001	.30
	Group \times Condition	4, 686	10.81	3586	<.001	.06
For Simon Error	Main effect of group	2, 343	19.94	32.24	<.001	.10
	Main effect of condition	2, 686	67.98	9.62	<.001	.17
	Group \times Condition	4, 686	9.19	9.62	<.001	.05
For Simon μ	Effect of group	2, 343	48.24	6588	<.001	.22
For Simon σ	Effect of group	2, 343	16.10	491	<.001	.09
For Simon τ	Effect of group	2, 343	20.35	11037	<.001	.11
For switching RT	Main effect of group	2, 320	34.82	1260786	<.001	.18
	Main effect of condition	1, 320	143.77	107091	<.001	.31
	Group \times Condition	2, 320	12.63	107091	<.001	.07
For switching error	Main effect of group	2, 320	34.23	107.72	<.001	.18
	Main effect of condition	1, 320	16.16	12.65	<.001	.05
	Group \times Condition	2, 320	2.02	12.65	.14	.01
For switching μ	Effect of group	2, 320	17.69	525062	<.001	.10
For switching σ	Effect of group	2, 320	6.76	109659	<.001	.04
For switching τ	Effect of group	2, 320	9.02	403709	<.001	.05

group comparisons of switch costs (see Logan & Gordon, 2001, for a review); therefore, one needs to be cautious about the comparisons across different switching tasks. The important emphasis in the present study is how early stage DAT influences the RT distributional characteristics in the present type of switching task, to which we now turn.³

Ex-Gaussian Parameters and Vincentile Plots

Figure 2 summarizes the mean ex-Gaussian parameters in these three tasks, and Figure 3 presents the Vincentile plots in all of these tasks. For each plot, the empirical Vincentiles are represented by data points and standard error bars, and the Vincentiles for the respective best-fitting ex-Gaussian distribution are represented by lines. The theoretical Vincentiles were computed by a line search on the numerical integral of the fitted ex-Gaussian distribution. The goodness of fit between the empirical and theoretical Vincentiles reflects the extent to which the empirical RT distributions are being captured by the ex-Gaussian parameters (see, e.g., Andrews & Heathcote, 2001). The Greenhouse–Geisser correction was used in all analyses involving Vincentiles to avoid the potential violation of sphericity. The statistics of the one-way ANOVAs for the ex-Gaussian parameters are listed in Table 2. For the three attention tasks, all three ex-Gaussian parameters increased across groups. For the Stroop task, follow-up tests showed that all three ex-Gaussian parameters were higher for healthy older

adults than they were for young adults (μ : $p < .001$, $\eta_p^2 = .11$; σ : $p < .001$, $\eta_p^2 = .10$; τ : $p = .001$, $\eta_p^2 = .04$). As noted earlier, an increase in all three parameters is consistent with a general slowing model of

³ As pointed out in Footnote 1, although our participants also received the blocks with only consonant–vowel trials and only odd–even trials, we did not include their pure-block data in estimating the ex-Gaussian parameters for the switching task in order to make this task comparable to the other two. Previous studies (e.g., Belleville et al., 2008) reported that global switch cost (i.e., subtracting RT/error of these pure blocks from RT/error of the nonswitch trials) was greater for very mild DAT individuals than for healthy older adults and greater for healthy older adults than for young adults. To check whether this could be replicated in our sample, we performed the analyses for global switch cost. First, although very mild DAT individuals showed numerically, albeit nonsignificantly, greater global switch cost in RT than healthy older adults (1,201 ms vs. 1,017 ms), $F(1, 290) = 1.30$, $MSE = 574422$, $p = .26$, $\eta_p^2 = .004$, the DAT-related difference in global switch cost in errors was robust and significant (5.6% vs. 0.4%), $F(1, 290) = 21.28$, $MSE = 37.85$, $p < .001$, $\eta_p^2 = .07$. These analyses controlled for participants' ages. Second, although healthy older adults showed numerically, albeit nonsignificantly, greater global switch cost in errors than young adults (0.4% vs. -0.8%), $F(1, 261) = 1.84$, $MSE = 21.51$, $p = .18$, $\eta_p^2 = .007$, the age-related difference in global switch cost in RT was robust and significant (1,017 ms vs. 173 ms), $F(1, 261) = 41.70$, $MSE = 454841$, $p < .001$, $\eta_p^2 = .14$. Hence, the pattern of global switch cost was consistent with those reported in previous studies.

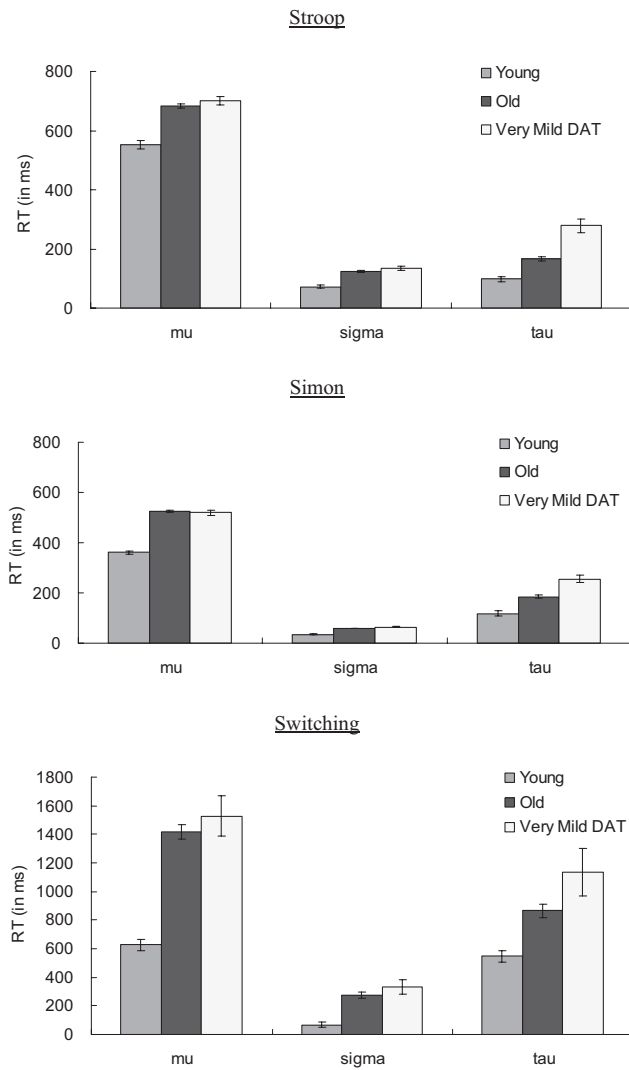


Figure 2. The ex-Gaussian parameters in Stroop, Simon, and switching tasks as a function of group. Error bars indicate standard errors of means.

aging. It is important to note however, that, after controlling for age, τ , but not μ or σ , was higher for very mild DAT individuals than it was for healthy older adults (μ : $p = .68$, $\eta_p^2 = .001$; σ : $p = .22$, $\eta_p^2 = .005$; τ : $p < .001$, $\eta_p^2 = .10$). In the Vincentile plots, the increase in RT across the distributions was sharper for very mild DAT individuals than it was for healthy older adults after controlling for age, $F(1.24, 392.92) = 56.14$, $MSE = 4104$, $p < .001$, $\eta_p^2 = .15$, and it was sharper for healthy older adults than it was for young adults, $F(1.29, 353.10) = 37.79$, $MSE = 2476$, $p < .001$, $\eta_p^2 = .12$.

For the Simon task, all three ex-Gaussian parameters were higher for healthy older adults than they were for young adults (μ : $p < .001$, $\eta_p^2 = .27$; σ : $p < .001$, $\eta_p^2 = .10$; τ : $p < .005$, $\eta_p^2 = .04$). Again, after controlling for age, τ , but not μ or σ , was higher for very mild DAT individuals than it was for healthy older adults (μ : $p = .11$, $\eta_p^2 = .01$; σ : $p = .34$, $\eta_p^2 = .003$; τ : $p < .001$, $\eta_p^2 = .05$). In the Vincentile plot, the increase in RT across the distribution was sharper for very mild DAT individuals than it was for healthy older adults after controlling for age, $F(1.11, 351.49) = 10.35$,

$MSE = 4173$, $p < .001$, $\eta_p^2 = .03$, and it was sharper for healthy older adults than it was for young adults, $F(1.12, 302.06) = 11.35$, $MSE = 3380$, $p < .001$, $\eta_p^2 = .04$.

For the switching task, all three ex-Gaussian parameters were higher for healthy older adults than they were for young adults (μ : $p < .001$, $\eta_p^2 = .13$; σ : $p < .001$, $\eta_p^2 = .05$; τ : $p < .01$, $\eta_p^2 = .03$). Once again, after controlling for age, τ , but not μ or σ , was higher for very mild DAT individuals than it was for healthy older adults (μ : $p = .44$, $\eta_p^2 = .002$; σ : $p = .27$, $\eta_p^2 = .004$; τ : $p < .05$, $\eta_p^2 = .02$). In the Vincentile plot, the increase in RT across the distribution was sharper for very mild DAT individuals than it was for healthy older adults after controlling for age, $F(1.22, 354.46) = 9.52$, $MSE = 175189$, $p < .005$, $\eta_p^2 = .03$, and it was sharper for healthy older adults than it was for young adults, $F(1.18, 309.01) = 18.21$, $MSE = 119719$, $p < .001$, $\eta_p^2 = .07$. It should be noted that even though the ex-Gaussian distributions were not always fitted very well in the slowest bin for all three attention tasks (see Figure 3), the overall pattern of Vincentile plots still clearly demonstrate that the DAT-related effect was particularly stronger in the last few bins of the RT distribution.

In sum, the results from the RT distributional analyses are remarkably clear. Whereas healthy aging has a consistent effect on μ , σ , and τ , early stage DAT only influences the tail of the distribution, as reflected by changes in τ . This pattern was replicated across all three attention tasks.⁴

Relationship Between Ex-Gaussian Parameters and Psychometric and Span Measures

Because the overall patterns of μ , σ , and τ were quite similar across the Stroop, Simon, and switching tasks, we conducted a confirmatory factor analysis to determine whether these three variables loaded on three distinct latent factors, reflecting the three ex-Gaussian parameter estimates. Indeed, the results from this analysis yielded three latent variables with an excellent-fit, $\chi^2(15) = 21.17$, $p = .13$; root-mean-square error of approximation (RMSEA) = .04, comparative fit index (CFI) = .99, using a minimum criterion for acceptability of fit as a CFI > .90 (Hu & Bentler, 1995) and a RMSEA < .10 (Browne & Cudeck, 1993). We therefore computed a composite μ , σ , and τ for the following correlation analyses. For each participant, we computed the z scores of μ , σ , and τ (based on the overall mean and standard deviation across groups) for each of the three tasks and then

⁴ Because of the relatively small samples within conditions within each task, the most informative analyses are across all trials within a task. To observe the pattern of cell means for each condition in the three selective attention tasks, we randomly combined every three participants into a supersubject in each of the three groups such that we would have enough observations per cell to estimate the ex-Gaussian parameters within each condition in the three tasks. The overall pattern was very similar across three conditions; that is, the age-related effect occurred in μ , σ , and τ , whereas the DAT-related effect occurred primarily in τ . This suggests that the increased tails we observed in very mild DAT individuals were more likely due to difficulty with maintaining their task goals at the list-wide level instead of the specific condition level. However, these data should be interpreted with caution because collapsing data across participants might have distorted the characteristics of their underlying individual RT distributions. Future research should increase the number of observations within each condition to further examine the differential effects of condition on ex-Gaussian parameters.

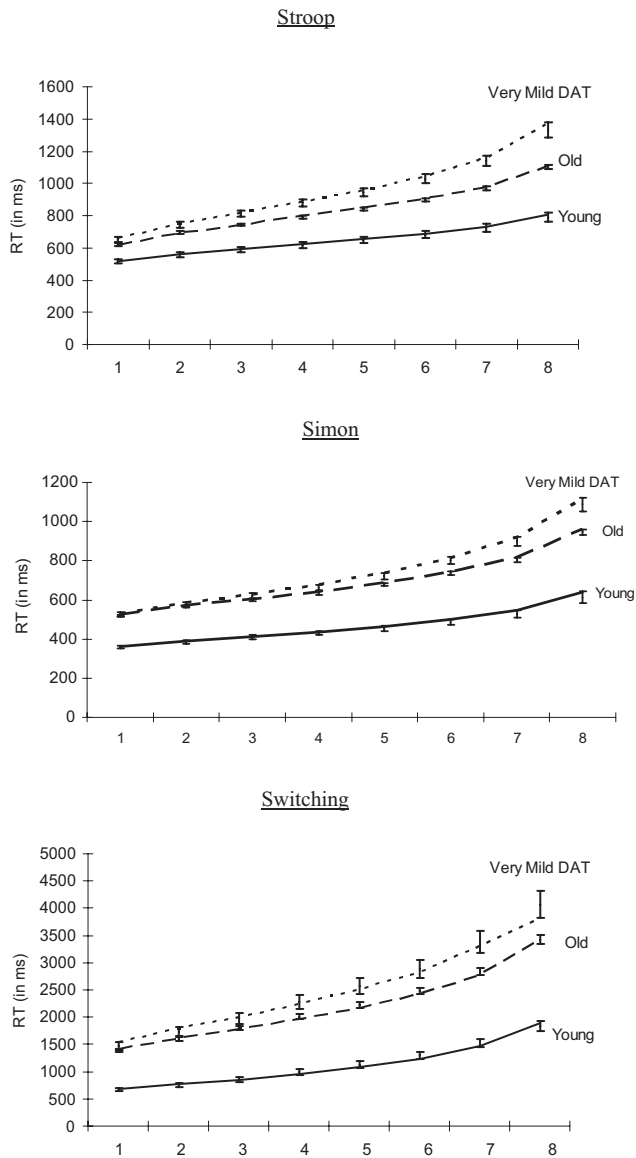


Figure 3. The Vincentile plot for Stroop, Simon, and switching tasks as a function of group.

averaged the z scores of μ , σ , and τ across all three tasks. These composite scores represent the mean (μ) and standard deviation (σ) of the Gaussian distribution and the tail (τ) of the RT distribution across the three attention tasks.

Table 3 summarizes the correlations between the composite composite μ , σ , and τ and the psychometric, span, and personality measures listed in Table 1. All 15 psychometric and span measures (except MMSE and personality measures) were first classified under three types of cognitive abilities: episodic/semantic memory, processing speed, and working memory. This classification was assessed by confirmatory factor analyses, with each type of cognitive ability represented by a latent factor.⁵ There were four outlier tasks that were not well fit by the model in this sample. For example, Forward Digit Span did not load highly on any of the three latent factors. Moreover, although Backward Digit Span,

Crossing Off, and the Boston Naming Test loaded as expected, their loadings were not very strong (all < 1.321), and excluding them significantly *improved* the fit of the overall model, as reflected by the fit statistics. Hence, we did not include these three variables in our composite measures. In the final model, all loadings for the three latent variables were higher than 1.441 , suggesting that the variables that contributed to each of these three latent variables should be representative enough for the cognitive abilities in a particular domain. To perform the following correlation analyses, we computed composite measures for working memory by averaging the z scores of Reading Span, Computation Span, and Rotation Span; for episodic/semantic memory, we averaged the z scores of logical memory, associate recall, WAIS Information and Animal Fluency; and for processing speed, we averaged the z scores of Word Fluency *S-P*, WAIS Digit Symbol, Trail Making A, and Trail Making B. These composite scores are analogous to the factor scores estimated in the confirmatory factor analyses.

We separately performed the correlation analyses for healthy older adults and for very mild DAT individuals, controlling for age. We also conducted the analyses for the *overall* sample, controlling for age and CDR status (0 vs. 0.5; see Table 3). Whereas μ and σ were correlated only with processing speed, τ was correlated with all three composite scores. The Pearson correlations were generally higher for working memory and processing speed than those for episodic/semantic memory. When we controlled for the effects of the other two composite scores, (a) all three ex-Gaussian parameters were no longer correlated with episodic/semantic memory; (b) processing speed was still correlated with all ex-Gaussian parameters, with all partial correlations being stronger for τ ; and more important, (c) working memory was still significantly correlated with τ . We return to the specific τ -working memory relationship in the Discussion section.

Relationship Between Ex-Gaussian Parameters and Personality

All three ex-Gaussian parameters were negatively correlated with conscientiousness for healthy older adults (see Table 3). Despite the small effect size, the relationship between τ and conscientiousness is consistent with previous studies (e.g., Duchek et al., 2007, 2008), which have suggested that conscientiousness reflects the ability to maintain goals and to suppress irrelevant information in the attentional control system. It is noteworthy that the correlations in the overall sample are consistent with the prediction that τ is positively correlated with neuroticism and negatively correlated with conscientiousness. The only other significant correlation in the overall sample was a negative correlation between μ and conscientiousness. Again, although these correlations are modest, these results clearly converge with recent evidence that suggests a relationship between variability in these attention tasks and personality traits (see Duchek et al., 2007;

⁵ Episodic memory and semantic memory were originally considered to be separate factors. Because they are highly correlated, $r = +.85$, we combined these factors, and this significantly improved the model fit, as indicated by chi-square statistics. Although working memory and processing speed were also highly correlated, $r = +.72$, combining them into one factor did not improve the model fit. Thus, we treated these as two separate factors.

Table 3
Correlation Between Composite μ , σ , and τ and Psychometric, Span, and Personality Measures

Measure	Healthy old (CDR = 0)			Very mild DAT (CDR = 0.5)			Overall sample		
	μ	σ	τ	μ	σ	τ	μ	σ	τ
Mini-Mental State Exam	-.03	-.06	-.30**	-.13	-.06	-.35**	-.06	-.05	-.33**
Forward Digit Span	-.06	-.04	-.14*	.12	.10	-.11	.02	.02	-.12*
Backward Digit Span	.00	-.05	-.20**	.07	-.01	-.24*	.03	-.03	-.20**
Boston Naming	-.05	-.08	-.15*	-.18	-.20^	-.18	-.08	-.11^	-.16*
Crossing Off	-.19**	-.08	-.20**	-.11	-.14	-.31*	-.15**	-.09	-.21**
Conscientiousness	-.15*	-.15*	-.17*	-.05	.00	-.14	-.12*	-.11^	-.15*
Neuroticism	-.01	.05	.07	.04	.05	.28*	.02	.06	.15*
Working memory	-.10	-.12	-.38**	-.02	.04	-.41**	-.07	-.07	-.38**
Partial correlation	.05	-.04	-.17**	.03	.07	-.09	.04	.00	-.15**
Reading Span	-.05	-.09	-.19**	-.01	.02	-.35**	-.04	-.06	-.24**
Computation Span	-.07	-.07	-.29**	.01	.03	-.28*	-.05	-.05	-.27**
Rotation Span	-.10	-.14*	-.36**	-.16	-.08	-.33**	-.13*	-.13*	-.34**
Episodic/semantic memory	-.10	-.08	-.28**	.01	.07	-.43**	-.07	-.04	-.32**
Partial correlation	.04	.01	-.01	.08	.12	-.17	.03	.04	-.05
Logical Memory	-.09	-.14*	-.15*	.05	.05	-.26*	-.05	-.09	-.17**
WMS Associate Recall	-.09	-.11	-.26**	-.11	.02	-.37**	-.10^	-.08	-.29**
WAIS Information	-.04	-.05	-.27**	.16	.15	-.33**	.03	.01	-.28**
Animal Fluency	-.07	.02	-.17*	-.10	-.01	-.34**	-.09	.00	-.21**
Processing speed	-.28**	-.17**	-.49**	-.25*	-.22^	-.59**	-.25**	-.18**	-.53**
Partial correlation	-.27**	-.13^	-.35**	-.27*	-.28*	-.48**	-.24**	-.17**	-.40**
WAIS Digit Symbol	-.29**	-.25**	-.41**	-.23^	-.17	-.53**	-.24**	-.21**	-.44**
Word Fluency S-P	-.26**	-.07	-.35**	-.15	-.17	-.27*	-.20**	-.09	-.31**
Trail Making A	.22**	.17*	.36**	.12	.11	.44**	.15*	.13*	.40**
Trail Making B	.05	.03	.35**	.25*	.22^	.53**	.11^	.09	.44**

Note. CDR = Clinical Dementia Rating scale; DAT = Dementia of the Alzheimer's type; WMS = Wechsler Memory Scale; WAIS = Wechsler Adult Intelligence Scale. The μ , σ , and τ were based on the averaged z score of μ , σ , and τ in Stroop, Simon, and switching tasks. The composite scores of episodic/semantic memory, working memory, and processing speed were based on the averaged z score of psychometric and span variables under the subheadings. The "Partial Correlation" row under each subheading indicates the correlation between the composite score in one domain (e.g., processing speed) and μ , σ , and τ after controlling for the scores in other two domains (e.g., working memory and episodic/semantic memory). All correlation analyses for older adults and very mild DAT individuals were controlled for age, and those for overall samples were controlled for age and CDR status.
^ $p < .10$. * $p < .05$. ** $p < .01$.

Robinson & Tamir, 2005), and points to the importance of the relatively slow RTs in producing the changes in variability.

Discussion

In the present research, we investigated the characteristics of RT distributions in three attention tasks, Stroop, Simon, and switching, to better understand the changes that occur in healthy aging and in the earliest detectable changes in very mild DAT. These attention tasks have been shown to be sensitive to the effects of healthy aging and early stage DAT (e.g., Castel et al., 2007; Spieler et al., 1996). We also examined how ex-Gaussian parameters are associated with various cognitive abilities, as measured by standard psychometric tasks and with specific personality traits (neuroticism and conscientiousness) that likely tap attentional control systems. It is worth emphasizing that the current study provided a comparison of a well-characterized group of individuals in the earliest detectable stage of DAT with healthy older adults who were free of any cognitive impairment. A designation of very mild DAT on the CDR scale (CDR = 0.5) denotes cognitive impairment at a very comparable stage to MCI without dementia (Storandt et al., 2006).

The results are very straightforward. When examining the mean-level RT performance across groups in the three attention tasks, we found the typical age-related and DAT-related changes in the

Stroop effect, Simon effect, and local switch cost, suggesting that healthy older adults and, to a larger extent, very mild DAT individuals had greater difficulty controlling the prepotent pathway when there was an incongruent mapping between a stimulus (e.g., the word *red* presented in green color) and the appropriate response (e.g., green). This is consistent with the notion of a breakdown in attentional control in early stage DAT (see also Balota & Faust, 2001; Castel et al., 2007; Duchek & Balota, 2005; Spieler et al., 1996). The analyses of ex-Gaussian parameters that estimate different components of participants' overall RT distributions indicated that healthy aging affected all three components of RT distributions. Relative to young adults, healthy older adults demonstrated a shift (μ), an increase of variability of the Gaussian component (σ), and an increased tail (τ) of their RT distributions. Thus, all parameters appear to change, albeit to varying degrees. More important, only τ , but not μ or σ , is sensitive to the DAT-related change, indicating that the DAT-related increase in intra-individual variability in RT reported in prior research (e.g., Christensen et al., 2005; Dixon et al., 2007; Duchek et al., 2009) may be due to very mild DAT individuals producing a larger tail of the RT distribution than healthy older adults. It is noteworthy that all of these findings were replicated in three attention tasks, attesting to the consistency of DAT-related changes in a specific component (i.e., the tail) of the RT distribution.

Before elaborating on the implications of the current findings, it is important to clarify a conceptual distinction between selective attention and response selection and to rule out three alternative interpretations. First, although we have labeled the tasks used as “attention” tasks, it is the case that they likely measure both selective attention (how well participants attend to the task-relevant information, e.g., ink color in the Stroop task) and response inhibition (how well they inhibit the task-irrelevant information, e.g., color name in the Stroop task; see Faust & Balota, 2007). Some researchers have found it very difficult to separate the influence of selective attention and response inhibition (Gorfein & MacLeod, 2007), and others have tried to tease apart their contributions to task performance. For example, by manipulating the cue–target interval and quantitatively modeling young and older adults’ performance in a task-switching paradigm, Meiran and Gotler (2001) found that the age-related effect was stronger for the duration of response initiation and selection than it was for attentional selection (i.e., the time it takes to adjust the attentional focus). However, because the purpose of the present study was to explore the general influence of attentional control on the characteristics of the underlying RT distributions for healthy older adults versus very mild DAT individuals, our three tasks were not designed to tease apart the influences of selective attention and response inhibition on participants’ RT performance. Given that we found robust age- and DAT-related differences in the tail of the RT distributions (i.e., τ), future research should use specific paradigms (e.g., Meiran & Gotler; see also Yehene & Meiran, 2007) to further dissociate the roles of selective attention and response selection in these standard attention tasks.

Second, one could argue that very mild DAT individuals might have used a more stringent response criterion than young and healthy older adults. As shown by their psychometric performance (see Table 1), very mild DAT individuals produced worse performance than healthy older adults across various cognitive tasks. To compensate for a reduced reliability of their cognitive system, when making speeded responses, very mild DAT individuals might be biased toward awaiting the results of further processing to distinguish among the activated representations, rather than producing any available “well-formed” response, thus making slower responses more frequently than their healthy counterparts. If this were the case, one would expect that those individuals who were more accurate in their responses should yield larger τ in all three attention tasks. However, we found *negative* correlations between composite τ and overall accuracy for young adults ($r = -.12, ns$), healthy older adults ($r = -.43, p < .01$), and very mild DAT individuals ($r = -.66, p < .01$). Those who showed a larger tail in their RT distribution were in fact less accurate in their responses, suggesting that the age- and DAT-related differences in τ were unlikely due to speed–accuracy trade-offs.

Third, one could argue that the size of τ in very mild DAT individuals might have been artificially inflated by their high error rates. Because these individuals made more errors in our attention tasks (see Figure 1) and RTs are typically slower following erroneous trials (e.g., Rabbitt, 1966), their larger τ could be attributed to having more error trials, rather than producing a particularly large proportion of slower responses in the tasks. To address this possibility, we reanalyzed the estimates for τ in all three attention tasks after excluding the trials that were preceded by errors. After averaging the findings across the three tasks due to their high

similarity, τ was still larger for very mild DAT individuals (613 ms) than for healthy older adults (446 ms), and in turn for young adults (269 ms; all comparisons yielded $ps < .01$). If anything, the size of τ was numerically larger when the trials with preceding errors were excluded from the analyses than when they were included (young: 255 ms; healthy old: 405 ms; and very mild DAT: 557 ms). Hence, the age-related and DAT-related differences in τ are not likely due to the fact that very mild DAT individuals and healthy older adults produced more errors in the attention tasks.

Fourth, for the switching task, it is possible that the difference in performance between healthy older adults and very mild DAT individuals could be partially attributed to their use of different strategies. Given that very mild DAT individuals have poorer working memory abilities (see Table 1), they might have difficulty keeping track of the predictable AABB sequence in the switching task and thus rely more on the cues presented at the top of the screen than healthy older adults. This could partially account for their larger τ relative to young and healthy older adults. Indeed, we measured the number of trials (of 60) that participants looked at the cue during the switching task (i.e., *look-up frequency*) for 70% of healthy older adults and very mild DAT individuals. It is important to note that both groups were likely to intermittently look at the cues. There was no difference in the frequency between the two groups, 45.8 versus 45.3, $t(224) = 0.19$. Nevertheless, to determine whether this variable affected the pattern of our results, we performed the same set of analyses on RTs, errors, and ex-Gaussian parameters, with the frequency of looking at the cues and participants’ age being treated as covariates. The patterns were highly similar to those reported above. The local switch cost in RT was smaller for very mild DAT individuals than that for healthy older adults ($p < .001, \eta_p^2 = .05$), although the local switch cost in error rates was not different between healthy older adults and very mild DAT individuals ($p = .42, \eta_p^2 = .003$). More important, the pattern of ex-Gaussian parameters was replicated. Only τ , but not μ or σ , was higher for very mild DAT individuals than it was for healthy older adults (μ : $p = .57, \eta_p^2 = .001$; σ : $p = .63, \eta_p^2 = .001$; τ : $p < .05, \eta_p^2 = .03$). The increase in RT across the distribution was sharper for very mild DAT individuals than it was for healthy older adults, $F(1.15, 255.18) = 7.65, MSE = 1025595, p < .005, \eta_p^2 = .03$. Hence, the potential differences in participants’ strategies between healthy older adults and very mild DAT individuals did not significantly influence the pattern of our findings. Of course, this potential strategic difference could not account for why very mild DAT individuals also showed larger τ in two other attention tasks as well.

After ruling out these alternative explanations, the important question then becomes why the very mild DAT individuals produced particularly slower RTs than healthy older adults in the slow tail of their RT distributions. Among various potential neurobiological and physiological mechanisms, such as neural transmission speed and fatigue, we believe that the larger τ effect in early stage DAT could be interpreted within an attentional control framework (see Balota & Faust, 2001). One of the major goals of a cognitive system is to flexibly tune itself to current task demands and stay tuned across time to those demands via attentional control mechanisms (see, e.g., Baddeley et al., 2001; Engle & Kane, 2004). As attentional control systems begin to deteriorate, these systems may no longer be as well tuned across time to the specific goals of the

task (Duncan et al., 1996). Hence, individuals in the earliest stage of DAT may more frequently take a longer time to avoid the distracting information, thereby demonstrating a larger tail in their RT distributions. This extends West’s proposal (e.g., West, 2001; West et al., 2002) that the age-related changes in cognitive performance are associated with the deterioration of an attentional control system that maintains the goals of a task across time and regulates competing pathways (see also Bunce et al., 2007, for a discussion of the connection between intraindividual variability in RT and white matter hyperintensities in the frontal lobe, one of the major anatomical areas implicated in attentional control).

In the present study, the relationship between τ and the abilities to maintain a task goal over time was supported by our correlation analyses. We found that τ , rather than μ and σ , was correlated with various psychometric measures, in particular those that tap working memory and processing speed. It is intriguing that the relationship between τ and working memory was still significant after controlling for participants’ age and CDR status, as well as their differential episodic/semantic memory or processing speed performance (cf. Engle et al., 1999).

As noted earlier, Schmiedek et al. (2007) reported an interesting relationship between τ , but not μ and σ , and working memory constructs via structural equation modeling. Because we also had working memory measures available in the present study, we attempted to replicate this theoretically important relationship in our sample. Hence, we computed a structural equation model using maximum likelihood estimation. Because the distributions of several variables were significantly skewed, the data were transformed to reduce skewness. For the Stroop τ and Simon μ parameters, the data were log transformed. For the Simon σ , Simon τ , switching μ , switching σ , and switching τ parameters, the data were square-root transformed. Missing WMC data (for eight healthy older adults and nine very mild DAT individuals) were replaced with the mean of each variable within each group (i.e., within the healthy older adult and DAT groups). The resulting model is shown in Figure 4. The model fit was excellent, $\chi^2(39) = 47.38, p = .17$; RMSEA = .03; CFI = .98, using a minimum criterion for acceptability of fit as a CFI > .90 (Hu & Bentler, 1995) and a RMSEA < .10 (Browne & Cudeck, 1993). Remarkably, as shown in Figure 4, the factor intercorrelation between the τ construct and the working memory construct was very strong ($-.90$), whereas the factor intercorrelations for both μ and σ factors were much weaker (.24 and $-.09$, respectively). These data indicate that the pattern of relations reported by Schmiedek et al. in a young adult sample generalized to a sample of healthy older adults and DAT individuals with more attention-demanding cognitive tasks. Because working memory capacity has been conceptualized as an attentional control ability required for goal maintenance (Engle & Kane, 2004; McCabe et al., in press), these data provide converging evidence demonstrating a role of goal maintenance in τ .

Apart from the relationship between cognitive measures and ex-Gaussian parameters found in the attention tasks, we also explored the relationship between these parameters and personality traits. As previously mentioned, recent studies have reported that there is an increase in neuroticism and a decrease in conscientiousness in very mild DAT individuals relative to healthy older adults, which accounted for unique variance in discriminating these two groups above and beyond standard neuropsychological tests (Duchek et al., 2007; see also Table 1). This is consistent with the claim that differences in

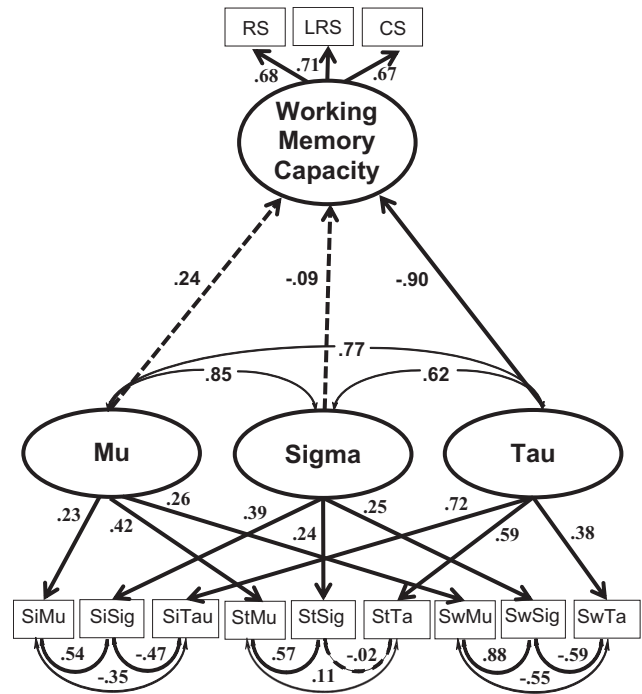


Figure 4. Model of the relationship between the latent construct of working memory and the latent construct of ex-Gaussian parameters. Note. RS = reading span; LRS = letter rotation span; CS = computational span; SiMu = μ in the Simon task; SiSig = σ in the Simon task; SiTau = τ in the Simon task; StMu = μ in the Stroop task; StSig = σ in the Stroop task; StTau = τ in the Stroop task; SwMu = μ in the switching task; SwSig = σ in the switching task; SwTau = τ in the switching task; dotted lines denote nonsignificant correlations.

these personality traits may serve as a “noncognitive” indicator of the early onset of DAT (see also Wilson et al., 2003, 2007). In the current study, we found DAT-related differences in conscientiousness and neuroticism.⁶ For the overall participants controlling for age and CDR status, the larger τ was associated with a higher score in Neuroticism and a lower score in Conscientiousness, supporting the notion that τ , a specific component of the RT distribution, appears to be relatively more sensitive to the personality changes that occur with onset of the disease. As noted earlier, both neuroticism and conscientiousness could be easily tied to mechanisms that are related to attentional control.

Of course, there are alternative ways to capture RT distributions, such as the Weibull and ex-Wald models (see Luce, 1986; Van Zandt, 2002, for excellent reviews), and clearly there is some debate about which distribution is best. Cousineau et al. (2004; see also Balota et al., 2008) listed a number of guiding principles for considering an appropriate model for distributional analyses. First, parameters from a

⁶ Discriminant function analyses showed that the increases in correct classification rates via these two personality traits on the group status, after taking into account various composite measures (see Table 3), were either null or very small (1–2%). Hence, for the current samples, the personality traits could discriminate the very mild DAT individuals from healthy older adults as well as other composite measures, replicating Duchek et al. (2007).

particular model should capture the manipulations in a useful manner. It is unclear whether a RT distributional model provides any new information if *all* parameters are consistently changing across manipulations. In the current study, in contrast to healthy aging, only the exponential component captured DAT-related changes. Second, the model should be parsimonious in the number of parameters that are used to describe the RT distribution. The relatively simple three-parameter ex-Gaussian model would appear efficient by this criterion. In short, we have chosen the ex-Gaussian approach because of recent evidence suggesting that it is useful in understanding changes across conditions within a task and across tasks and also its relation to the standard mean analyses (i.e., the sum of μ and τ is the mean). Ultimately, any RT distributional analyses should be coupled with specific computational models of a given task performance (see, e.g., Balota & Spieler, 1999; Norris, 2009; Ratcliff, Gomez, & McKoon, 2004), and so the present study and analyses should be considered only as the first descriptive account of both age-related and DAT-related changes in the RT distributions across standard attentional control tasks.

In conclusion, the current study supports the utility of examining the characteristics of RT distributions for capturing changes in variability that occur both in healthy aging and in early stage DAT. To our knowledge, this is the first study that uses three attention tasks (Stroop, Simon, and switching) and employs ex-Gaussian analyses to pinpoint the specific components of RT distributions that are affected by healthy aging as well as early stage DAT. Of course, how well such variability actually predicts early stage DAT conversion depends on large-scales longitudinal studies of well-characterized healthy controls. We are currently engaged in such a study. Finally, we argue that the consistent increase in the tail of the RT distributions across the three attention tasks in early stage DAT is consistent with the notion of a breakdown in attentional control systems very early in the disease process.

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