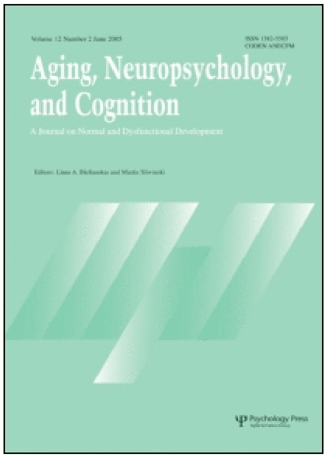

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Age Differences in Stroop Interference: Contributions of General Slowing and Task-Specific Deficits

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ABSTRACT

This study examined the contributions of general slowing and task-specific deficits to age-related changes in Stroop interference. Nine hundred thirty-eight participants aged 20 to 89 years completed an abbreviated Stroop color-naming task and a subset of 281 participants also completed card-sorting, simple reaction time, and choice reaction time tasks. Age-related increases in incongruent color-naming latency and card-sorting perseverative errors were observed. Hierarchical regression analyses showed that the processing speed measures accounted for significant variance on both dependent measures, but that there was also a significant residual effect of age. An additional regression analysis showed that some of the variance in incongruent color-naming, after controlling for processing speed, was shared with the variance in perseverative errors. Overall, findings suggest that the age difference in Stroop interference is partially attributable to general slowing, but is also attributable to age-related changes in task-specific processes such as inhibitory control.

The Stroop effect (Stroop, 1935) is observed when participants are asked to name the color of ink that words are printed in when the words are color names. In an incongruent condition (e.g., the word BLUE written in red ink) color-naming is slowed relative to a congruent condition in which the name of the word matches the color of ink (e.g., the word BLUE written in blue ink) or a neutral condition in which random letter strings or color swatches are shown in various ink colors (e.g., XXXX written in blue ink) (MacLeod,

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1991). Explanations of the Stroop effect propose that efficient performance in the incongruent condition depends on one's ability to resolve the competition between the two responses evoked by each of the stimulus dimensions (Dyer, 1973). Some researchers portray this competition as a race between a habitual reading response that a participant must suppress and a controlled naming response that must be activated (cf. Posner & Snyder, 1975).

Many studies have revealed an age difference in Stroop performance, with older adults exhibiting greater interference than younger adults (for a brief review, see MacLeod, 1991). There is disagreement, however, on the mechanism(s) responsible for the age-related increase in Stroop interference. One view suggests that the age difference primarily reflects general slowing. A recent meta-analysis of 20 studies provides support for this view (Verhaeghen & De Meersman, 1998). According to the slowing account, older adults should be especially slower than younger adults when a task requires a controlled response. Color naming is presumed to be a more controlled response than word reading. Thus, in the incongruent condition in which the controlled naming response must be selected over the more habitual reading response, older adults should be disproportionately slower than younger adults.

Investigations of the slowing explanation have typically adopted one of two approaches. One approach is to examine the effect of age on proportional interference scores (i.e., incongruent naming latency divided by neutral naming latency; or incongruent minus neutral naming latency, divided by neutral naming latency). Proportional interference scores control for the age difference in baseline response latency, so if general slowing fully accounts for the age-related increase in Stroop interference, one would not expect an age difference when proportional scores are used. If the age difference in Stroop performance reflects the decline of cognitive processes more specific to incongruent color-naming, then an age effect would be expected (cf. Uttl & Graf, 1997). Although one study reported no effect of age on proportional scores for adults 65 years of age and older (Graf et al., 1995), studies that included younger and older adults have consistently revealed an age difference in Stroop interference using proportional scores (e.g., Dulaney & Rogers, 1994; Houx, Jolles, & Vreeling, 1993; Spieler et al., 1996; West & Baylis, 1998).

Another approach is to use hierarchical regression analyses in which the age-related variance in performance on incongruent trials is examined after statistically controlling for performance on neutral trials or alternative measures of processing speed (cf. Salthouse, 2001; also see Salthouse, 1996). Salthouse and Meinz (1995) used this approach in a comprehensive study on the contribution of inhibition to age differences in working memory. Stroop interference was included as a measure of inhibition and several tasks were administered to obtain a composite measure of processing speed. Analyses revealed that the residual age-related variance in Stroop interference, after control of speed measures or neutral naming scores, was a relatively small percentage (15% and 39%, respectively) of the total age-related variance in Stroop interference. Salthouse and Meinz therefore concluded that age differences specific to Stroop interference were minimal, relative to general slowing. Note, however, that the relationship between age and Stroop interference was still significant after statistical control of the processing speed composite or neutral naming scores (see also West & Baylis, 1998). This finding, combined with the results of studies using proportional interference scores, suggests that there is at least some unique age-related effect on Stroop interference that warrants further investigation.

An alternative to the slowing view is that heightened Stroop interference for older adults relative to younger adults reflects an age-related deficit in inhibitory control (Spieler et al., 1996). In the Stroop paradigm, inhibition is thought to prevent the allocation of attention to the irrelevant stimulus dimension (i.e., the name of the word), thereby allowing the participant to focus on the relevant dimension (i.e., the color of ink in which the word is written). A decline in inhibitory control would therefore produce greater Stroop interference. This explanation is consistent with Hasher and Zacks' (1988) inhibitory deficit hypothesis and is supported by both behavioral and electrophysiological findings. West and Baylis (1998), for example, manipulated the degree to which inhibitory control was required in separate blocks of the Stroop task by varying the proportion of incongruent and congruent trials within a block. The mostly incongruent block (66% incongruent trials) presumably placed a greater demand on inhibitory control than the mostly congruent block (66% congruent trials). Older adults exhibited more interference than younger adults in the mostly incongruent block but not in the mostly congruent block. The age difference in the mostly incongruent block held when proportional interference scores were used, suggesting that the interference effect was not fully attributable to general slowing.

In an event-related potential (ERP) study, West and Alain (2000) contrasted the inhibitory deficit view and the general slowing view by comparing the amplitude and latency of several ERP modulations believed to reflect inhibitory processing. Behaviorally, older adults exhibited greater Stroop interference than younger adults. An analysis of covariance using neutral-trial performance as the covariate revealed that some of the age-related difference could be attributed to general slowing, but the effect of age remained significant. In addition, the amplitudes of two ERP modulations thought to reflect the suppression of competing word information, the N500 and a left parietal-frontal bilateral modulation, were significantly reduced in older adults relative to younger adults.

The above review suggests that general slowing does not completely account for the age-related increase in Stroop interference. In the current study, we further examined the general slowing explanation of the age difference in Stroop performance. Following the strategy suggested by Salthouse

(2001) for investigating individual differences in executive processes, we examined the extent to which the age difference in the ability to inhibit prepotent responses in the Stroop task was independent of the age difference in processing speed. We also used the statistical control procedure suggested by Salthouse to examine the contributions of age and processing speed to a second measure that is often assumed to reflect inhibitory control, perseverative errors on a card-sorting task (Amos, 2002; Cepada et al., 2000; Zook et al., 2004).

OVERVIEW OF THE STUDY

A variation of the Stroop task was administered to 938 participants ranging in age from 20 to 89 years old. A subset (n = 281) of the participants also completed two reaction-time tasks and a card-sorting task. The primary goal of the study was to examine the contribution of age and processing speed to performance in the incongruent condition of the Stroop task. Following Salthouse and Meinz (1995), we included several measures of processing speed: response time in the neutral condition of the Stroop task, simple reaction time, and choice reaction time. We then examined the residual age-related variance in the incongruent condition after statistically controlling for variance on the processing speed measures. If general slowing contributes to the age-related decline in Stroop performance, one would expect a significant reduction in the age-related variance in the incongruent condition after controlling for measures of processing speed. If general slowing fully accounts for the age difference in Stroop interference, the effect of age should not be significant after controlling for processing speed. If, on the other hand, other factors specific to incongruent color-naming contribute to the age difference in Stroop performance, one should observe a significant residual effect of age after controlling for processing speed. A secondary goal was to examine the contributions of age and processing speed to an additional measure that is often presumed to reflect inhibitory control, perseverative errors on the Wisconsin Card Sorting Test. Inclusion of this second measure allowed us to examine whether the residual age-related variances in Stroop interference and card-sorting perseverative errors, if found, were shared variances.

Although similar to past studies, the present study has several advantages over past research. First, we have included a larger sample size than used in past studies. This is especially important given the statistical control procedure used here, which requires a large sample size to detect small-to-medium residual effects (cf. Salthouse, 2001). Our larger sample also allows us to better examine developmental changes across the lifespan. Other studies using similar procedures were limited to older adults 65 and older (Graf et al., 1995) or grouped together participants in their 70s and 80s because of limited sample sizes in these age ranges (Salthouse & Meinz, 1995). With a sufficient number of adults in all age decades from the 20s to 80s, we were able to examine changes across adulthood, as well as examine potential differences between young-old and old-old adults. An additional contribution of the current study is that we used different measures of processing speed (simple and choice reaction time) and inhibitory control (perseverative errors on a card-sorting task) than used in past research, allowing us to examine the generalizability of past findings.

METHOD

Participants

There were 938 participants ranging from 20 to 89 years of age. Younger adults were recruited from the student population at the University of Colorado at Colorado Springs and received class credit for their participation or for recruiting older relatives to participate. Older adults were also recruited from local senior citizen organizations in Colorado Springs, CO. Volunteers 60 years of age or older received $10 for participation. All participants completed a questionnaire that collected information about demographics, medical history, alcohol and drug use, and educational history. Participants were eliminated from participation if they reported a history or condition of stroke, head injury accompanied by loss of consciousness, hypertension, diabetes, neurological disorder, current psychiatric diagnosis, current usage of anti-depressants or any medication that based on self-report might be affecting their thinking, or medical condition that would interfere with testing. All older adult participants included in the study reported that they were in an independent living situation and described themselves as being in good health. For a description of the demographic characteristics of participants according to age decade, see Table 1. All groups achieved a similar level of education, with the exception of the 50 year olds, who reported significantly more years of education than the 20, 60, and 70 year olds, $p < .05$. All 938 participants completed the Stroop task described below as part of a larger neuropsychological battery. A subset of 281 participants also

TABLE 1. Demographic Characteristics of the Sample as a Function of Age Decade

	20s	30s	40s	50s	60s	70s	80s
Number	324	119	122	96	85	127	65
Age							
Mean	22.9	34.2	44.2	53.3	64.4	74.5	82.7
SD	2.9	3.1	2.8	2.7	2.7	2.8	2.5
Education							
Mean	14.7	14.8	14.9	15.4	14.6	14.6	14.6
SD	1.1	1.2	1.4	2.0	2.3	2.3	2.2
% Female	70	84	84	67	67	69	62

completed the Wisconsin Card-Sorting Test, Simple Reaction Time Task, and Choice Reaction Time Task.[1] The battery of tasks was administered across multiple test sessions, with each session 1 to 2 h in duration. Numerous breaks were given, especially during the longer sessions, and no more than one lengthy task (20–30 min) was administered per session. Participants completed the tasks in random order.

Cognitive Measures

Stroop Task

An abbreviated Golden Stroop Color Word Test was administered in standard fashion to measure susceptibility to Stroop interference (cf. Golden, 1978; Stroop, 1935). Three conditions were given in a fixed order: (1) a word reading condition in which participants read color words presented in black ink; (2) a neutral color-naming condition in which participants named the ink color of dots, and (3) an incongruent color-naming condition in which participants named the ink color of color words ("RED") presented in a conflicting color ink. For each type of trial, participants were asked to respond verbally as quickly as possible. The measure of interest was response time, which refers to the total time to complete an individual condition. Response times were determined by means of a stopwatch.

Wisconsin Card Sorting Test (WCST)

A computerized version of the WCST was administered in which participants were required to match a card in the center of the screen with one of four cards located at the top of the screen that served as references (Heaton et al., 1993). The cards were sorted based on a rule that used color (red, green, blue, or yellow), shape (circle, square, star, cross), or number (one, two, three, or four). Once 10 consecutive sorts were achieved, the rule was changed without warning and the process repcated until six sets were completed or 128 cards were sorted. The number of perseverative erros, the number of times a participant repeated an incorrect response following corrective feedback, was the dependent variable. A computational model proposed by Amos (2000) indicated that frontal lobe dysfunction results in an increase in perseverative errors that is indicative of an inability to inhibit prepotent responses. Other researchers have also suggested that the perseverative errors index may be used as a measure of inhibitory dysfunction (e.g., Everett et al., 2001).

Simple Reaction Time (SRT) Task

The SRT task consisted of two segments. For both segments, participants were shown a series of visual stimuli (left and right pointing

[1] In the reduced sample, groups attained a similar level of education, $p > .05$.

arrows) in the center of a computer screen and asked to respond by pressing the appropriate response key on a game pad. The first segment included 16 trials in which the arrow was pointing to the right and participants were to give a right key response. The second segment included 16 trials in which a left-pointing arrow was shown and participants were to give a left key response. Accuracy and reaction time were recorded for all trials.

Choice Reaction Time (CRT) Task

The CRT task consisted of 32 trials, comprised of 16 trials with left arrows and 16 trials with right arrows presented in pseudo-random order. In each of four blocks of eight trials, four left and four right arrows were shown. Participants were told that the direction of the arrows would be unpredictable and were instructed to press either the right or left key on a game pad as quickly as possible, according to the direction of the arrow. Accuracy and reaction time were recorded for all trials.

RESULTS

Stroop Interference

The alpha level for all analyses was set at .01. Consistent with the typical pattern of means observed on the Stroop task, participants were significantly faster at reading words ($M = 1.69$ s, $SD = 0.61$) than naming colors ($M = 1.98$ s, $SD = 0.83$), $t(937) = -10.38$, $p < .001$. Response times were also significantly slower in the incongruent color-naming condition ($M = 6.52$ s, $SD = 6.74$) than the neutral color-naming condition, $t(937) = -21.27$ $p < .001$. Linear regression analyses revealed significant age-related increases in response time on all three Stroop measures ($F > 10$, $p < .01$) (see Figure 1), but the increase was notably larger for the incongruent color-naming condition ($R^2 = .27$) than the other conditions ($R^2 = .02$ and .07 for the word reading and neutral color-naming conditions, respectively).

Using performance in the neutral color-naming condition as a measure of processing speed, we then examined the extent to which speed accounted for the age difference in incongruent color-naming. To accomplish this, we conducted a forced-entry hierarchical regression analysis with incongruent color-naming latency as the dependent variable, neutral color-naming latency as the first predictor, and age as the second predictor (cf. Salthouse, 2001). As indicated in Table 2, neutral color-naming latency accounted for significant variance in incongruent color-naming, but age also accounted for significant additional variance beyond that of neutral color-naming. Seventy-four percent of the initial age-related

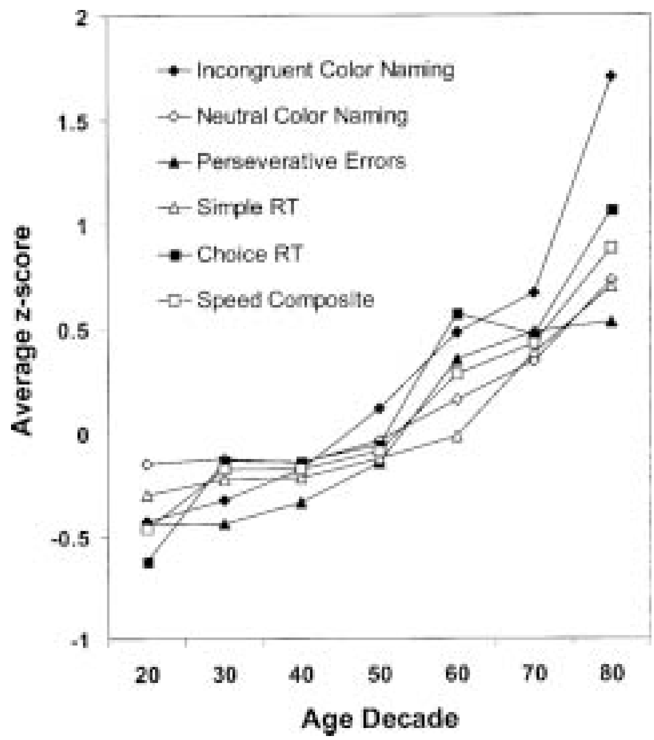

FIGURE 1. Means by age decade for the inhibitory and processing speed measures. Note that the data has been graphed such that higher z-scores represent slower or less accurate performance.

variance remained unaccounted for after control of neutral color-naming latency.[2]

Parallel analyses were conducted using the two independent measures of processing speed that were obtained from the subset of 281 participants who completed the simple and choice reaction-time tasks. Linear regression analyses revealed significant age-related increases in simple reaction time [$F(1, 279) = 35.64$, $p < .001$, $R^2 = .11$] and choice reaction time [$F(1, 279) = 127.87$, $p < .001$, $R^2 = .31$] (see Figure 1). Forced-entry hierarchical regression analyses showed that although simple and choice reaction time each accounted for significant variance in incongruent

[2] Parallel analyses were conducted using a subset of the participants who completed the Rey verbal memory test as part of the neuropsychological battery, after removing participants whose scores on the memory test were more than two standard deviations below the mean. This served to screen participants with large memory impairments. Results were nearly identical to those observed with the full sample with the same significant effects.

TABLE 2. Age-Related Variance in Incongruent Color-Naming and Card-Sorting Perseverative Errors Before and After Control of Processing Speed Measures

	Incongruent Color-Naming		Perseverative Errors	
Regression Equation	R^2	Incremental R^2	R^2	Incremental R^2
Full Sample (n = 938)				
Age	.27*	—	—	—
Neutral Color-Naming	.09*	—	—	—
Neutral Color-Naming + Age	.29*	.20*	—	—
Partial Sample (n = 281)				
Age	.32*	—	.10*	—
Neutral Color-Naming	.05*	—	.03*	—
Neutral Color-Naming + Age	.33*	.28*	.11*	.08*
Simple Reaction Time	.08*	—	.08*	—
Simple Reaction Time + Age	.33*	.25*	.14*	.06*
Choice Reaction Time	.11*	—	.06*	—
Choice Reaction Time + Age	.32*	.21*	.11*	.05*
Processing Speed Composite	.12*	—	.09*	—
Speed Composite + Age	.32*	.20*	.13*	.04*

*$p < .01$.

color-naming, age accounted for significant additional variance after these processing speed measures were controlled for (see Table 2). Seventy-eight and 66 percent of the initial age-related variance remained unaccounted for after statistical control of simple and choice reaction time, respectively. The same pattern held when a composite processing speed measure (the average of z-scores from the simple and choice reaction time tasks) was used as the first predictor.

Perseverative Errors

Comparable analyses were then conducted using perseverative errors on the Wisconsin Card-Sorting Test as the dependent measure. A linear regression analysis revealed a significant age-related increase in the number of perseverative errors [$F(1, 279) = 31.03$, $p < .001$, $R^2 = .10$] (see Figure 1). Forced-entry hierarchical regression analyses showed that all three processing speed measures accounted for a significant amount of the variance in perseverative errors, but in each case, age accounted for additional variance (see Table 2). Eighty, 60, and 50 percent of the initial age-related variance in perseverative errors remained unaccounted for after statistically controlling for neutral color-naming latency, simple reaction time, and choice reaction time, respectively.

Additional analyses were conducted to determine whether the residual variance in Stroop interference, after control of processing speed, was shared with the variance in card-sorting perseverative errors. We used a forced-entry hierarchical regression analysis with incongruent color-naming latency as the dependent variable, neutral color-naming latency as the first predictor, and perseverative errors as the second predictor. Perseverative errors accounted for significant additional variance beyond that of neutral color-naming (total $R^2 = .12$, incremental $R^2 = .07$, $p < .01$). A follow-up regression analysis that included age as the third predictor showed, however, that age accounted for additional variance beyond that of both neutral color-naming and perseverative errors (total $R^2 = .34$, incremental $R^2 = .22$, $p < .01$).

DISCUSSION

A primary goal of this study was to examine the contribution of age and general slowing to performance in the incongruent condition of the Stroop task. Although the processing speed measures accounted for significant variance in incongruent color-naming, a large proportion of the age-related variance remained unaccounted for after statistical control of processing speed. In our full sample of 938 participants, 74% of the initial age-related variance in Stroop interference was unaccounted for by neutral color-naming latency. In a subset of 281 participants, a similar pattern was observed, with 88%, 78%, and 66% of the initial age-related variance unaccounted for after control of neutral color-naming latency, simple reaction time, and choice reaction time, respectively.

These findings are consistent with past research in showing that the processing speed measures accounted for a significant amount of variance in Stroop performance, but that the effect of age was still significant after control of the processing speed measures. Note, however, that the residual age-related variance in Stroop interference was larger in our study than the one by Salthouse and Meinz (1995), despite similarities in the methods and statistical procedures used. The difference in magnitude for some analyses may be due to the use of different processing speed measures. Whereas Salthouse and Meinz used letter comparison, pattern comparison, digit digit, and digit symbol tasks to measure processing speed, we used simple and choice reaction-time tasks. Note, however, that both studies included a hierarchical regression analysis of incongruent color-naming latency using neutral color-naming latency as a control variable. Whereas we found that 74% of the initial age-related variance in incongruent color-naming remained unaccounted for after control of neutral color-naming, the comparable value from the Salthouse and Meinz study was 39%.

We believe that the difference in the magnitude of the residual effect of age most likely reflects the use of different variations of the Stroop task. Specifically, we used a more abbreviated version of the task than was used by Salthouse and Meinz (1995). Previous research has shown that the age difference in Stroop interference is larger for earlier portions of a Stroop task than later portions, suggesting that an abbreviated version of the task may be more sensitive to age differences (Klein et al., 1997). In addition, one might expect greater difficulty in suppressing a habitual naming response when a participant has limited exposure to and practice with incongruent trials, as compared to a situation in which a participant receives numerous incongruent trials given one after another in blocked fashion. As such, our task may have placed greater demands on inhibitory control processes (cf. West & Baylis (1998) for similar arguments regarding other task variables). In any case, the same general pattern was observed in our study and past studies: Processing speed measures accounted for significant variance in incongruent color-naming, but the effect of age was still significant after statistically controlling for processing speed.

A similar pattern was obtained for perseverative errors on the card-sorting task. The processing speed measures accounted for significant variance in perseverative errors, but the residual age-related variance was also significant. For this dependent measure, 80%, 60%, and 50% of the initial age-related variance was unaccounted for after control of neutral naming latency, simple reaction time, and choice reaction time, respectively.

Overall, the key finding of the present study was that the age-related decline in Stroop performance was partially attributable to a general decline in processing speed, but also reflected influences more specific to the Stroop task. A secondary finding was the extension of this conclusion to the age-related increase in perseverative errors. Although the amount of variance accounted for by processing speed and task-specific factors differed for the Stroop and WCST (i.e., the incremental R^2 value for age, after control of the processing speed composite measure, was .04 for perseverative errors compared to .20 for the incongruent color-naming condition), both findings suggest that a single factor (i.e., generalized slowing) cannot fully account for age differences in performance on the Stroop or WCST. Our findings therefore add to a growing body of literature showing significant contributions of processing speed as well as other factors (e.g., inhibition) to age differences in cognitive processes such as attention and memory (Persad et al., 2002), language (Kwong See & Ryan, 1995), and Stroop interference (West & Baylis, 1998).

Although the present study does not allow one to reach conclusions about the exact nature of the age-related influences on Stroop performance, our view is that these influences at least partially reflect deficient inhibitory control processes. This interpretation is supported by the finding that there was shared variance between incongruent color-naming latency (after control of processing speed) and perseverative errors. It is likely, though, that there are other age-related influences on color-naming latency given that age accounted for additional variance beyond that accounted for by processing speed and perseverative errors. It is also possible that incongruent color-naming reflects different inhibitory control processes than those recruited in the WCST. After all, Kramer et al. (1994) found low between-task correlations for several purported measures of inhibition (WCST performance, response compatibility, negative priming, and stop-signal performance), suggesting that these measures may reflect different inhibitory processes. A second possibility is that the age differences reflect non-inhibitory factors that are important to Stroop performance (Kerns et al., 2004), such as the ability to monitor and recruit control processes in response to the conflict that arises on incongruent trials. Consistent with this idea, a recent ERP study reported an age-related disruption in the neural mechanisms supporting the ability to detect conflict during a Stroop task (West, 2004).

Further study is needed, however, to better understand the unique effects of age on Stroop interference, beyond the influence of general slowing. One suggestion would be to follow the approach of West and Baylis (1998), experimentally manipulating aspects of the Stroop task such as the degree of conflict involved on an incongruent trial. If conflict monitoring plays a key role in the age-related increase in Stroop interference—above and beyond the role of processing speed—one would expect a larger age difference in the high-conflict condition than the low-conflict condition, even when proportional interference scores are used. On the other hand, if general slowing can fully account for the age-related decline, an age-by-condition interaction would not be expected when proportional interference scores are used. Using this approach, one can begin to identify the task-specific factors that contribute to the age-related decline in Stroop performance.

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