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Stroop Performance in Healthy Younger and Older Adults and in Individuals With Dementia of the Alzheimer's Type

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Components of the Stroop task were examined to investigate the role that inhibitory processes play in cognitive changes in healthy older adults and in individuals with dementia of the Alzheimer's type (DAT). Inhibitory breakdowns should result in an increase in Stroop interference. The results indicate that older adults show a disproportionate increase in interference compared with younger adults. DAT individuals show interference proportionate to older adults but a disproportionate increase in facilitation for congruent color–word trials, and an increased intrusion of word naming on incongruent color naming trials. An ex-Gaussian analysis of response time distributions indicated that the increased interference observed in older adults was due to an increase in the tail of the distribution. Application of the process dissociation analysis of the Stroop task (D. S. Lindsay & L. L. Jacoby, 1994) indicated that older adults showed increased word process estimates, whereas DAT individuals showed differences in both color and word process estimates. Taken together, the results are consistent with an inhibitory breakdown in normal aging and an accelerated breakdown in inhibition in DAT individuals.

The Stroop effect (Stroop, 1935) is one of the most well-studied findings in experimental psychology. This effect refers to the increase in response latency to name the color of ink in which a word is printed when that word is an incompatible color name relative to when it is an unrelated word or color patch. MacLeod (1991) noted more than 700 articles that either directly examined the Stroop effect or used it as a tool to investigate other cognitive processes.

The Stroop task has been especially useful as a tool to investigate inhibitory processes. The conflict between the relevant (color of the word) and irrelevant (name of the word) dimensions of the stimulus on incongruent trials presents a particularly difficult task for the selective attentional system. A system that efficiently suppresses the irrelevant dimension (i.e., the word) should exhibit faster color naming than a system in which impaired suppression of the word dimension allows greater competition between the word name and the color name for response output. Thus, the magnitude of Stroop interference has been used as an indicant of the efficiency of the inhibitory system (cf. Dempster, 1992).

The purpose of the current study was to use the Stroop task as a tool to understand changes in cognitive processing that occur in healthy older adults and individuals with dementia of the Alzheimer's type (DAT). For example, Hasher and Zacks (1988) have proposed that changes in inhibitory processing are central to age-related changes in cognitive functioning. Balota and Duchek (1991; also see Balota & Ferraro, 1993) have extended this inhibitory framework to DAT individuals, arguing that at least some of the cognitive deficits associated with the disease process may arise from further breakdowns in inhibitory processing. We now turn to a brief review of the available evidence supporting these positions, with particular emphasis on Stroop performance.

Stroop Interference in Healthy Older Adults

One of the first studies to address Stroop interference in healthy older adults was a life-span developmental investigation conducted by Comalli, Wapner, and Werner (1962). They found that the amount of interference remained constant across middle adulthood and then began to increase in the 65- to 80-year-old group. Later studies comparing younger adults with older adults obtained similar results: namely, larger interference effects for older adults (Cohn, Dustman, & Bradford, 1984; Hartley, 1993; Panek, Rush, & Slade, 1984).

The results of studies indicating increased Stroop interference effects with age are, at first glance, quite consistent with arguments by Hasher and Zacks (1988) concerning the

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importance of age-related changes in inhibitory processes. However, care must be taken when interpreting changes in the size of the Stroop interference effect. Generalized slowing accounts (Cerella, 1990; Myerson, Hale, Wagstaff, Poon, & Smith, 1990) of age-related changes in cognitive performance predict that effect sizes should increase in groups with slower processing speeds. A simple general slowing account predicts larger interference effects in older adults than in younger adults as a result of the slowed processing in older adults. Thus, it is important to demonstrate that effects in older adults are larger (or smaller) than one might predict solely on the basis of a general slowing model. The difficulty with this approach is that it requires one to make certain assumptions about how effect sizes change with changes in processing speed. At present, there is little consensus regarding the actual function that relates the response times (RTs) of younger adults to those of older adults. The analysis we chose assumes that effect size remains a constant proportion of an individual's overall response latency. Therefore, in the present article, we report the Stroop effect as a proportion of each individual's overall response latency. This correction has the advantage of preserving the interpretability of the effects (unlike nonlinear transforms such as logarithms). Moreover, there are theoretical and empirical justifications for assuming constant proportionality of effects within the range of response latencies typically found in cognitive tasks (for a detailed discussion, see Faust, Balota, & Ferraro, 1995).

Unfortunately, previous studies have not consistently reported analyses that controlled for speed differences. When interference proportions are computed with the data reported in three previous studies, the data from two studies suggest a disproportionate increase in interference in older adults (Comalli et al., 1962; Panek et al., 1984), whereas one study indicated only a slight increase in older adults (Cohn et al., 1984). More recently, Dulaney and Rogers (1994) used effect proportions and reported a disproportionate increase in the interference effect in older adults. Thus, although there are some differences across previous studies, it does appear that older adults produce a disproportionate increase in interference in comparison with younger adults.

Stroop Effects in Individuals With Dementia of the Alzheimer's Type

Despite the amount of attention that the Stroop paradigm has received and the existence of a psychometric version of the test, we are aware of only two studies that have addressed Stroop task performance in DAT individuals. There are also a few studies that have investigated the Stroop performance of "demented" individuals, and it is likely that a significant proportion of these participants did have Alzheimer's disease (Bettner, Jarvik, & Blum, 1971; Comalli, Krus, & Wapner, 1965). However, these latter populations probably reflect heterogeneous dementia etiologies, so firm conclusions regarding DAT-related performance changes are not possible.

Koss, Ober, Delis, and Friedland (1984) addressed Stroop performance in DAT individuals. Their study included two groups of DAT individuals: a mild DAT group and a moderate DAT group. Using analysis of covariance to control for speed differences, Koss et al. found that DAT individuals produced a larger Stroop interference effect than did age-matched controls. They also found that the mild DAT group had a larger interference effect than did the more impaired moderate DAT group. This difference may be attributable to a speed–accuracy trade-off resulting from a significantly higher error rate in the moderate DAT group. Note that an impairment of selective attention should result not only in increased interference effects in the Stroop task but also in a higher error rate in the incongruent color–word condition. As shown later, the types of errors and the speed of error responses in an incongruent condition were of particular theoretical importance in the present study.

Fisher, Freed, and Corkin (1990) also investigated Stroop performance in DAT individuals. Rather than measuring response latency directly, Fisher et al. measured how many correct responses participants made within a 45-s time interval. Comparing a DAT group with healthy older adults, they found that, overall, DAT individuals made fewer correct responses and that there was an increased interference effect. Using data reported by Fisher et al., we computed interference as a proportion of overall number of responses and found that these corrected interference measures appeared to be greater in the DAT group than in the healthy older adults (.70 and .49, respectively), although no statistical comparison was possible.

The findings from these two studies are consistent with an impairment of inhibitory processing that results in an increased Stroop interference effect in DAT individuals. At this juncture, it is not possible to say whether the increased Stroop interference effect is manifested as an increased interference effect in RTs or an increased intrusion error rate, or both. Thus, the specific nature of this impairment and the relationship between the severity of the disease and the efficiency of inhibitory processes are unclear. Characterization of the effects of both aging and Alzheimer's disease on Stroop task performance may benefit from more recent theoretical developments concerning the processes underlying Stroop performance.

Recent Developments in Understanding Stroop Interference

A review of the extensive literature concerning the mechanisms underlying Stroop performance is clearly beyond the scope of this article (but see Dyer, 1973; MacLeod, 1991). Early explanations of Stroop interference usually embodied the idea of a race between the color code and word code to reach an output selection stage. Because word reading is faster than color naming, the word information arrives at the response buffer before the color information and thus competes with the color for output. However, explanations only in terms of the difference in speed between word reading and color naming are now viewed as inadequate in light of studies that have manipulated the relative speed and practice for the relevant and irrelevant dimensions of the stimulus (Dunbar & MacLeod, 1984; Glaser & Glaser, 1982; MacLeod & Dunbar, 1988). Recently, there have been two investigations of Stroop performance that provide new insights into the characteristics of the task. We now turn to a discussion of each of these developments emphasizing the relevance to the present study.

Process Dissociation Analysis

Lindsay and Jacoby (1994) presented a particularly intriguing approach to the Stroop task. They used Jacoby's (1991) process dissociation technique to decouple the contributions that word processing and color processing make to Stroop performance. They reasoned that a correct response in incongruent trials may be made only through the use of color information. On the other hand, correct responses for congruent trials may reflect a combined contribution of color and word information. On the basis of this reasoning and the assumption that these two processes operate independently, they applied the process dissociation technique (see Jacoby, 1991) to derive process estimates for color naming and word reading. The equations used to derive the process estimates from the congruent and incongruent conditions are as follows:

$$p(\text{Correct}|\text{Congruent}) = \text{Word} + \text{Color}(1 - \text{Word}) \quad (1)$$

and

$$p(\text{Correct}|\text{Incongruent}) = \text{Color}(1 - \text{Word}). \quad (2)$$

Thus, a correct response by some response deadline in the congruent condition may occur on the basis of information from either the word pathway or the color. In contrast, a correct response in the incongruent condition may be made on the basis of information from the color processes but not from the word processes. To test this model, Lindsay and Jacoby set response deadlines and then calculated the proportion of correct responses made by each deadline. By using the proportion of correct responses occurring by a particular response deadline for the incongruent and congruent condition, the two equations can be solved simultaneously to derive the color and word process.

Lindsay and Jacoby (1994) also demonstrated that one can use post hoc deadlines (e.g., at 650, 700, and 750 ms) and examine the time course of color and word process estimates. The results from one such analysis reported by Lindsay and Jacoby are shown in Figure 1. As can be seen, word processes predominate early in processing, as one might expect given the more fluent processing of the word codes in comparison with the color codes. However, with additional passage of time, color processing dominates, reflecting the increasing influence of selection for task-relevant information. Thus, this analysis allows one not only to decouple the influences of color and word information but to examine the time course of the selection process.

Lindsay and Jacoby (1994) also presented evidence that experimental manipulations exist that affect one process while having little or no effect on the other, supporting the notion that these two processes make independent contributions to performance. For example, presenting dull or bright colors affects the color process estimates but not the word processes, as shown in Figure 1. By applying this analytic technique to the healthy younger and older adults and the DAT groups, we hoped to further specify the impact that aging and DAT have on Stroop performance. In particular, the purpose of inhibition is to reduce the influence of inappropriate information on performance, and the efficiency of inhibitory processes should be directly reflected by the magnitude of word process estimates. A reduction in inhibitory processing should result in an increase in word process estimates while leaving the color processes relatively unaffected.

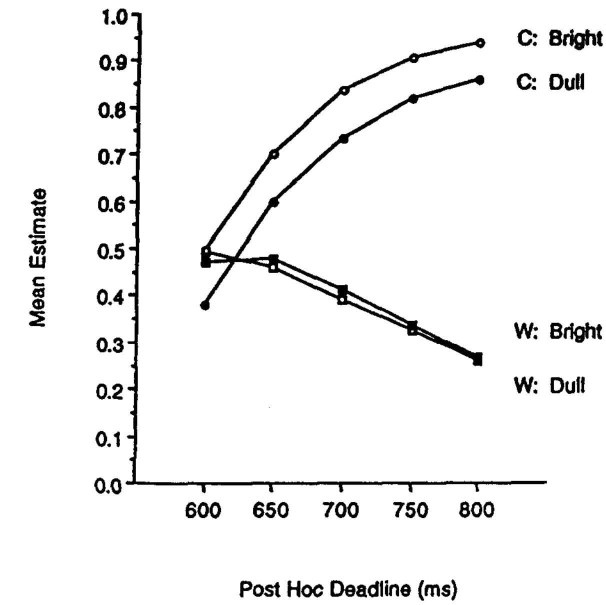


Figure 1. Color (C) and word (W) process estimates for dull and bright colors reported. *Note.* From "Stroop Process Dissociations: The Relationship Between Facilitation and Interference" by D. S. Lindsay and L. L. Jacoby, 1994, *Journal of Experimental Psychology: Human Perception and Performance, 20,* p. 225. Copyright 1994 by the American Psychological Association. Reprinted with permission of the author.

Ex-Gaussian Analyses

Another recent development in the analysis of Stroop performance is examination of the influence of different conditions on the nature of the RT distribution. There are two ways in which one might address changes in RT distributions. The traditional method of specifying the shapes of RT distributions is to use sample estimates of the moments of the distribution (e.g., skewness and kurtosis). The problem with this approach is that these higher order moments require far more data than typically practical (Ratcliff, 1979). However, another method of quantifying such changes is possible if one assumes an explicit mathematical model of RT distributions. A number of researchers have shown that a convolution of a Gaussian and an exponential distribution, called an ex-Gaussian distribution, frequently yields close approximations of the observed RT distribution (Hockley, 1984; Hohle, 1965; Ratcliff, 1979). By using an ex-Gaussian model to fit observed distributions, one obtains three parameters that reflect different aspects of the distribution. The modal portion of the distribution is reflected by μ (mu), which is the mean of the Gaussian component. σ (sigma) reflects the standard deviation of the Gaussian component. The third parameter is τ (tau), which is the mean and standard deviation of the exponential distribution and primarily a reflection of the rightmost tail of the ex-Gaussian distribution. Thus, conditions that result in a shift in the entire distribution will be reflected primarily in changes in μ (mu), whereas conditions resulting in increased skewness are likely to be primarily reflected in τ.

Recently, Heathcote, Popiel, and Mewhort (1991) showed that there are consistent changes in the shapes of RT distributions between conditions in the Stroop task. Heathcote et al. applied the exGaussian model to RT distributions from congruent, incongruent, and neutral conditions in a Stroop task. This analysis revealed that the incongruent condition resulted in increases for all parameters (i.e., μ, σ, and τ) in relation to the neutral condition. More interestingly, however, is the finding that the congruent condition showed a reduction in μ and an increase in τ. Heathcote et al. pointed out that the mean RT for the congruent condition in their data (which can be approximated by the sum of μ and τ) did not show any facilitation relative to their neutral condition because the facilitation in μ was obscured by an increase in τ. Such opposing effects in μ and τ were also noted by Mewhort, Braun, and Heathcote (1992), who suggested that the decrease in τ in the neutral condition relative to the congruent and incongruent conditions may have occurred because the nonlexical neutral condition could be selected against at an early perceptual level.

Such consistent changes in components of RT distributions indicate that ex-Gaussian estimates of RT distributions carry information that is not available with only mean RT. For example, general slowing accounts of age effects are typically couched in terms of a multiplicative relationship between the mean RT of young adults and the mean RT of older adults (e.g., see Cerella, 1985, 1990). As Heathcote et al. (1991) have shown, there may be changes in different characteristics of an RT distribution that are not reflected in mean RT. A general slowing account appears to predict that the overall shape of a distribution should be similar in younger adults and older adults (and potentially also in DAT individuals) but more "stretched out" in slower populations. On the other hand, qualitative changes in RT distributions across younger adults, older adults, and DAT individuals would appear inconsistent with an unembellished slowing model. Such information may also provide insight into specific processes that are affected by aging and the progression of DAT. If one adopts the notion that τ reflects a more central processing component (Gordon & Carson, 1990; Hohle, 1965), decrements in the efficiency of inhibitory processing should increase the τ component because of the additional time required on some incongruent trials to resolve the conflict between the color and word codes. Thus, populations experiencing a decrease in the efficiency of inhibitory processing should exhibit greater increases in τ in incongruent conditions relative to the neutral condition than those groups with more efficient inhibitory processes.

In summary, there have been two recent theoretical developments that allow a more fine-grained analysis of the processes involved in the Stroop task. One goal of the present study was to use the process dissociation technique of Lindsay and Jacoby (1994) and the ex-Gaussian modeling of RT distributions (Heathcote et al., 1991; Mewhort et al., 1992) to better understand the processes underlying Stroop performance in healthy older adults and DAT individuals. In addition to these theoretical analyses, there are potential limitations of previous studies arising from the particular methodology that was used. These concerns are the topic of the next section.

Methodological Issues

The Stroop task commonly used in clinical settings consists of at least two lists; participants are timed in terms of how long it takes them to respond to all of the items on each list. One list is used to obtain a baseline of how long it takes individuals to name colors. This list typically consists of color patches or rows of characters (e.g., *X*s, symbols, or non-color-related words). The other list is the interference list, consisting of color names printed in nonmatching ink colors. The participant's task is to name the ink colors for each word. The increase in time to complete the interference list over the neutral list provides a measure of Stroop interference. Both of the recent studies examining Stroop performance in DAT individuals have used this method (Fisher et al., 1990; Koss et al., 1984), as have most of the studies concerned with healthy older adults (Cohn et al., 1984; Comalli et al., 1962; Panek et al., 1984; but see Hartley, 1993).

Unfortunately, this particular version of the Stroop task imposes serious restrictions on stimuli and the manner of presentation. One problem with the list version of the Stroop task is that condition type (neutral vs. conflicting) is blocked. Logan, Zbrodoff, and Williamson (1984; see Tzelgov, Henik, & Berger, 1992, for similar arguments) have shown that the proportion of conflicting trials can modulate the size and even the presence of the Stroop interference effect. When conditions are blocked, participants may adopt strategies that involve some attention to the supposedly irrelevant dimension. Such strategies may be especially problematic when making cross-group comparisons because of the potential differences in strategy use.

Another disadvantage of the list version of the Stroop task is that it typically does not include the condition in which the color and the word are congruent (e.g., *BLUE* printed in blue ink). Lindsay and Jacoby (1994) argued that to the extent to which participants increasingly rely on word information to drive their responses, there should be an increase not only in interference for the incongruent trials but also in the amount of facilitation for the congruent trials. Thus, one obtains Lindsay and Jacoby's process dissociation estimates only by comparing the relative difference between the congruent and incongruent conditions.

Of course, the partitioning of effects into facilitation and interference is intimately tied to the choice of baseline. All of the previously mentioned studies used either color patches or strings of letters (*X*s or random letters). There are at least three problems with these types of neutral conditions. The first is that both are nonlinguistic stimuli and thus differ qualitatively from the other stimuli in the test (Neely, 1991). Second, there is some indication that nonlexical neutral stimuli may differentially disrupt processing in older adults in comparison with younger adults (Balota & Duchek, 1989), thus underestimating the interference in older adults relative to when a less disruptive neutral condition is used. Third, both of the typical Stroop neutral conditions present no conflicting information at all in the irrelevant dimension. Lexical items that are not part of the response set require participants to remain focused on the specific task demands and, we believe, represent a more appropriate baseline measure.

The presence of error responses is also problematic when the list version of the Stroop task is used. Although this version of the task does allow one to collect data on error rates, it typically does not allow one to collect data regarding other characteristics of error responses. In fact, because the dependent measure is typically derived from the time to complete an entire list, the times reported for the neutral and incongruent conditions frequently include varying mixtures of correct and incorrect RTs. In addition to separating errors from correct responses, the current study also examined response latency for individual error responses. Given that word naming latencies are typically shorter than color naming latencies, it is possible that, early in the processing of the stimulus, more word information than color information is available. In a case such as this, one function of inhibitory processing is to prevent the word code from controlling the response. A decrease in inhibitory efficiency would result in an increased intrusion error rate. Moreover, given that the word code becomes available earlier than the color code, a failure to inhibit the word response would result in an error that occurs before a color naming response would be made. The present study examined this possibility by measuring and analyzing the RTs for errors, in addition to correct responses.

The motivation of the present study was to extensively evaluate changes in inhibitory processing changes in two populations that, previous researchers have argued, suffer from an inhibitory deficit. In this light, the study (a) used analyses that take into account overall speed differences across younger, older, and DAT individuals; (b) minimized strategic differences across groups that may result from blocking of conditions; (c) included a lexical neutral baseline that can adequately measure facilitatory and inhibitory effects; (d) used Lindsay and Jacoby's (1994) process dissociation technique to decouple the influences of word and color processes in performance; and (e) applied the exGaussian analysis of RT distributions to explore the qualitative changes in the nature of these distributions across the populations studied.

Method

Participants

One hundred thirty-nine individuals participated in this study. The 27 younger participants (*M* age = 20.4 years, *SD* = 2.4, range = 17–26) were recruited from the undergraduate student population at Washington University. The remaining 112 participants were recruited through the Washington University Alzheimer's Disease Research Center (ADRC). The latter group was initially screened for disorders potentially affecting cognitive functioning (e.g., depression, severe hypertension, and reversible dementias). For the DAT group, the inclusions and exclusions followed National Institute of Neurological and Communicative Disorders and Stroke–Alzheimer's Disease and Related Disorders Association criteria (McKhann et al., 1984). Each participant was rated on dementia severity according to the Washington University Clinical Dementia Rating (CDR) scale (Berg, 1988). Participants exhibiting no signs of dementia were given a CDR of 0. Very mildly demented participants were given a CDR of 0.5, and mildly demented participants received a CDR of 1.0.

The CDR is based on a 90-min interview with both the patient and his or her collateral source. The interviews are conducted by one of eight board-certified physicians (four neurologists and four psychiatrists), and each interview is videotaped and subsequently reviewed by a second physician for purposes of reliability. The interview is intended to assess cognitive functioning in areas of memory, orientation, judgment and problem solving, community affairs, hobbies, and personal care. To date, 96% (102 of 106) of patients given an Alzheimer's disease diagnosis on the basis of this rating have had the diagnosis confirmed at autopsy (Berg & Morris, 1994).

Twenty-two participants received a CDR of 0.5 (*M* age = 73.2 years, *SD* = 6.5, range = 60–83), and 40 participants received a CDR of 1.0 (*M* age = 73.7 years, *SD* = 8.8, range = 51–87). In addition to the DAT participants, there were 50 healthy older adults who showed no symptoms of dementia: 25 healthy young-old adults (*M* age = 70.5 years, *SD* = 6.7, range = 58–79) and 25 healthy old-old adults (*M* age = 85.6 years, *SD* = 3.4, range = 80–93).

Apparatus

A CompuAdd 386 computer was used to control the stimulus display and to collect RTs with ms resolution. Stimuli were displayed on an NEC Multisynch 2A 35-cm (14-in.) video graphics array (VGA) color monitor. A Gebrands Model G1341T voice-operated relay was interfaced with the computer to measure voice onset latency.

Materials

The word stimuli consisted of four color names (*red, blue, green,* and *yellow*) and four neutral words (*bad, poor, deep,* and *legal*). The neutral words were matched to the color names for onset phoneme characteristics and frequency (as listed by Kucera & Francis, 1967). The blue, green, red, and yellow colors available from Microsoft QuickBasic 4.5 were used. Words used in the study were printed in a 40-column mode and subtended approximately 2° to 3° of visual angle.

The experiment consisted of a word naming block and a color naming block. Each block of trials contained 36 congruent trials, 36 incongruent trials, and 32 neutral trials. In the congruent condition, each of the four color names appeared nine times in its corresponding color. In the incongruent condition, each color name appeared three times in each of the three nonmatching colors. In the neutral trials, each of the four neutral words appeared twice in each of the four colors. The order of presentation in each block was randomized, with the restriction that a word or color would not be repeated more than twice on consecutive trials. A different random order was used for each block and for each participant. The task order (color naming or word reading) was counterbalanced across participants within each group.

Procedure

As a means of gradually familiarizing the participants with the task, each participant was first shown examples of the colors and words that would be used in the experiment. First, each color appeared as a patch, with the color name printed underneath the patch, and then the eight words used in the experiment were displayed. Participants then went through two blocks of trials. For the word reading block, participants were told to read the words as quickly and as accurately as possible. For the color naming block, participants were told to name the colors in which the word appeared as quickly and as accurately as possible. Participants were presented with a block of 16 practice trials at the beginning of each of the color naming and word naming blocks. Each of the three conditions was represented in the same proportions that occurred during the test trials. Participants who made more than four errors were given an additional 16 practice trials. The experimenter remained in the testing room throughout the entire testing session.

Each trial began with a fixation stimulus consisting of three plus signs displayed for 700 ms. The screen was then blank for 50 ms, and then the stimulus appeared. The stimulus was displayed on a black background and remained on the screen until the participant responded. Once the voice-operated relay was triggered, the experimenter pressed one of three keys to code the response. One key coded the response as correct. The other two keys were for error responses. One key corresponded to errors that consisted of stutters, false starts, or other noises that triggered the voice key before the participant's response. The third key was pressed when the participant produced an incorrect response such as naming the word when the task was to name the color. Of course, such intrusion errors could be detected only in the incongruent and neutral trials. Once the experimenter coded the participant's response, a 1,750-ms intertrial interval was initiated before the next trial. During the experiment, participants were given a break halfway through each block (after 52 trials) and also between the word reading and color naming blocks. The experimenter allowed pauses at other times during the experiment at the participant's request.

Psychometric Test Results

Participants recruited through the Alzheimer's Disease Research Center (healthy older adults and DAT individuals) received a psychometric test battery designed to assess various aspects of psychological functioning, including language, memory, psychomotor performance, and intelligence (see Hill, Storandt, & LaBarge, 1992, for a full description). As is apparent in Table 1, performance on these tests decreased across the young-old, old-old, very mild DAT, and mild DAT groups. Separate analyses of variance (ANOVAs) resulted in group main effects for each test ($ps < .001$).

Results

Response Latency Analysis

Response latencies from trials with incorrect responses were excluded from the response latency analyses (error response latencies were analyzed separately). Correct RTs that fell below 200 ms or less than three standard deviations below the mean for each condition were assumed to be anticipations, and RTs falling beyond 4,000 ms or greater than three standard deviations above the mean were as-

Table 1
Mean Psychometric Test Scores as a Function of Participant Group

	Group								
	Young-old		Old-old		Very mild DAT		Mild DAT		
Test	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	$F(3, 80)$
Benton Copy (Form C)	6.74	1.32	4.81	1.97	4.44	2.13	2.88	1.65	19.16
Benton Copy (Form D)	9.91	0.29	9.67	0.66	9.31	0.87	8.33	1.93	8.42
Benton Copy, errors	0.09	0.29	0.33	0.66	0.69	0.87	2.04	2.60	8.05
Benton Recall, errors	5.09	2.83	8.52	3.75	11.56	4.79	16.21	4.12	34.80
Logical Memory	10.72	2.29	7.86	2.87	4.64	3.08	2.92	2.51	38.09
Mental Control	8.09	1.38	5.86	2.59	5.81	2.69	5.12	2.25	7.59
Associate Recall	16.15	3.40	12.74	4.10	9.44	3.77	6.71	2.71	31.42
Digit Span (Forward & Backward)	11.83	2.33	11.05	2.16	10.19	2.14	9.25	1.89	6.26
WAIS-R Information	22.57	3.22	19.9	4.13	14.87	5.76	12.13	6.06	21.13
WAIS-R Block Design	36.48	7.52	25.67	8.23	25.94	6.84	16.79	9.25	23.08
WAIS-R Digit Symbol	48.26	10.66	39.76	9.36	34.38	10.03	20.92	14.31	23.55
Word Fluency (letters S & P)	32.78	9.55	28.48	11.29	20.38	9.09	17.54	8.08	12.15
Boston Naming Test	57.04	3.17	54.10	3.88	47.50	10.60	38.67	11.68	23.09
Trail Making (Form A)	41.48	12.01	52.33	11.48	55.63	25.07	77.00	38.89	8.33

Note. DAT = dementia of the Alzheimer's type; WAIS-R = Wechsler Adult Intelligence Test—Revised.

sumed to be lapses of attention and were eliminated from all analyses. This screening procedure eliminated 1.2% of responses for the young adults, 1.5% for the young-old group, 1.4% for the old-old group, 2.3% for the very mild DAT group, and 4.1% for the mild DAT group. Three additional participants from the mild DAT group were excluded because of error rates that exceeded 70% in the incongruent color naming condition. These high error rates were potentially informative, but the need for adequate estimates of mean RTs required that they be dropped from the analysis. These exclusions did not affect the general conclusions.

Tables 2 and 3 show the mean response latencies for each group for word reading and color naming, respectively. First, note that overall response latencies increased across group. Second, for all groups, word reading was faster than color naming. For the word reading block (see Table 2), there was little difference between the congruent and incongruent conditions (although the difference did increase for the DAT groups); for the color naming block (see Table 3), each group produced a large interference effect for the incongruent condition and a large facilitation effect for the congruent condition relative to the neutral condition.

These observations were confirmed by an overall 5 (group) × 2 (task) × 3 (condition) mixed-factors ANOVA.[1] There was a main effect of group, $F(1, 147) = 39.11$, $p < .001$, $MSE = 205{,}024$. The difference between word reading and color naming was also highly significant, $F(1, 147) = 372.00$, $p < .001$, $MSE = 80{,}117$, and there was a significant interaction between group and task (word naming or color naming), $F(4, 147) = 20.26$, $p < .001$, $MSE = 80{,}117$, indicating that the group differences increased more for color naming than for word reading. We now turn to separate analyses of the word naming and color naming trials.

Word Naming

Inspection of the word naming latencies for each condition reveals that the neutral condition was consistently slower in all groups. This was probably due to the greater repetition priming of the color names in comparison with the neutral words. The color words were named in a 2:1 ratio relative to the neutral words. Such repetition effects were clearly not a problem in the color naming data discussed subsequently. Nevertheless, this difference suggests that the neutral words may not have constituted an appropriate control condition for the word naming block; as a result, the neutral condition was not included in the word reading analyses. A 5 (group) × 2 (condition: congruent vs. incongruent) mixed-factors ANOVA was conducted on the word naming latencies to examine the effect of congruency in word reading. This analysis revealed reliable main effects of group, $F(4, 108) = 21.00$, $p < .001$, $MSE = 35{,}612$, and condition, $F(1, 108) = 9.69$, $p < .005$, $MSE = 1{,}476$, and there was a reliable Group × Condition interaction, $F(4, 108) = 5.20$, $p < .005$, $MSE = 1{,}476$. The main effect of condition and the Group × Condition interaction are interesting because typically one does not find Stroop effects in word naming (MacLeod, 1991). As shown in Table 2, there were only small differences between the congruent and incongruent conditions for the healthy younger and older adults. In fact, separate comparisons of the congruent and incongruent conditions for each group indicated that only the mild DAT group experienced a reliable effect of color congruency on word reading, $F(1, 25) = 7.97$, $p < .01$, $MSE = 5{,}342$ (all other $ps > .10$). Thus, even on word naming trials, mildly demented individuals apparently experience some difficulty with competing word and color codes.

Color Naming

We now turn to the more important color naming data. These analyses were broken down into two parts. The first set of analyses examined the performance of the young adult and healthy older adult groups. These analyses allowed the assessment of age effects. The second set of analyses examined differences between the young-old group and the DAT groups; this allowed assessment of the effects of Alzheimer's disease on performance. All analyses yielded strongly reliable group and condition main effects (all $ps < .001$). However, because of space limitations, only the interactions are discussed in detail.

Age effects. The effects of aging on interference and facilitation in color naming were examined. Interference was addressed in a 3 (group: young vs. young-old vs. old-old) × 2 (condition: incongruent vs. neutral) mixed-factors ANOVA. There was a reliable Group × Condition interaction indicating an increased interference effect in the older adults in comparison with the younger adults, $F(2, 69) = 10.91$, $p < .001$, $MSE = 3{,}072$. A second 3 (group) × 2 (condition: congruent vs. neutral) mixed-variables ANOVA was conducted to examine facilitation effects across the younger and older adults. The facilitation effects appeared to increase across these three groups; however, the increase was not reliable, $F(2, 69) = 2.36$, $p > .10$, $MSE = 4{,}436$.

As a means of accounting for overall speed differences between groups, interference and facilitation ratios were analyzed for each group. Interference ratios were formed by subtracting each participant's mean RT in the neutral condition from his or her mean RT in the incongruent condition and then dividing by the mean for the neutral condition. The facilitation ratio was formed by dividing the difference between the congruent and neutral conditions by each participant's mean for the neutral condition. In this way, two

[1] An analysis of response latencies that included task order as a factor revealed only a marginal Order × Task interaction, $F(1, 103) = 3.49$, $p = .06$, $MSE = 89{,}439$, indicating that participants were somewhat better at the first task they performed than at the second task. There was no main effect of task or interactions involving task order (all $ps > .15$). An analysis of error proportions that included task order as a factor did not reveal a reliable main effect, $F(1, 103) < 1$, or any reliable interactions involving task order (all $ps > .10$). In light of these analyses, task order was not included in any of the remaining analyses.

Table 2
Mean Word Naming Latencies (ms) as a Function of Participant Group and Condition

Group	Condition			Effect	
	Congruent	Incongruent	Neutral	Facilitation	Interference
Young					
M	502	506	519	17	−13
SD	55	55	60		
Young-old					
M	613	616	635	22	−19
SD	83	82	80		
Old-old					
M	662	657	700	38	−43
SD	110	92	134		
Very mild DAT					
M	704	719	776	72	−57
SD	141	148	194		
Mild DAT					
M	801	858	905	104	−47
SD	186	256	258		

Note. DAT = dementia of the Alzheimer's type.

ratios (facilitation and interference) were obtained for each participant. These data are summarized in Table 4.

Two separate between-subjects ANOVAs were conducted on the facilitation and interference ratios for the young, young-old, and old-old adult groups. The analysis of interference ratios revealed a reliable difference among these groups, $F(2, 69) = 4.85$, $p < .05$, $MSE = 0.0066$. Interference increased in the young-old group in comparison with the younger adults. Interference was slightly less for the old-old group than for the young-old group. For the facilitation ratios, there was no difference across the young, young-old, and old-old groups, $F(2, 69) < 1$, indicating that the slight increase in facilitation observed in Table 3 can be attributed to speed differences across these three groups.

Error analyses. Mean error percentages for color naming are reported in Table 5. These errors typically consisted of individuals naming the word when the task was naming the color; thus, these errors are termed *intrusion* errors. However, a small number of color confusion errors were also included in these error rates; although not problematic for between-conditions comparisons, such errors may complicate cross-group comparisons of error rates. The error rates from the congruent condition were not included because it was impossible to establish whether the participant was naming the color or reading the word. All analyses reported were conducted on arcsine-transformed error rates (Winer, 1971). Analyses performed on raw error percentages yielded similar results. Transformed error proportions were submitted to a 3 (group) × 2 (condition: incongruent vs. neutral) mixed-factors ANOVA. The Group × Condition interaction did not reach significance, $F(2, 69) = 2.36$, $p > .10$, $MSE = 0.0172$.

Table 3
Mean Color Naming Latencies (ms) as a Function of Participant Group and Condition

Group	Condition			Effect	
	Congruent	Incongruent	Neutral	Facilitation	Interference
Young					
M	621	759	671	50	88
SD	86	82	67		
Young-old					
M	813	1,069	894	81	175
SD	106	125	121		
Old-old					
M	937	1,223	1,046	109	177
SD	270	282	213		
Very mild DAT					
M	915	1,404	1,134	219	270
SD	183	389	241		
Mild DAT					
M	1,299	1,853	1,561	262	292
SD	528	541	545		

Note. DAT = dementia of the Alzheimer's type.

Table 4
Interference and Facilitation Ratios for Color Naming as a Function of Participant Group and Condition

Group	Ratio: Facilitation	Ratio: Interference
Young		
M	.08	.13
SD	.08	.07
Young-old		
M	.09	.20
SD	.07	.09
Old-old		
M	.11	.17
SD	.13	.09
Very mild DAT		
M	.19	.23
SD	.09	.17
Mild DAT		
M	.17	.21
SD	.14	.14

Note. DAT = dementia of the Alzheimer's type.

Alzheimer's Disease Effects

To examine the issue on Alzheimer's disease effects on Stroop task performance, we compared the healthy young-old group and the two DAT groups. The young-old group was used as the reference group for comparisons with the DAT groups because that group was the more similar, in terms of age, of the two healthy older adult groups. A 3 (group: young-old vs. very mild DAT vs. mild DAT) × 2 (condition: incongruent vs. neutral) mixed-factors ANOVA was conducted on mean response latencies. This analysis revealed a marginally reliable increase in interference across the young-old, very mild DAT, and mild DAT groups, $F(2, 61) = 2.51$, $p < .10$, $MSE = 17{,}876$. A 3 (group: young-old vs. very mild DAT vs. mild DAT) × 2 (condition: congruent vs. neutral) mixed-variables ANOVA was conducted to examine the facilitation effects across these three groups. This analysis revealed a reliable Group × Condition interaction indicating an increase in facilitation across the three groups, $F(2, 61) = 7.02$, $p < .005$, $MSE = 14{,}942$.

Again, to control for differences in overall speed, we conducted a second set of analyses on the facilitation and interference ratios. The analysis of the interference ratios for the young-old and very mild and mild DAT groups did not reveal a reliable increase in interference across these three groups, $F(2, 61) < 1$. The analysis of facilitation ratios indicated a reliable increase in facilitation across the three groups, $F(2, 61) = 4.94$, $p < .01$, $MSE = 0.0111$. Thus, in contrast to the increased interference effect observed in healthy older adults in comparison with the young adults, DAT individuals produced an increase in facilitation for congruent trials but no increase in interference relative to the young-old individuals.

Error analyses. A 3 (group) × 2 (condition: incongruent vs. neutral) mixed-factors ANOVA was conducted on the transformed error rates. This analysis revealed a reliable main effect of group, $F(2, 61) = 19.75$, $p < .001$, $MSE = 0.0868$, and a highly reliable Group × Condition interaction, $F(2, 61) = 10.54$, $p < .001$, $MSE = 0.0329$. Error rates generally increased in the very mild DAT and mild DAT groups relative to the young-old group, and the increase in error rate was much greater for the incongruent condition than for the neutral condition.

Error response times. As noted in the introduction, error RTs can provide important information. Specifically, fast intrusion errors, defined as those faster than the mean color naming RT in the neutral condition, can be viewed as indicating that the word response failed to be inhibited in favor of the correct information from the color dimension. Therefore, an analysis was conducted in which the intrusion errors for each participant were divided into two categories, those falling above and those falling below the mean for the neutral condition, which is the best estimate of color naming latency. Comparisons for the young, old-young, and very mild DAT groups were all nonsignificant, $ts < 1$. However, the comparison for the mild DAT group indicated reliably more fast errors than slow errors (4.6 vs. 3.3, respectively), $t(25) = 1.87$, $p < .05$ (one-tailed), suggesting that fast intrusion errors (i.e., naming the word when the task was color naming) were more likely than slow intrusion errors in the mild DAT group.

Ex-Gaussian Analyses

The next analysis represented an attempt to more accurately capture age-related and disease-related changes in characteristics of RT distributions. As mentioned in the introduction, a number of researchers have shown that there are consistent changes in the shapes of RT distributions that are not captured in an analysis of the mean RT (Heathcote et al., 1991; Hockley, 1984; Mewhort et al., 1992). With respect to the present study, the disproportionate increase in interference in older adults in comparison with younger

Table 5
Error Percentages for Color Naming as a Function of Participant Group and Condition

Group	Condition: Incongruent	Condition: Neutral
Young		
M	3.5	1.0
SD	4.9	2.3
Young-old		
M	3.9	0.4
SD	4.5	1.4
Old-old		
M	7.2	1.3
SD	8.8	2.5
Very mild DAT		
M	13.9	3.8
SD	11.7	4.3
Mild DAT		
M	22.0	6.3
SD	14.3	7.6

Note. DAT = dementia of the Alzheimer's type.

adults could have been the result of an increase in the modal portion of the distribution or an increase in the skew of the distribution (or a mixture of both). Determining how RT distributions change across these groups has important implications for the interpretation of age-related and disease-related changes in Stroop performance. As noted earlier, one useful mathematical model is the ex-Gaussian distribution (Luce, 1986; Ratcliff, 1979).

The ex-Gaussian distribution may be fit with as few as 100 observations per condition (Ratcliff, 1979). The current study involved maximums of 36, 36, and 32 observations for the congruent, incongruent, and neutral conditions, respectively. When the number of observations falls short of the 100 needed, Vincent averaging, or "Vincentizing," makes it possible to combine distributions from multiple participants while preserving the shape of the distribution (Ratcliff, 1979; Vincent, 1912). This method involves rank ordering the observations from each participant for each condition. These observations are then divided into quantiles, and the mean for each quantile is computed (10 quantiles were used in the present study). Corresponding quantiles are then averaged across a number of participants. This Vincent averaging creates "super-subjects" for which the ex-Gaussian distribution is fit.

In the present analyses, the RTs for 3 participants were combined to form each super-subject for the young, young-old, old-old, and very mild DAT groups. The error rates for these four groups were low enough to ensure that the number of observations for each condition was approximately 100. Because of the increased error rates for the mild DAT group, 4 participants were combined to form each super-subject for this group. Each super-subject contributed one distribution for each of the three conditions (congruent, incongruent, and neutral). Three mild DAT individuals were excluded from this analysis because their error rate in the incongruent condition (>60%) produced relatively noisy distributions. The fits of the ex-Gaussian to the observed distributions were obtained with the RTSYS program (Heathcote, 1993), and these fits were evaluated in a chi-square goodness-of-fit test. None of the 59 fits for the young adults, young-old adults, or old-old adults were rejected at the .05 level. The fits for the DAT groups were not quite as good because 1 of the 12 fits for the very mild DAT group and 3 of 15 fits for the mild DAT group (1 super-subject was not fit for any of the conditions) were rejected at the .05 level.

Inspection of the parameter estimates in Figure 2 indicates that the pattern for the young adults replicated the findings of Heathcote et al. (1991) and Mewhort et al. (1992). Specifically, μ and τ increased in the incongruent condition relative to the neutral condition. More interestingly, for the congruent condition, μ decreased and τ increased relative to the neutral condition.

Recall that the healthy older adults showed a disproportionate increase in interference for the incongruent condition in comparison with the younger adults. An inspection of the μ parameter estimates (see Figure 2) reveals that the young and young-old groups had similar patterns of interference and facilitation. The disproportionate increase in

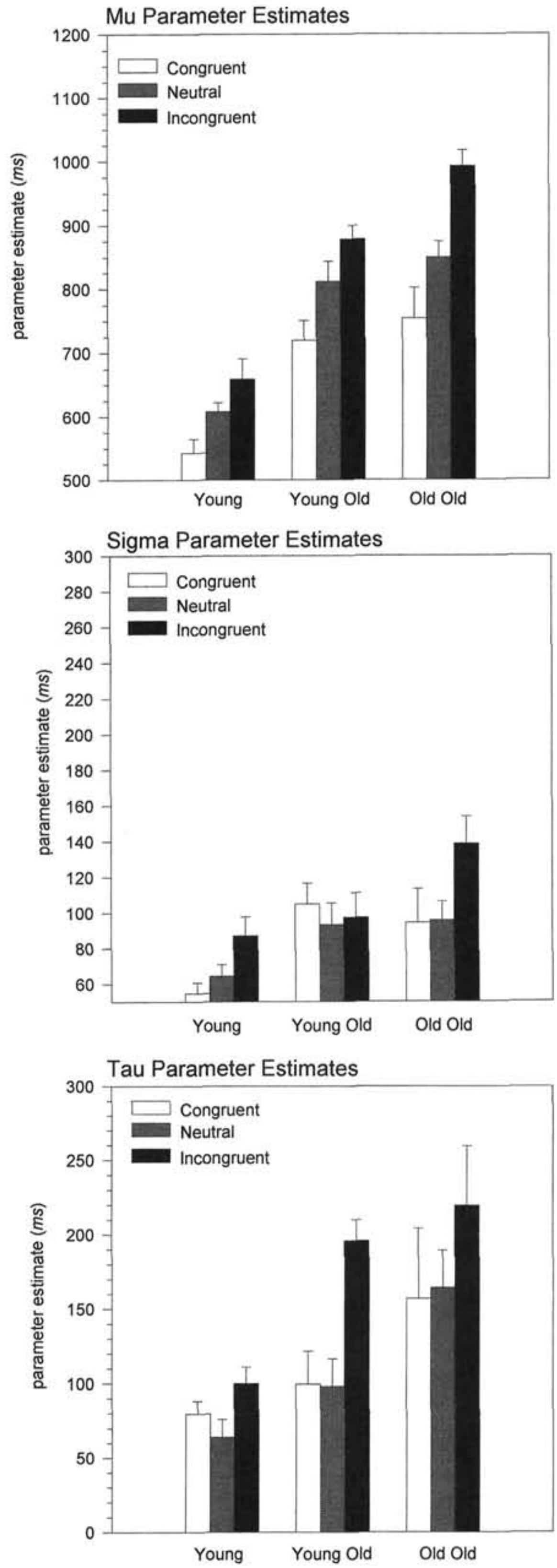


Figure 2. μ, σ, and τ parameter estimates for healthy younger and older adults.

interference for the young-old individuals appeared to result entirely from an increase in τ, which reflects the tail of the distribution. These observations were supported by an analysis of the μ parameter estimates for the young and young-old groups. This analysis did not result in a reliable Group × Condition interaction ($p > .20$). However, the analysis of τ parameter estimates for the young and young-old groups revealed a reliable Group × Condition interaction, $F(2, 28) = 6.01$, $p < .01$, $MSE = 1{,}067$. The old-old group produced slightly more interference and facilitation in μ than the young-old group, $F(2, 22) = 3.64$, $p < .05$, $MSE = 1{,}812$ (Group × Condition interaction). The pattern of τ estimates for the old-old group did not differ reliably from that for the young-old group, $F(2, 22) < 1$ (Group × Condition interaction).

In summary, there are two important results from this analysis. First, the younger adults replicated the pattern of μ and τ across the congruent, incongruent, and neutral conditions reported by Heathcote et al. (1991) and Mewhort et al. (1992). This replication is important because it indicates that these changes in the shapes of the distributions across the three conditions are consistent and robust. The neutral condition in the present study consisted of words, and thus the decrease in τ that was also found in the present study cannot be attributed to a prelexical perceptual selection mechanism (as suggested by Mewhort et al.). Moreover, the results from the exGaussian analysis comparing the younger adults and the healthy older adults are intriguing in that they suggest that the disproportionate increase in interference for the older adults was due to an increase in the tail of the distribution. In other words, on the majority of the trials, the younger adults and older adults showed approximately equivalent interference. However, on a proportion of the trials, the older adults evidenced an increased interference from the word dimension, and so they must have expended additional processing time to resolve this difficulty. This additional processing resulted in an increased number of trials falling in the tail of the distribution.

In terms of the DAT groups, once again, the young-old group was used in comparisons with the two DAT groups. These data are displayed in Figure 3. First, note that the effects in μ appeared to increase between the very mild DAT group and the mild DAT group. This large increase in interference for the mild DAT group, however, may have been partially offset by a decrease in τ from the neutral to the incongruent condition. The very mild DAT group also showed a larger interference effect in μ than the young-old group. The μ parameter estimates for the young-old, very mild DAT, and mild DAT groups were examined in a 3 (group) × 3 (condition) mixed-factors ANOVA. This analysis revealed a reliable Group × Condition interaction, $F(4, 26) = 18.76$, $p < .001$, $MSE = 3{,}133$. For the τ parameter estimates, there was again a reliable Group × Condition interaction, $F(4, 26) = 3.64$, $p < .05$, $MSE = 2{,}435$. The overall pattern for the very mild DAT was qualitatively similar to that of the young adults: namely, increases in τ for both the congruent and incongruent conditions. This observation, however, should be viewed with caution, given that only 4 super-subjects made up the very mild DAT group. As

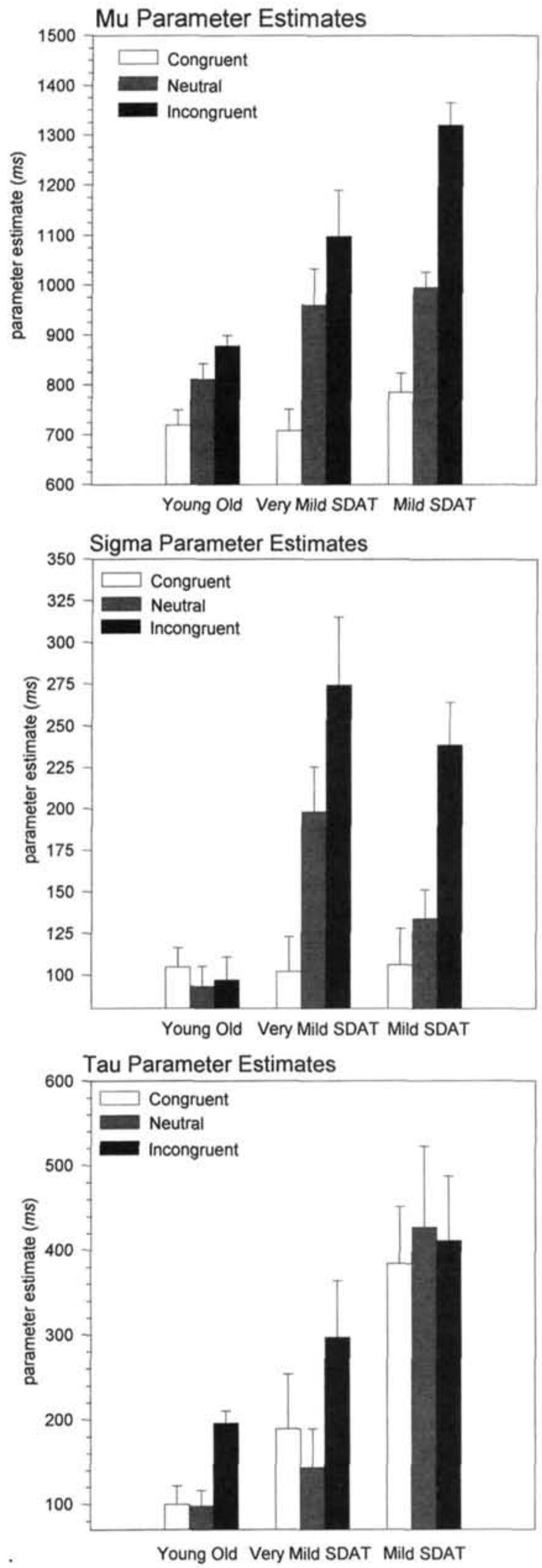


Figure 3. μ, σ, and τ parameter estimates for the young-old group and for the groups with very mild and mild dementia of the Alzheimer's type (SDAT).

shown in Figure 3, those in the mild DAT group actually showed no interference effect in τ.[2]

Apparently, when the older adults experienced strong interference from the word dimension, they were able to take additional time and eventually produced a correct response. The cost of avoiding an intrusion error is the increase in the number of RTs falling in the tail of the distribution. The very mild DAT group also showed signs of a large increase in the tail of the distribution. The very mild DAT individuals showed an intrusion error rate three times that for the young-old group; however, when they produced a correct response, the effect of the conflicting dimension was similar to that seen with the young-old adults (i.e., an increased proportion of these trials falling in the tail of the distribution). The mild DAT group showed evidence of more extensive breakdowns in performance. These individuals evidenced a large increase in the probability of producing an intrusion error. Furthermore, even when they produced a correct response, they showed an increased interference effect that resulted in a shift of the entire distribution (μ). In terms of an inhibitory framework, initial decrements in inhibitory processing result in the need for additional processing time on a proportion of incongruent trials, increasing the number of trials falling within the tail of the distribution. When presented with strongly conflicting information, the DAT individuals, especially the mild DAT individuals, were less likely to take the additional processing time required to produce a correct response. Instead, the DAT individuals were increasingly likely to allow the stimulus to drive the response, resulting in a fast intrusion error.

We now turn to the final sets of analyses in which we attempted to isolate the contributions of the relevant color and irrelevant word processes to performance. We used Lindsay and Jacoby's (1994) process dissociation framework to examine Stroop performance across these five participant groups.

Process Dissociation Analyses

The method used by Lindsay and Jacoby (1994) involved imposing a deadline (such as 800 ms) on responding and measuring the proportion of correct responses produced in each condition. Lindsay and Jacoby (1994, Experiment 2) also demonstrated that this procedure may be used by specifying post hoc deadlines and measuring the proportion of responses occurring under a given deadline. Hence, for the present analysis, the proportion of each participant's responses that occurred by each deadline in each condition was calculated. These proportions were then used to derive the color and word process estimates by solving Equations 1 and 2 simultaneously. By substitution, one may estimate the word contribution as follows: Word = $P(\text{Correct}|\text{Congruent}) - P(\text{Correct}|\text{Incongruent})$. Once the word estimate has been obtained, the color estimate is derived by the equation Color = $P(\text{Correct}|\text{Incongruent})/1 - \text{Word}$.

In the present analysis, we used 15 post hoc deadlines ranging from 600 ms to 2,000 ms in 100-ms increments. The results for the young adults are shown in Figure 4. With the exception of the earlier deadlines in the present analysis, it is quite clear that the overall pattern replicated the results obtained by Lindsay and Jacoby (1994; see Figure 1). Early in processing, word processes exerted greater influence on performance than color processes, as a result of the greater fluency of processing lexical information as compared with color identification. However, at the later deadlines, color processes dominated, reflecting the fact that the task demanded a response on the basis of the color rather than the word. The results from this analysis for the healthy younger and older adults are shown in Figure 5, and the results for the young-old group and the two DAT groups are shown in Figure 6. Clearly the time course of processing differed across the five groups, as did the point at which color processes dominated over word processes. Moreover, there also appeared to be group differences in the contribution of word processes.

However, as in the analyses of RTs, the process dissociation analysis raises the question of how to compare groups that differ in overall speed of processing. The goal was to

[2] Recall that our screening procedure eliminated 4.1% of the responses from the CDR 1.0 group. One possible account of our distribution analysis is that this screening procedure resulted in the lack of an effect of condition on τ estimates in this group. Although this may have contributed to the pattern for the CDR 1.0 group, it should be noted that the CDR 0.5 group had a screening rate of 2.3%. This rate, although smaller than that of the CDR 1.0 group, was still larger than that of any other group. If the failure to find an effect in τ was due to our screening procedure, then this should also have been acting, to a lesser extent, on the CDR 0.5 group. In fact, if anything, the CDR 0.5 group had larger effects in τ than any other group. One of the advantages of the exGaussian analysis is that it is able to capture changes in the shapes of distributions without requiring the large number of observations required for stable measures of skewness (Ratcliff, 1979). One question that might be raised is the extent to which the exGaussian analysis captures such changes in the actual RT distributions that are used to fit the exGaussian curve. To examine this, we computed correlations for τ and σ and the Pearson skewness estimate for the Vincentized distributions for each group of participants across the congruent, incongruent, and neutral conditions. Even though skewness is a relatively unstable estimate, the correlations between τ and skew ranged from .64 to .84. The sole exception was a negligible correlation for the mild DAT group (.05). Overall, the correlations between σ and skew were negative, ranging from $-.37$ to $-.66$; the exception was a negligible correlation for the very mild DAT group (.15). These results indicate that τ captured many of the changes in skew across the healthy younger and older adults. The correlation between σ and τ was generally negative in the present study ($-.15$ to $-.40$); however, the very mild DAT group evidenced a positive correlation (.40). Finally, as shown in Figure 3, it is clear that the pattern of parameter estimates across conditions in each group was not consistent with the notion that there is a simple trade-off between σ and τ. For example, there was a large increase in σ in the incongruent condition for both the very mild and mild DAT individuals; there was no difference between the τ estimates for the mild DAT group, but there was a large difference for the very mild DAT group.

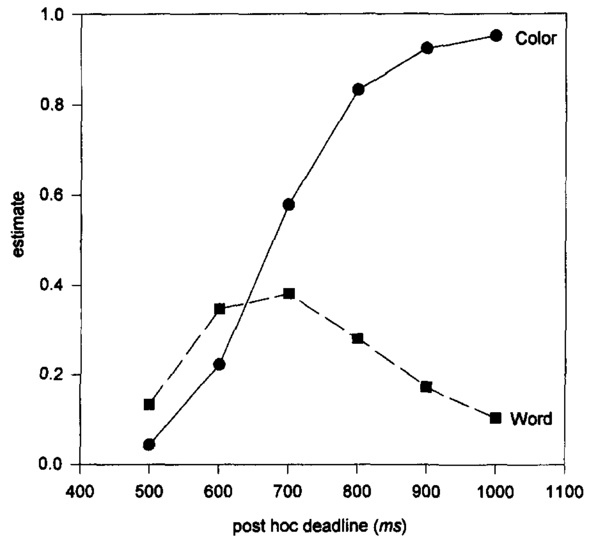


Figure 4. Color and word process estimates for younger adults.

select deadlines such that each reflected approximately equivalent points in processing across the five groups. This goal was complicated by the fact that individuals in the different groups differed not only in processing speed but also in the variance of their response latencies. Note that in examinations of the time course of the process estimates, a 100-ms period between deadlines covers a larger proportion of distributions with small variances than of those with larger variances. If the intent is to compare the time course of the process estimates across groups, it is preferable to set deadlines that take into account such differences in variability. Thus, the deadlines for the following analyses were set in standard deviation units (z scores) for each participant's mean color naming latency (collapsing across color naming condition).

z-Score Deadlines

The analyses reported were derived from the proportions of correct responses of the total possible correct minus voice-key errors. The z-score deadlines were set at -1.0, -0.5, 0.0, 0.5, and 1.0 standard deviations from each participant's mean color naming latency. The obtained process estimates were analyzed in a 5 (group) $\times$ 2 (process: color vs. word) $\times$ 5 (deadline) mixed-factors ANOVA. This analysis revealed main effects of process, $F(1, 108) = 154.69$, $p < .001$, $MSE = 0.0263$, indicating that color process estimates were larger than word process estimates, and deadline, $F(4, 432) = 1{,}116.42$, $p < .0001$, $MSE = 0.0068$, indicating that the process estimates were larger at later deadlines. There was no main effect of group, although the Group $\times$ Process and Group $\times$ Deadline interactions were reliable, $F(4, 108) = 3.01$, $p < .05$, $MSE = 0.0263$, and $F(16, 432) = 1.70$, $p < .05$, $MSE = 0.0068$, respectively. As expected, the Process $\times$ Deadline interaction was highly significant, $F(4, 432) = 931.60$, $p < .0001$, $MSE = 0.0071$, indicating that color processes increased across the deadlines, whereas word processes increased initially and then decreased for the later deadlines. Finally, the Group $\times$ Process $\times$ Deadline interaction was significant, $F(16, 432) = 3.60$, $p < .001$, $MSE = 0.0071$.

To further isolate processing changes, we divided the analyses into those comparing performance of the young, young-old, and old-old groups, which allowed for the assessment of age differences, and those comparing the young-old group with the two DAT groups, which allowed for the assessment of the effects of the disease process. All of the analyses resulted in main effects of process and deadline and reliable Process $\times$ Deadline interactions when both color and word process estimates were analyzed ($ps < .001$). In the interests of space and clarity, only the group main effects and those interactions that involved the group variable are reported.

Age Differences

Color and word process estimates for the young, young-old, and old-old groups, as shown in Figure 7, were analyzed in a 3 (group) $\times$ 2 (process) $\times$ 5 (deadline) mixed-factors ANOVA. This analysis revealed a reliable Group $\times$ Process interaction, $F(2, 69) = 5.58$, $p < .01$, $MSE = 0.0265$. Color process estimates were approximately equal across the three groups, whereas word process estimates increased across the young, young-old, and old-old groups. Thus, there appeared to be an increased influence of the inappropriate word process across groups. This is consistent with the previous analyses of response latencies.

Alzheimer's Disease Effects

As in the previous analyses, the young-old group was used as the reference group for comparisons with the DAT

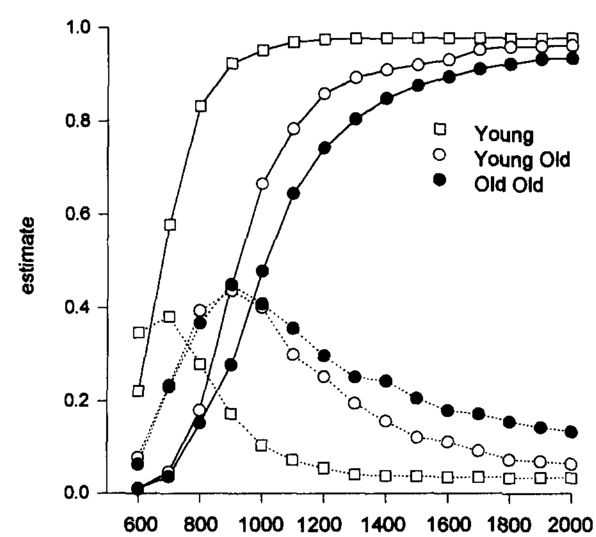


Figure 5. Time course of color (solid lines) and word (broken lines) process estimates for healthy younger and older adults.

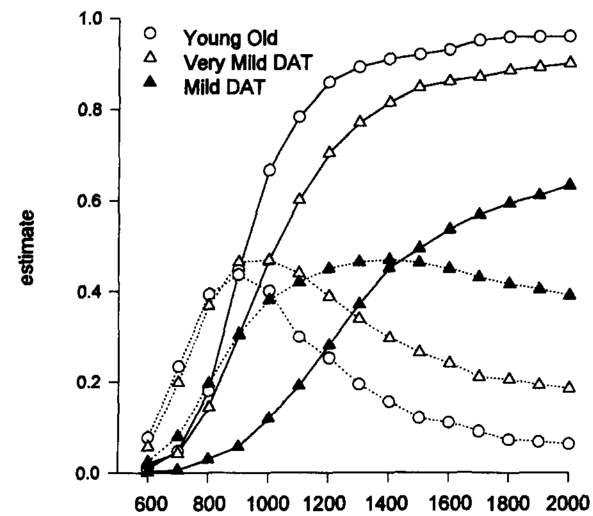


Figure 6. Time course of color (solid lines) and word (broken lines) process estimates for the young-old group and the very mild and mild DAT groups. DAT = dementia of the Alzheimer's type.

groups. A 3 (group: young-old vs. very mild DAT vs. mild DAT) × 2 (process) × 5 (deadline) mixed-factors ANOVA yielded a reliable Group × Process × Deadline interaction, $F(8, 244) = 4.03$, $p < .001$, $MSE = 0.0079$. Separate analyses of the color and word process estimates were then conducted to further isolate the differences between groups. The word process estimates were analyzed in a 3 (group) × 5 (deadline) mixed-factors ANOVA. There was a marginally reliable main effect of group, $F(2, 61) = 2.49$, $p < .10$, $MSE = 0.0572$. The word process estimates were approximately equal in the young-old and very mild DAT groups, and both of these groups had larger word estimates than the mild DAT group. The groups did not differ in the time course of word processing (Group × Deadline interaction, $p > .10$). A similar analysis was done on the color process estimates, resulting in a reliable Group × Deadline interaction, $F(8, 244) = 5.31$, $p < .001$, $MSE = 0.0073$. For the early deadlines, the color process estimates were larger for the DAT groups than for the young-old group. In the later deadlines, the color estimates did not rise as sharply for the mild DAT group as for the other two groups (see Figure 8).

Summary of the Process Dissociation Results

The results of the analysis of process estimates for younger and older adults are straightforward. There was no evidence of differences in the color process estimates between the younger and healthy older adults, nor was there any evidence of a difference in the time course of process estimates for either color or word estimates. The only reliable difference was that, overall, word process estimates were larger for the older adults, indicating that word information made larger contributions to the performance of the older adults than to that of the younger adults. These results are consistent with the notion that older adults suffer from a decrement in inhibitory processing. The purpose of inhibition is to limit the influence of the word pathway so that a decrement in inhibition results in increased word processing.

The fact that we failed to find any differences in the color process estimates should be viewed with caution. The method for setting deadlines in the present study was appropriate, given the sizable differences in speed and variability of processing across the groups. However, other methods of selecting deadlines may have resulted in differ-

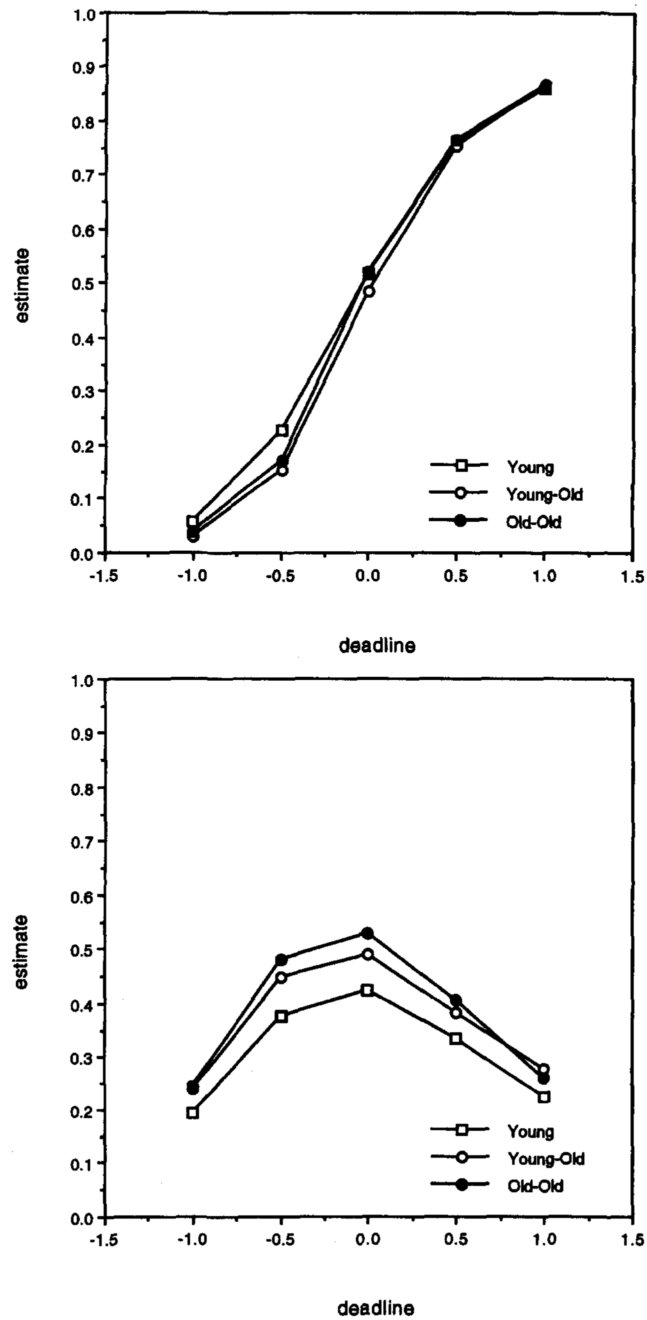
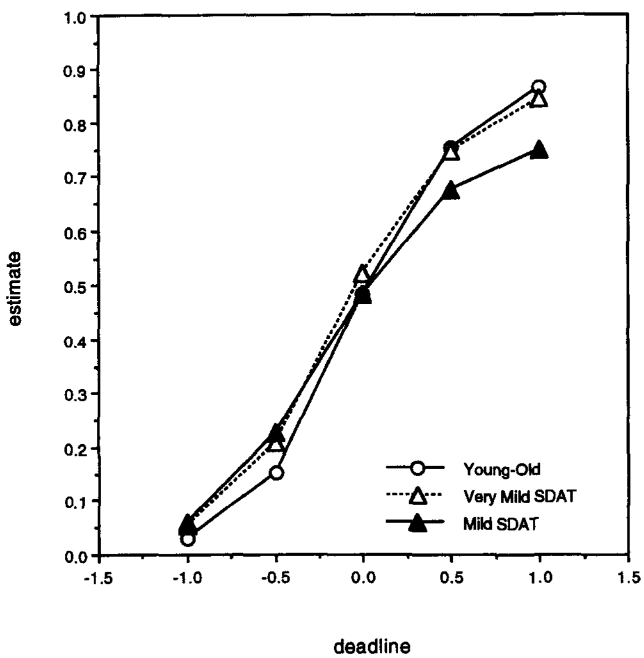


Figure 7. Color and word process estimates for healthy younger and older adults (*z*-score post hoc deadlines).



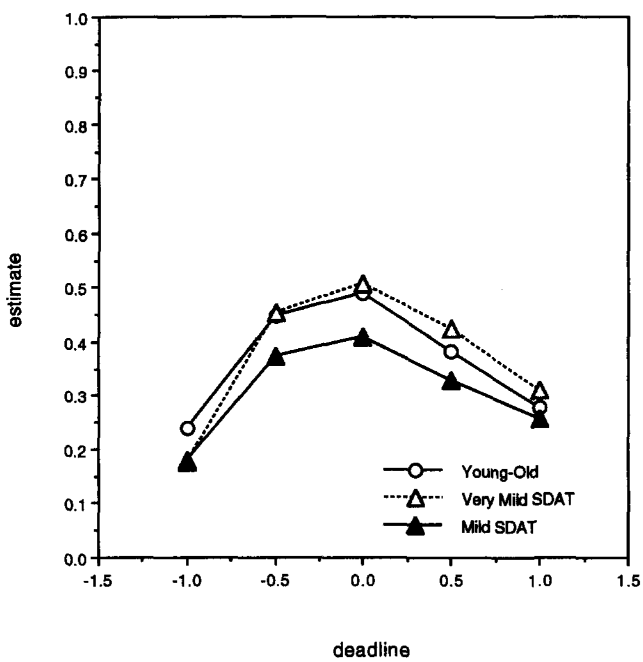


Figure 8. Color (top) and word (bottom) process estimates for the young-old group and for the groups with very mild and mild dementia of the Alzheimer's type (SDAT; *z*-score post hoc deadlines).

ences in the color process estimates across the healthy participant groups. In this light, we believe that these results should be viewed as tentative. Nevertheless, the results do offer converging evidence for a decrement in older adults' ability to resist the influence of word processes.

The results from the DAT groups are less clear. Unlike the results from the analyses of younger and healthy older adults, the analyses of DAT individuals revealed differences in the color process estimates. The color estimates for the two DAT groups did not rise to as high a level as for the young-old group, and this difference was especially pronounced in the mild DAT group. For the word process estimates, the very mild DAT group appeared to continue the trend established for the older adults (specifically, increasing word process estimates). However, this pattern changed for the mild DAT individuals, who showed smaller word process estimates than did the young-old participants.

The results from the DAT groups may be complicated by their increased error rate. Recall that the DAT groups had high intrusion error rates (see Table 5) and that for the mild DAT group, these intrusion errors were likely to occur early in processing. Within the process dissociation framework, intrusion errors are treated in the same manner as when a participant does not make any response. The effect of intrusions is not reflected in the process estimates at the time that the intrusions occur. Instead, the effect of elevated intrusions is observed at the later deadlines, when high numbers of intrusions limit the values to which the proportion correct can rise. In fact, at its current level of development, it is not possible to take into account increased intrusion error rate when computing word process estimates, even though intrusion errors are, in a sense, the maximal effect of word processes on performance. Thus, the time course of process estimates does not accurately reflect the actual time course of processing in groups, such as DAT individuals, that produce relatively high numbers of intrusions. Clearly, it would be useful to take into account these disparate aspects of performance in future developments of the process dissociation framework.

Discussion

Stroop and Aging

The results of the present study provide data regarding changes in attentional selection across three groups of healthy younger and older adults. The results clearly indicate that older adults have an increased difficulty in the Stroop task when the irrelevant word dimension of the stimulus provides information that conflicts with the correct color naming response. The increase in interference for the older adults was disproportionate, and therefore this increased interference was not simply a scaling effect resulting from differences in overall speed of processing. These results are consistent with proposals by Hasher and Zacks (1988) regarding changes in inhibitory processes with age. A decrease in the efficiency of inhibitory processing for older adults would result in increased susceptibility to interference from irrelevant dimensions of a stimulus. This conclusion is also supported by the results from the process dissociation analysis. On the basis of the notion that selection involves the activation of the appropriate pathway and the inhibition of the inappropriate pathway, the word pathway should be inhibited and the color pathway should be activated. Although there were no age-related differences in the contribution of the color processes, there were large age-related increases in the word process estimates. This pattern is quite consistent with the notion that processes that activate appropriate information appear to remain intact in older adults (Balota & Duchek, 1988, 1989; Duchek & Balota, 1993), whereas processes engaged to inhibit irrelevant information appear to decline (Hasher & Zacks, 1988). Lindsay and Jacoby (1994) pointed out that increased interference could be reflected either in a decrease in the contribution of color processes or in an increase in word processes (or both). The fact that differences were found only in the word process estimates offers converging evidence for the presence of a deficit in inhibitory processes in older adults.

This study also demonstrates the importance of looking at performance characteristics beyond the mean RTs for each condition. To the extent that there are consistent changes in the shapes of RT distributions across different experimental conditions and across different participant populations, theories need to offer an account for such changes. The results from the ex-Gaussian analysis revealed a pattern of μ and τ parameter estimates in the congruent, incongruent, and neutral conditions in the younger adults consistent with the patterns reported by Heathcote et al. (1991) and Mewhort et al. (1992). Both the congruent and incongruent conditions produced an increase in the tail of the distribution relative to the neutral condition. Mewhort et al. suggested that the smaller τ estimate for their neutral condition may have been due to the nonlexical nature of that condition. Given our use of words as a neutral condition, this clearly cannot be the case.

The ex-Gaussian analyses also indicate that the disproportionate increase in interference in the healthy older adults in comparison with the younger adults may be attributed to an increase in the tail of the RT distributions in the incongruent condition for these older adults. This increase in the tail reflects a population of trials in which the older adults experienced increased interference from the word dimension. This is consistent with the notion that a decrement in an individual's ability to inhibit a conflicting word code means that on some trials, additional processing time is required to resolve the conflict and produce the correct response. Lyons, Kellas, and Martin (1994) have also noted that RT distributions for older adults appear more skewed. The increase in the tail of the distribution for older adults relative to younger adults may indicate that older adults are more likely to experience attentional lapses, resulting in decreased performance on a proportion of trials (Kellas, Simpson, & Ferraro, 1987; but see Salthouse, 1993). Of course, the difficulty at present is that most studies have not examined RT distributions, so it is not clear which age effects reported in the literature are due to changes in the modal portion of the distribution and which are due to increases in the tail of the distribution. This study provides evidence that disproportionate age effects may arise from an increase in the tail of the distribution rather than simply from a shift in the entire distribution, as might be predicted by some generalized slowing accounts of age effects (see also Balota, Spieler, & Faust, 1994; but see Hale, Myerson, Zheng, & Chen, 1995).

Stroop and Alzheimer's Disease

The comparisons between the healthy older adults and the DAT individuals yielded a picture of processing changes very different from that of the comparison between younger and older adults. With respect to the RT and error analyses, the DAT individuals showed a slightly larger Stroop interference effect, which is consistent with the previous studies on DAT individuals (Fisher et al., 1990; Koss et al., 1984). However, if one controls for the sizable changes in overall speed between the healthy older adult groups and the DAT groups, one finds that the DAT individuals had an interference effect proportionately equivalent to that of healthy older adults. The increased difficulty that DAT individuals have when they are presented with conflicting information is manifested in their large increase in intrusion errors relative to healthy older adults. Rather than take the additional processing time required to produce a correct response, DAT individuals are more likely to allow irrelevant dimensions of the stimulus to drive their response. This intrusion error rate increased with the severity of the disease. Moreover, the data from the mild DAT individuals suggest that these intrusions were more likely to be fast errors. Interestingly, DAT individuals also showed a disproportionate increase in the facilitation effects for congruent color–word trials relative to the healthy older adult groups. It is possible that some of the increased facilitation in the mildly demented individuals was a reflection of an increased reliance on the word code, which, in the congruent condition, was the correct response.

Recall that the ex-Gaussian analysis revealed that the disproportionate increase in interference for the young-old adults resulted from an increase in the tail of the distributions. On trials in which healthy older adults experienced strong interference from the word dimension, they were able to take additional processing time and eventually produced a correct response. This increased processing time resulted in more responses' falling in the tail of the distribution, thus increasing τ. In contrast, the mild DAT individuals were much more likely to produce an intrusion error rather than to take the additional processing time. The errors for the mild DAT individuals (and, to a lesser extent, the very mild DAT individuals) were more likely to be fast errors; this indicates that, on a proportion of the trials, a well-formed code (the word) was available and that rather than engage in further processing, these individuals simply produced the incorrect response driven by the word code. The result of this is that trials that would end up in the tail of the distribution for healthy older adults were removed from the distribution as error responses in the DAT groups. Thus, there was primarily a change in μ between the incongruent and neutral conditions for the mild DAT individuals, with little evidence of a change in τ. Those in the very mild DAT group, on the basis of their RT distributions and error rates, might be viewed as representing an intermediate level of performance between those in the young-old and mild DAT groups.

The results of applying Lindsay and Jacoby's (1994) process dissociation framework to the performance of the DAT groups were less clear. It was not possible, within this analysis, to take into account what one might view as the maximal effect that the word may have on color naming: namely, an intrusion error. The result is that when applied to populations with large intrusion error rates, word process estimates are probably underestimated, and the time course of the process estimates also may not accurately reflect the relative contribution of color and word processes. This does not invalidate the process dissociation technique; indeed, the results from the healthy younger and older adults strongly support the dissociation between color and word processes. However, these results do indicate that this technique should be applied with caution in populations with high intrusion error rates.

The performance of the DAT individuals, specifically with respect to the increase in intrusion errors, cannot simply be due to a failure on the part of these individuals to understand the task demands. If this were the case, the neutral dimension should have been just as effective at eliciting an intrusion error as the incongruent condition because the neutral condition also had word information that participants could use to drive an incorrect response. Instead, the large increase in the intrusion errors for the incongruent condition indicates that these individuals are experiencing difficulty when multiple responses are activated *within* the same processing dimension (e.g., semantic category).

One possible interpretation of the results from the DAT groups is that there is a change in response bias in DAT individuals in comparison with healthy younger and older adults. Obviously, as indicated by the psychometric data in Table 1, DAT individuals experience breakdowns in a wide variety of tasks. In an attempt to compensate for a reduced reliability of the cognitive system, DAT individuals may be biased toward producing any available "well-formed" response rather than awaiting the results of further processing to distinguish among the activated representations. The question is why such a shift might occur in DAT individuals.

Our finding that DAT groups experience strong interference in task performance from irrelevant dimensions of a stimulus is consistent with the findings of Balota and Ferraro (1993). Their study addressed speeded naming performance in DAT populations. According to dual-route theories of naming performance, there are two ways in which people may name an isolated word aloud. The first consists of mapping the orthographic string onto a phonological output on the basis of orthographic to phonological correspondences. For example, the string *mint* may be assembled from the sounds of the constituent letters. However, there are irregular words such as *pint* for which the correct phonological output can be produced only by analyzing the word as a single unit. Balota and Ferraro found that the DAT individuals were much more likely to produce a response based on the assembled phonological output rather than to access the correct pronunciation from the lexicon (see also Patterson, Graham, & Hodges, 1994). They interpreted these findings as reflecting a failure to inhibit the available assembled pronunciation.

The account offered by Patterson et al. (1994) with respect to the observation that DAT individuals are more likely to regularize irregular words emphasized the importance of the semantic representations that support the selection process. Patterson et al. argued that such performance may arise from a breakdown in lexical–semantic representations of irregular words. The degraded semantic representation offers less support for the retrieval of the appropriate phonological code for output, and this results in DAT individuals' being more likely to allow the stimulus to drive their response. Such a pattern is similar to that observed in the DAT individuals in the present study. When these individuals were presented with conflicting color word information, they were much more likely to produce the incongruent color word. Their degraded semantic representation of color information means that these individuals are less able to distinguish between the incorrect, strongly activated response and the perhaps less strongly activated correct response. On the other hand, the neutral words have sufficiently distinct representations such that they do not involve enough featural overlap to override the correct color response; thus, DAT individuals are much less likely to produce the neutral word as an intrusion.

These two accounts are probably not mutually exclusive. The semantic and contextual degradation account offers a possible reason for why competing information is more likely to intrude on performance in particular populations. Such a degradation may also place greater emphasis on the integrity of inhibitory processing because of the increased and more frequent competition between processing pathways. Thus, degradation in supportive structures (e.g., lexical–semantic information for irregular words) should result in performance similar to that expected by a deficit in inhibition, and it is likely that such a degradation would serve to magnify any decrements in inhibitory processing (for further discussion of the role of context in selection, see Cohen, Dunbar, & McClelland, 1990; Kimberg & Farah, 1993). An important issue that will need to be pursued in the future is the extent to which apparent breakdowns in inhibition reflect real breakdowns in inhibitory processing or reflect a general degradation in the supporting structures that drive task-relevant and appropriate processing pathways.

Finally, it is worth noting that there has been considerable recent interest in the underlying neural structures involved in inhibitory processes. For example, performance on the Stroop task is commonly impaired in individuals with damage to the frontal lobes. The notion of frontal involvement in the Stroop task has also been supported by neuroimaging studies (Pardo, Pardo, Janer, & Raichle, 1990) showing that regions in the frontal lobes, especially anterior cingulate gyrus, are activated during Stroop performance. In neuropsychological studies, Moscovitch and Winocur (1992; see also Craik, Morris, Morris, & Loewen, 1990) have noted that healthy elderly individuals appear to show deficits on tasks in which performance is also impaired in populations with frontal lobe damage. Moreover, there is evidence that DAT individuals show a pattern of impairment consistent with frontal damage (e.g., see Morris et al., in press; Parasuraman & Haxby, 1993). Finally, there is some evidence of neurophysiological changes in normal aging (Squire, 1987), and positron emission tomography studies of regional cerebral blood flow suggest that there are metabolic reductions in frontal regions in at least a subpopulation of DAT individuals (Parasuraman & Haxby, 1993). Thus, although numerous neural systems are implicated in the performance of the Stroop task, the present increase in Stroop interference in healthy older adults and in DAT individuals is consistent with the changes that have been found in the frontal lobe and its presumed role in inhibitory control.

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