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Age-Related Changes in Attentional Selection: Quality of Task Set or Degradation of Task Set Across Time?

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The present study explores the nature of attentional selection in younger and older adults. Following R. De Jong, E. Berendsen, and R. Cools (1999, *Acta Psychologica*, Vol. 101, pp. 379–394), we manipulated the response to stimulus interval (RSI) in two attentional selection paradigms to examine if there are age-related differences in the quality of task set and/or the maintenance of task set across time. In Experiment 1, we found that the interference effect in a spatial interference task was (a) overall larger in older adults compared with younger adults, and (b) smaller at the short RSI (200 ms) compared with the long RSI (2000 ms), and (c) not associated with an interaction between age and RSI. The second experiment explored the same variables in a Stroop color interference paradigm. Again, older adults produced a disproportionately larger interference effect than younger adults, the interference effect was smaller at the short RSI compared with the long RSI, and there was no evidence of an interaction between age and RSI. In both experiments, the larger interference effect could not be attributed to age-related general slowing and there was evidence from Vincentile analyses of increasing interference and age effects at the slower response latencies. These results indicate that attentional selection deficits in these two experiments were due to a breakdown in the quality of the task set as opposed to age-related differences in the maintenance of the task set across time.

Keywords: Stroop, attention, aging, task set, response-stimulus interval

Attentional selection involves the ability to select an internal or external stimulus dimension from competing dimensions for further processing. It is paramount for virtually all cognitive activities. Researchers often study aspects of attentional selection by developing tasks that place the task-relevant dimension in conflict with activated but irrelevant task dimensions. Such tasks include local/global processing, flanker, Simon, and, of course, the classic Stroop task (Stroop, 1935). Although there are clear differences among the mechanisms underlying different attentional selection tasks (see, e.g., Spieler, Balota & Faust, 2000), these tasks are sometimes conceived as Stroop-type interference tasks (see De Jong, Berendsen, & Cools, 1999), as they pit a selected dimension against an irrelevant nonselected but potent dimension.

The Stroop color interference task is viewed as the gold standard of attentional selection (see MacLeod, 1991). Although there are many variations, there are typically two major conditions in the standard Stroop color-naming task: a congruent condition, in which the word and its hue are concordant (e.g., the word RED presented in red), and an incongruent condition, in which the word and its hue are discordant (e.g., the word RED presented in green). The participant names the color of the stimulus. Incongruent conditions are slower and less accurate than congruent conditions. Attentional selection is nicely captured in this task because the participant has to select the color dimension, which, in the incongruent condition, conflicts with the prepotent word dimension.

De Jong et al. (1999) provided evidence that Stroop-type interference may in part reflect a breakdown in the ability to maintain task goals across intertrial intervals. The authors contrasted two accounts of Stroop-type interference. In the traditional account, they suggested that Stroop-type interference is due to a limit of the quality of attentional selection. That is, the attentional system simply cannot control the irrelevant prepotent dimension (e.g., word reading in a classic Stroop color-naming task), irrespective of task-set robustness. However, De Jong et al. also identified a second mechanism that appears to contribute to Stroop-type interference effects. Specifically, they proposed that Stroop-type interference occurs in part because the task set degrades over time. If one could eliminate this temporal degradation in the task set, then Stroop-type interference should decrease. The authors provided a test of the two mechanisms by reducing the response to stimulus interval (RSI) to 200 ms in a two-response spatial Stroop-type paradigm (responding to the words ABOVE and BELOW either spatially above or below fixation). They argued that with a short RSI, individuals should be able to maintain the task set across trials and thus reduce the interference effect, because there is little opportunity for the task set to degrade. De Jong et al. contrasted this short-RSI condition with a longer RSI, which is more typically used in Stroop tasks (2,000 ms), contending that the long delay between trials should allow the task set to degrade more than in the

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short-RSI condition. The authors found that at the short RSI, the interference effect was indeed reliably smaller than at the long RSI, suggesting that at the more typical long RSIs, part of the Stroop-type interference effect is due to a degradation of task set across time.

De Jong et al. (1999) also examined differences in the reaction time (RT) distribution as a function of RSI condition. Distributional analyses are useful in providing information about how a manipulation influences response latency beyond the level of the mean. For example, a difference of 100 ms between two conditions can be accounted for by a shift of the entire RT distribution and/or by a skewing of the slow tail of the distribution. Indeed, in some cases, one can find tradeoffs in the different components of RT distributions (Balota & Yap, 2011; Heathcote, Popiel, & Mewhort, 1991), which are masked when one only analyzes mean response latencies. De Jong et al. binned response latencies into Vincentiles for both short and long RSIs, such that the fastest 10% of trials were plotted in the first bin, the second fastest 10% were plotted in the next bin, and so forth. At both RSIs, the authors found a larger interference effect in the slowest bins relative to faster bins, although this effect was reliable only at the long RSI. This suggests that tight maintenance of attentional selection can indeed minimize a Stroop-type interference effect, especially on the slowest trials.

The present study extends the De Jong et al. (1999) study by examining the influence of RSI on Stroop-type interference in younger and older adults. This study was in part motivated by Spieler, Balota, and Faust (1996), who highlighted age-related differences in performance on a classic Stroop color-naming task. The authors found a reliably larger Stroop interference effect for older compared with younger adults, and this effect could not be attributed to age-related general slowing. Moreover, Spieler et al. found that age differences in the classic Stroop effect were attributable not to a simple shifting of the RT distribution from younger to older adults, but by a disproportionate increase in the slow tail of the RT distribution, similar to the influence of RSI on the interference effect obtained by De Jong et al.

Within the De Jong et al. (1999) framework, there are two possible accounts of the Spieler et al. (1996) results. One account assumes an age-related breakdown in attentional selection processes, possibly the inhibition of the prepotent word dimension. The alternative account suggests that older adults cannot maintain the task set across time as well as younger adults, possibly due to age-related changes in working memory (e.g., Balota, Dolan, & Duchek, 2000; Hasher, Lustig, & Zacks, 2007). Some related research favors the former account, namely, that older adults do not engage the same quality of task set as younger adults. For example, a review by De Jong (2001) suggested that although older adults are not able to reestablish the task set in a switching paradigm to the same degree as younger adults, there are no age-related differences in the rate of task-set decay. Hence, based on this review, one might expect the interference effects in the current study to be similarly reduced in both younger and older adults at the short RSI compared with the long RSI condition. Work by West and colleagues (West & Baylis, 1998; West & Schwarb, 2006) also provides some suggestive evidence. Rather than manipulating the interval between trials, West and Baylis (1998) encouraged a more robust task set by altering the proportion of incongruent trials in a Stroop task administered to younger and older adults. Through ex-Gaussian distributional analysis, the authors identified the mean of the Gaussian portion of the distribution (μ) as indicative of participants' fastest trials and the exponential parameter (τ) as indicative of participants' slower trials. In the mostly incongruent condition, younger adults were able to eliminate the interference effect on their fastest trials, via the μ component, whereas older adults could reduce, but not completely overcome, interference for these trials. Hence, the authors argued that these results were supportive of an age-related difference in the quality of the task set.

In further support of this framework, West and Schwarb (2006) had participants respond to the number of items in a set rather than the specific numbers (e.g., 555), with an RSI of 500 or 2,000 ms. Here, older adults demonstrated a larger interference effect relative to younger adults, but there was no reported modulation of the interference effect as a function of RSI condition, much less a three-way interaction with age. It is possible that the 500-ms RSI used in the West and Schwarb study compared with the 200-ms RSI used in the original De Jong et al. (1999) study may have been sufficient for the task constraints to decay, thereby decreasing the sensitivity to pick up the critical RSI by congruency interaction. In any case, the similar performance between younger and older adults suggests a problem in the quality rather than maintenance of task set for older adults. Of course, it is critical to first obtain the congruency by RSI interaction to determine if there are age-related changes in the maintenance of task set. This is indeed one of the major goals of the present study, to which we shall now turn.

The present study contrasted the task-set quality framework against the task-set maintenance framework using the same RSI methods as in De Jong et al. (1999). Experiment 1 was designed to directly replicate the De Jong et al. spatial interference paradigm as closely as possible while extending the design to older adults. In Experiment 2, we further extended the De Jong et al. results to a more-standard Stroop color interference task. The predictions in both experiments are the same. Specifically, if older adults have an age-related breakdown in the quality of the task set underlying attentional selection, then they should produce greater Stroop-type interference than younger adults, but this effect should not interact with RSI. In contrast, if older adults have difficulty maintaining the appropriate task set across time, then they should produce disproportionately greater interference compared with the younger adults at the long RSI relative to the short RSI.

Experiment 1

Method

Participants. Fifty-one younger adults and 51 older adults took part in the study, with 26 younger and 26 older adults in the short-RSI condition and 25 younger and 25 older adults in the long-RSI condition. Younger adults were recruited from an undergraduate research pool and were given credit in partial fulfillment of course requirements, whereas older adults were recruited via an older adult volunteer pool maintained by the Washington University Aging and Development program, and were paid $10/hr as compensation for participation. Demographic information is summarized in Table 1. Older adults had more years of education, $t(78.095) = 2.03$, $p = .046$, and a higher vocabulary, $t(100) = 3.59$, $p = .001$, relative to younger adults.

Table 1
Means (SDs) Demographic Data for Experiment 1 As a Function of Age Group and RSI

Measure	Younger		Older	
	Short RSI	Long RSI	Short RSI	Long RSI
N (Female)	26 (12)	25 (15)	26 (18)	25 (16)
Age	21.5 (4.7)	21.6 (2.8)	77.2 (6.9)	76.7 (8.7)
Years of education	14.8 (1.5)	15.0 (1.4)	15.5 (2.5)	16.0 (2.7)
Shipley vocabulary age	18.8 (0.9)	18.7 (0.9)	19.4 (0.9)	19.3 (0.9)

Note. RSI = response to stimulus interval.

Materials and design. As in De Jong et al. (1999), stimuli for the spatial interference task consisted of the words ABOVE or BELOW presented spatially above or below a fixation row of plus signs (++++). Each trial consisted of a word congruent with the spatial position (e.g., the word ABOVE appearing above the fixation row) or incongruent with the spatial position (e.g., the word ABOVE appearing below the fixation row), with simultaneous onset of stimulus and fixation. Each word was presented equally in congruent and incongruent conditions. Participants were instructed to respond according to the location of the stimulus via the Q and P keys, which were counterbalanced across participants. Critically, the delay between participants' response on a given trial and the onset of the stimulus of the next trial (RSI) was either 200 ms or 2,000 ms for each experimental session. As in De Jong et al., participants were given 1,000 self-paced trials in 100-trial blocks, with a short break between each block. Fifty congruent and 50 incongruent stimuli were presented in a random order during each block. Each session was preceded by a short block of practice, which consisted of 10 trials with trial-level and cumulative accuracy feedback. Stimuli were centered in the display and appeared in white against a black background in 20-pt Arial Rounded MT Bold font, via either CRT or LCD monitors. The experiment was controlled using E-Prime 1.2 software (Psychology Software Tools, Pittsburgh, PA).

Procedure. After providing informed consent, participants were seated in front of a computer monitor, with no restrictions placed on participant movement. Participants sat approximately 50 cm from the monitor and were tested individually.

Analytic approach. As in De Jong et al. (1999), the first 100 trials were considered practice and were not included in the primary analyses. Following the analyses by De Jong et al., in addition to accuracy and RT data, we also examined the interference effect across the entire RT distribution. Vincentile analyses provide mean estimates of ascending bins of RTs for each condition. Here, response latencies are ordered from fastest to slowest, and means of each bin are plotted in 10% increments. In this way, the fastest 10% of trials are located in the first bin, the next fastest 10% are located in the second bin, and so on. Differences between levels of a variable can be plotted using Vincentiles to understand how the influence of a variable may change as a function of Vincentile bin. De Jong et al. found that the elimination of the Stroop effect at the short RSI occurred through reductions of the interference effect in the slowest bins. Because we are interested in age-related differences that are not contaminated by general slowing, we report Vincentiles calculated using the standardized response latencies.

Results

All results are presented after testing for unequal variances between groups using Mauchly's test of sphericity for analyses of variance. When necessary, lower-bound corrections were used for F tests. An alpha of .05 was set to indicate significance. Mean response latencies and accuracies, broken down by RSI and age group, are displayed in Table 2. In addition, as shown in Table 2, in order to control for any effects due to overall age-related slowing, all RTs were converted to within-participant z scores, based on a participant's individual mean and standard deviation (see Faust, Balota, Spieler, & Ferraro, 1999). These are reported as standardized response latencies. Vincentiles are reported in both unstandardized and standardized forms.

Outliers. Outliers were identified as response latencies faster than 200 ms or slower than 3,500 ms. Additionally, response latencies greater than three standard deviations ($z > \pm 3$) from an individual participant's mean were designated as outliers. Outliers constituted 2.0% of all trials, and were dropped from further analyses.

Each of the dependent measures was submitted to a 2 (age) × 2 (RSI) × 2 (congruency) mixed-factor ANOVA. Both age and RSI were between-participants factors.

Reaction latency analyses.

Response latencies. As shown in Table 2, the congruent condition was faster than the incongruent condition, $F(1, 98) = 34.01$, $p < .001$, $\eta_p^2 = .26$. Older adults produced slower response latencies than younger adults, $F(1, 98) = 35.53$, $p < .001$, $\eta_p^2 = .27$. Participants responded more quickly in the short RSI relative to the long RSI condition, $F(1, 98) = 5.34$, $p = .023$, $\eta_p^2 = .05$. The Age × Congruency interaction was significant, $F(1, 98) = 15.33$, $p < .001$, $\eta_p^2 = .14$, such that older adults produced a larger interference effect compared with younger adults, where the interference effect is defined by subtracting mean congruent RT from mean incongruent RT. The RSI × Congruency interaction was also significant, $F(1, 98) = 4.33$, $p = .040$, $\eta_p^2 = .04$, with the interference effect reliably smaller in the short-RSI compared with the long-RSI condition, a replication of De Jong et al. (1999). Neither the interaction of RSI and age nor the three-way interaction approached significance, both Fs < 1, η_p^2s $< .01$.

Table 2
Mean Response Latencies for Experiment 1 As a Function of Age Group and RSI

Measure	Younger		Older	
	Short RSI	Long RSI	Short RSI	Long RSI
Reaction time				
Congruent RT	405	546	722	795
Incongruent RT	407	559	750	847
Interference effect RT	2	13	28	52
Standardized reaction time				
Congruent zRT	−.09	−.12	−.13	−.13
Incongruent zRT	−.07	−.06	−.05	−.02
Interference effect zRT	.02	.05	.08	.11
Accuracy				
Congruent	.96	.98	.99	.99
Incongruent	.96	.98	.98	.98
Interference effect	.00	.01	.00	.01

Note. RSI = response to stimulus interval; RT = reaction time.

Standardized response latencies. As shown in Table 2, the congruent condition was faster than the incongruent condition, $F(1, 98) = 77.83$, $p < .001$, $\eta_p^2 = .44$. The main effects of age and RSI were not significant, both Fs < 1, η_p^2s $< .01$. The Age × Congruency interaction was again significant, $F(1, 98) = 14.25$, $p < .001$, $\eta_p^2 = .13$, such that older adults produced a larger interference effect compared with younger adults, after correcting for general slowing. The RSI × Congruency interaction was also reliable, $F(1, 98) = 4.11$, $p = .045$, $\eta_p^2 = .04$, with a smaller interference effect in the short-RSI compared with the long-RSI condition, replicating the pattern obtained by De Jong et al. (1999). Finally, the RSI × Age interaction was significant, $F(1, 98) = 8.79$, $p = .004$, $\eta_p^2 = .08$, such that there was an influence of RSI for the older adults, $t(49) = 2.57$, $p = .013$, but not for the younger adults, $t(49) = 1.65$, $p = .11$. Most importantly, the three-way interaction among congruency, age, and RSI did not approach significance, $F < 1$, $\eta_p^2 = .00$.

Vincentile analyses.

Vincentiles. The Vincentiles were analyzed with a 2 (age group) × 2 (RSI) × 2 (congruency) × 10 (Vincentile bin) mixed-factor ANOVA. The results of these analyses yielded a number of noteworthy findings. Vincentile bin interacted with congruency, $F(9, 882) = 22.41$, $p < .001$, $\eta_p^2 = .19$, demonstrating an increased interference effect at slower bins. Vincentile bin also interacted with age, $F(9, 882) = 8.89$, $p < .001$, $\eta_p^2 = .08$, and RSI, $F(9, 882) = 3.52$, $p < .001$, $\eta_p^2 = .04$. These latter two interactions were implicated in two 3-way interactions. Specifically, Vincentile bin interacted with congruency and age, $F(9, 882) = 7.81$, $p < .001$, $\eta_p^2 = .07$, in which the interference effect for older adults became much larger at slow bins compared with the interference effect for younger adults. Vincentile bin also interacted with congruency and RSI, $F(9, 882) = 2.39$, $p < .001$, $\eta_p^2 = .02$, suggesting that the interference effect at the long RSI was much larger at slow bins compared with the interference effect at the short RSI. None of the remaining interactions involving Vincentile bin were reliable, all Fs < 1.9, all ps $> .06$, η_p^2s $< .16$.

Standardized Vincentiles. Standardized Vincentiles were analyzed with a 2 (age group) × 2 (RSI) × 2 (congruency) × 10 (Vincentile bin) mixed-factor ANOVA. These findings largely corroborated those of the unstandardized Vincentiles. First, Vincentile bin interacted with congruency condition, $F(9, 882) = 39.89$, $p < .001$, $\eta_p^2 = .29$, such that the magnitude of the interference effect increased across bins. This interaction was further clarified by two 3-way interactions. First, Vincentile bin interacted with congruency and age, $F(9, 882) = 5.45$, $p < .001$, $\eta_p^2 = .05$, such that the interference effect for older adults was larger at the slow Vincentile bins compared with younger adults. Second, Vincentile bin interacted with congruency and RSI, $F(9, 882) = 2.43$, $p = .010$, $\eta_p^2 = .02$, in which slower bins produced a much larger interference effect at the long RSI relative to the short RSI, again replicating findings published in De Jong et al. (1999). All other interactions involving Vincentile bin were not significant, all Fs < 1.7, all ps $> .095$, η_p^2s $< .03$.

Accuracy analyses. The congruent condition was significantly more accurate than the incongruent condition, $F(1, 98) = 21.39$, $p < .001$, $\eta_p^2 = .18$. Older adults were more accurate than younger adults, $F(1, 98) = 20.73$, $p < .001$, $\eta_p^2 = .18$, and participants were more accurate in the long-RSI relative to the short -RSI condition, $F(1, 98) = 6.53$, $p = .012$, $\eta_p^2 = .06$. Age and RSI significantly interacted, $F(1, 98) = 5.31$, $p = .023$, $\eta_p^2 = .05$, such that the RSI difference in accuracy was smaller for older adults relative to younger adults. The three-way interaction among age group, RSI, and congruency was not significant, $F < 1$, $\eta_p^2 < .01$. It is important to note that accuracy was near ceiling for both groups in this experiment.

Discussion

The results from Experiment 1 are clear. Consistent with De Jong et al. (1999), we found a reliable interaction of congruency and RSI in response latencies that persisted under the *z*-score transform, with a smaller interference effect at the short-RSI relative to the long-RSI condition. Vincentile analyses revealed that this occurred via a reduction of Stroop-type interference at the slow tail of the RT distribution at the short RSI compared with the long RSI. This supports the De Jong et al. assertion that accelerating the presentation rate of stimuli can indeed mitigate the interference effect, especially on the most difficult slowest trials.

The Congruency × Age interaction was highly robust and occurred in both the raw and standardized response latencies, indicating that this interaction was not due to age-related slowing. Importantly, there was no hint that RSI modulated this interaction, as reflected by the lack of a three-way interaction of age, congruency, and RSI. RT and standardized Vincentile analyses demonstrated a disproportionately large interference effect across the slower bins for older adults, but did not reveal a disproportionate reduction in the slow-tail interference effect for older adults at the long RSI. Thus, the results from Experiment 1 appear to indicate that the age differences obtained in the De Jong et al. (1999) spatial attentional selection task do not appear to be due to age-related differences in the degradation of the task set across time. The results are more consistent with the hypothesis that older adults simply have poorer attentional selection ability in this task. We will further explore the nature of this attentional selection mechanism after a second experiment is presented.

Although the results serve as a clear replication of De Jong et al. (1999), the implications of these results may be limited by the use of a spatially oriented Stroop-type task. Work by Spieler et al. (2000) suggests that attentional tasks of spatial selection, like the De Jong et al. paradigm, qualitatively differ from attentional tasks of attribute selection, like standard Stroop color-naming experiments. Across four experiments, Spieler et al. (2000) contrasted the classic color-naming Stroop task with a local/global task and a flanker task. Although all three tasks are commonly used as proxies of attentional selection and control, the local/global and flanker tasks involve a more spatial selective attention mechanism, whereas the Stroop task involves selection of an integrated feature (i.e., word vs. color of the same stimulus). Based on analyses of RT distributions, Spieler et al. demonstrated that different selection mechanisms might be involved in spatial selection tasks compared with the standard Stroop color-naming task.

Work by Castel, Balota, Hutchison, Logan, and Yap (2007) and Pratte, Rouder, Morey, and Feng (2010) further demonstrate key differences among tasks of attentional control. Pratte et al. (2010) also contrasted spatial selection and feature integration by comparing the Stroop and Simon tasks. During the Simon task (Simon, 1969), participants make judgments to a stimulus using their left and right hands, and conflict occurs as a consequence of the indicated or spatial location of the stimulus. Typically, responses are fastest when they occur on the same side as the stimulus and are slowed when they occur on the opposite side. Pratte et al. reported that a key difference between Stroop and Simon tasks concerned the location of the largest interference effects in the RT distribution. In the Stroop task, the interference effect is at its largest in the slow tail of the distribution, whereas in Simon the interference effect is largest for the fastest trials. Castel et al. (2007) clarified that although this pattern holds for younger adults in the Simon task, older adults are less able to use controlled processing to reduce Simon interference at long response latencies. Clearly, the results from both Castel et al. and Pratte et al. converge with the results of Spieler et al. (2000) indicating that the nature of selection in spatial selection tasks such as the Simon task is qualitatively different from the selection involved in feature selection tasks, such as the color Stroop task.

In Experiment 2, we attempted to extend the De Jong et al. (1999) paradigm to a more standard color Stroop task. If the results seen in Experiment 1 are replicated, then one might argue that the results extend to more general attentional selection mechanisms. On the other hand, it is possible that the De Jong et al. results merely reflect a focusing of spatial attention and may not generalize to the standard color Stroop interference task, in which features are more integrated.

Experiment 2

Method

Participants. Fifty-two younger adults and 54 older adults took part in the study, with 26 younger adults and 27 older adults at each RSI. Participants were either given credit in partial fulfillment of course requirements or were paid $10/hr as payment for participation. Demographic information is summarized in Table 3. Similar to Experiment 1, older adults had more years of education, $t(63.700) = 4.51$, $p < .001$, and a higher vocabulary, $t(105) = 2.68$, $p = .009$, relative to younger adults.

Materials and design. Stimuli for the color Stroop task consisted of two color words (e.g., GREEN or BLUE) presented congruently (e.g., the word GREEN appearing in a green hue) or incongruently (e.g., the word GREEN appearing in a blue hue). Each word was presented equally in congruent and incongruent conditions, and all two-color permutations of red, green, blue, and yellow hues were equally represented. Like Experiment 1, participants were instructed to respond according to the color of the stimulus via the Q and P keys, which were counterbalanced across participants, along with color. The RSI was once again set at either 200 ms or 2,000 ms for each experimental session. As in Experiment 1, participants were given 1,000 self-paced trials in 100-trial blocks, with a short break between each block. Each session was preceded by a short block of practice, which consisted of 10 trials with trial-level and cumulative accuracy feedback.

Procedure. Procedure was executed as in Experiment 1. Again, following De Jong et al. (1999), the first 100 trials were considered practice and were therefore not considered in primary analyses.

Table 3
Means (SDs) Demographic Data for Experiment 2 As a Function of Age Group and RSI

	Younger		Older	
Measure	Short RSI	Long RSI	Short RSI	Long RSI
N (Female)	31 (13)	24 (12)	24 (20)	28 (18)
Age	19.3 (0.8)	19.3 (1.0)	77.8 (8.0)	77.7 (6.7)
Years of education	13.3 (1.2)	13.1 (1.0)	14.6 (2.4)	15.8 (3.5)
Shipley vocabulary age	19.0 (0.8)	18.5 (1.0)	19.2 (1.1)	19.4 (1.2)

Note. RSI = response to stimulus interval.

Results

As in Experiment 1, results are presented after testing for unequal variances between groups using Mauchly's test of sphericity for analyses of variance. When necessary, lower-bound corrections were used for *F* tests. An alpha of .05 was set to indicate significance. Mean response latencies, accuracies, and standardized response latencies as a function of condition are displayed in Table 4.

Outliers. As in Experiment 1, outliers were identified as trials faster than 200 ms or slower than 3,500 ms. Trials greater than three standard deviations ($z > \pm 3$) from an individual participant's mean were designated outliers. Outliers constituted approximately 2.1% of all trials and were dropped from analyses.

As in Experiment 1, each of the dependent measures were submitted to a 2 (age) × 2 (RSI) × 2 (congruency) mixed-factor ANOVA. Both age and RSI were between-participants factors.

RT analyses.

Response latencies. As shown in Table 4, the incongruent condition was slower than the congruent condition, $F(1, 103) = 84.78$, $p < .001$, $\eta_p^2 = .45$. Older adults were slower than younger adults, $F(1, 103) = 75.43$, $p < .001$, $\eta_p^2 = .42$. There was no main effect of RSI, $F < 1.5$, $p > .23$, $\eta_p^2 = .01$. Age again significantly interacted with congruency, $F(1, 103) = 48.93$, $p < .001$, $\eta_p^2 = .32$, such that older adults produced a larger interference effect compared with younger adults. Age also interacted with RSI condition, $F(1, 103) = 4.87$, $p = .045$, $\eta_p^2 = .045$, in which younger adults responded faster at the short RSI, whereas older adults had shorter response latencies at the long RSI. The Congruency × RSI interaction did not reach significance in the unstandardized RTs, $F < 1$, $\eta_p^2 = .008$. The three-way interaction was not reliable, $F < 1$, $\eta_p^2 = .002$.

Standardized response latencies. As shown in Table 4, participants responded more quickly to the congruent condition than the incongruent condition, $F(1, 103) = 130.82$, $p < .001$, $\eta_p^2 = .56$. Older adults were slower relative to younger adults, $F(1, 103) = 5.92$, $p = .017$, $\eta_p^2 = .05$. Participants also were faster in the short-RSI condition relative to the long RSI, $F(1, 103) = 21.33$, $p < .001$, $\eta_p^2 = .17$. Age and congruency significantly interacted, $F(1, 103) = 38.69$, $p < .001$, $\eta_p^2 = .27$, such that older adults produced a larger interference effect compared with younger adults. The RSI × Congruency interaction was also reliable, $F(1, 103) = 6.22$, $p = .014$, $\eta_p^2 = .06$, with a smaller interference effect at the short-RSI compared to the long-RSI condition, extending the De Jong et al. (1999) pattern to a color interference task. Finally, the RSI × Age interaction was significant, $F(1, 103) = 4.01$, $p = .048$, $\eta_p^2 = .04$, reflecting larger differences between the short- and the long-RSI conditions for the older adults relative to younger

Table 4
Mean Response Latencies for Experiment 2 As a Function of Age Group and RSI

Measure	Younger		Older	
	Short RSI	Long RSI	Short RSI	Long RSI
Reaction time				
Congruent RT	450	474	732	634
Incongruent RT	453	487	788	693
Interference effect RT	3	13	56	58
Standardized reaction time				
Congruent zRT	−.11	−.12	−.17	−.19
Incongruent zRT	−.07	−.04	−.01	−.06
Interference effect zRT	.04	.08	.17	.24
Accuracy				
Congruent	.95	.97	.99	.99
Incongruent	.94	.96	.98	.99
Interference effect	.01	.01	.01	.01

Note. RSI = response to stimulus interval; RT = reaction time.

adults, though both groups responded more quickly at the short RSI. Importantly, the three-way interaction among congruency, age, and RSI did not approach significance, $F < 1$, $\eta_p^2 < .01$.

Vincentile analyses.

Vincentiles. Once again, the Vincentiles were analyzed with a 2 (age group) × 2 (RSI) × 2 (congruency) × 10 (Vincentile bin) mixed-factor ANOVA. Vincentile bin interacted with congruency, $F(9, 927) = 55.94$, $p < .001$, $\eta_p^2 = .35$, demonstrating an increased interference effect at slower bins. Vincentile bin also interacted with age, $F(9, 927) = 13.32$, $p < .001$, $\eta_p^2 = .12$. These interactions were further qualified by two 3-way interactions. Specifically, Vincentile bin interacted with congruency and age, $F(9, 927) = 24.00$, $p < .001$, $\eta_p^2 = .19$, in which the interference effect for older adults became much larger at slow bins compared with the interference effect for younger adults. Vincentile bin also interacted with age and RSI, $F(9, 927) = 3.83$, $p < .001$, $\eta_p^2 = .04$, indicating that for older adults, the long RSI was much slower across Vincentile bin than the short RSI, whereas this relationship did not hold for younger adults. None of the remaining interactions approached significance, all Fs < 1, all ps > .52, η_p^2s < .08.

Standardized Vincentiles. Vincentile bin interacted with congruency condition, $F(9, 927) = 101.08$, $p < .001$, $\eta_p^2 = .50$, such that the magnitude of the interference effect increased across Vincentile bins. Vincentile bin also interacted with RSI, $F(9, 927) = 7.49$, $p < .001$, $\eta_p^2 = .07$. As in Experiment 1, these interactions were further clarified by two 3-way interactions. Vincentile bin interacted with congruency and age, $F(9, 927) = 28.58$, $p < .001$, $\eta_p^2 = .22$, such that the interference effect for older adults was larger at the slow Vincentile bins compared with younger adults. There was also an interaction of Vincentile bin, congruency, and RSI, $F(9, 927) = 3.61$, $p < .001$, $\eta_p^2 = .03$, such that the congruency effect at the long RSI increased more dramatically across Vincentile bin than at the short RSI. None of the remaining interactions approached significance, all Fs < 1.3, all ps > .25, η_p^2s < .01.

Accuracy. As shown in Table 4, the congruent condition was significantly more accurate than the incongruent condition, $F(1, 103) = 26.24$, $p < .001$. Older adults were more accurate than younger adults, $F(1, 103) = 59.47$, $p < .001$, $\eta_p^2 = .37$. There was neither a reliable main effect of RSI, nor any interactions among the independent variables, all Fs < 3.3, all ps > .07, all η_p^2s < .04. As in Experiment 1, it is important to note that accuracy was near ceiling for both groups in this experiment.

Discussion

Experiment 2 provided a replication and extension of the De Jong et al. (1999) spatial interference paradigm used in Experiment 1 to a more standard color Stroop design. The standardized response latencies revealed a reliable RSI × Congruency interaction indicating a smaller Stroop interference effect at the short RSI compared with the long RSI. Hence, according to the De Jong et al. framework, it appears that there is some contribution of loss of task set between trials to the observed Stroop color interference effect at long RSIs. This extension of the De Jong et al. results to a more typical color Stroop interference paradigm suggests that the original observations are not limited to spatial attention. Finally, as in Experiment 1, older adults produced a larger interference effect, compared with younger adults, and this effect increased across Vincentile bin. Importantly, however, both age groups reduced the interference effect to a similar degree in the short-RSI compared with the long-RSI conditions.

General Discussion

The present results indicate that one can reduce Stroop-type interference in spatial- and color-word interference tasks for both younger and older adults under short- relative to long-RSI conditions. This pattern replicates and extends the results of De Jong et al. (1999) within a broader scope of Stroop-type interference tasks. Importantly, across both experiments, younger and older adults were equal in their reduction of the Stroop-type interference effect at the short RSI compared with the long RSI. Moreover, in both experiments, older adults produced a disproportionately large interference effect, which did not interact with RSI. Hence, it appears that maintenance of the attentional set across time is not a major factor in producing the observed increased interference in older adults compared with younger adults, consistent with findings from other laboratories (De Jong, 2001; West & Baylis, 1998; West & Schwarb, 2006). There are a number of intriguing aspects of these results, which will be addressed in turn.

First, it is important to note that older adults produced a larger interference effect in the color Stroop interference task (Experiment 2), compared with the spatial interference task (Experiment 1). A direct comparison of the standardized interference effect across experiments is displayed in Figure 1. An ANOVA with Experiment as a factor indicated that age interacted with experiment and congruency, $F(1, 201) = 10.17$, $p = .002$, $\eta_p^2 = .05$, such that the interference effect was larger in the color than the spatial interference task for older adults, $t(101) = 4.67$, $p < .001$, whereas the difference in the interference effect across tasks was not reliable in the younger adults, $t(104) = 1.55$, $p = .125$. Thus, there appears to be increased difficulty for older adults in the color version of the interference task. Importantly, because these are

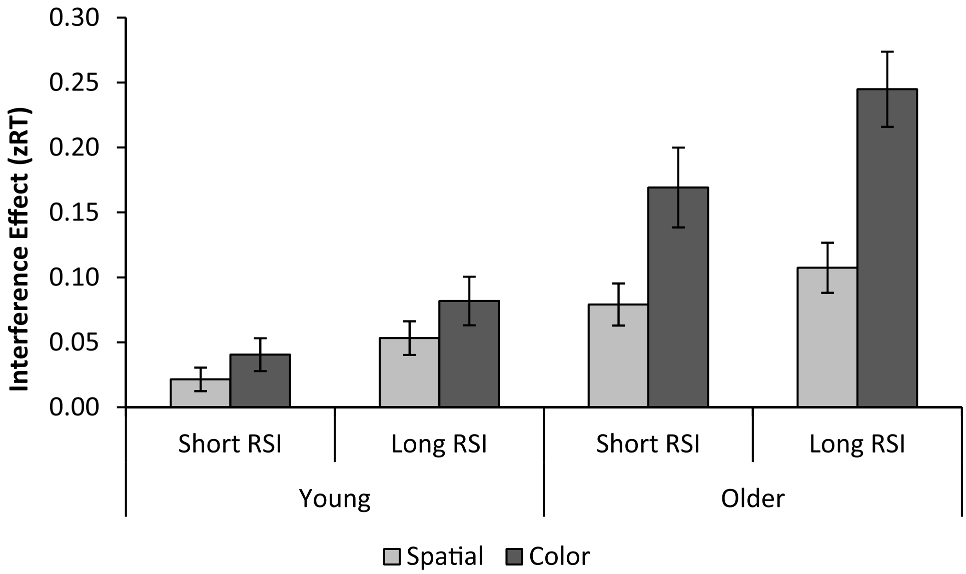

Figure 1. Standardized interference effect as a function of RSI and age in the spatial and color tasks.

standardized RTs, this difference cannot be attributed to age-related general slowing differences (see Faust et al., 1999). It appears that the tight coupling of the relevant color and irrelevant word features in the color task presents additional challenges to older adults, as suggested by Spieler et al. (2000).

In order to provide further insight into the age-related sensitivity to the color version of the interference task, we compared the normalized Vincentiles of Experiment 1 and Experiment 2. Figure 2 plots the mean standardized interference effect as a function of task, age, and Vincentile. As shown here, older adults produced a larger interference effect compared with younger adults. Importantly, this difference increased across Vincentiles and was strongest for the color version of the task compared with the spatial version. This was reflected by a reliable interaction among task, congruency, age, and Vincentile, $F(9, 1809) = 9.38$, $p < .001$, $\eta_p^2 = .05$. Hence, older adults appear to be particularly disrupted on the slower trials in the color-word interference task.

We conducted additional post hoc analyses to provide further evaluation for the conclusion regarding age equivalence in the reduction of the interference effect. Following Salthouse (1993), we constructed two hierarchical linear models for each task, using the 50th or 90th percentile standardized interference effect as the dependent variable. In the first step, we entered the 10th percentile standardized interference effect; in the second, RSI. The third step entered age, the fourth step included all two-way interactions, and the fifth step entered the three-way interaction. Through examination of the beta weights in the final step, we were able to examine the independent contributions of each variable in performance; namely, whether age accounts for variance in the interference effect at either the 50% bin or the 90% bin over and above fast trials, slow trials, and RSI, or whether it interacts with these variables. In the spatial task, though the first, third, and fourth steps (90th percentile only) contributed significant variance to the model, age was the only significant predictor in the final step for both the 50th, $\beta = .325$, $t = 2.88$, $p = .005$, and 90th percentile interference effect models, $\beta = .329$, $t = 2.61$, $p = .011$. In the color task, the first and third steps contributed significant variance for both the 50th and 90th percentile interference effect models. Age, however, was again a significant predictor in the final step for both the 50th, $\beta = .282$, $t = 3.21$, $p = .002$, and 90th percentile interference effect, $\beta = .426$, $t = 4.09$, $p < .001$. In addition, a significant contribution of the Age × 10th Percentile standardized interference effect emerged in the final step for both the 50th, $\beta = .489$, $t = 2.64$, $p = .010$, and 90th percentile models, $\beta = .579$, $t = 2.64$, $p = .010$. These effects suggest that age is indeed modulating the slower bins above and beyond the faster bins in the data. Indeed, this converges with the reliable Task × Age × Vincentile × Congruency interaction on the standardized Vincentiles presented earlier.

Taken together, the two experiments reported here were successful in replicating the critical finding of De Jong et al. (1999), such that at a shorter RSI, participants were able to reduce the interference effect. This implies that task-set degradation over time at least partly contributes to interference in Stroop-type tasks. Evidence from Experiment 2 further clarifies the role of task-set maintenance across time. When using a color Stroop design, the interference effect was reduced but not fully eliminated at the short RSI. It is possible that an exploration of even shorter RSIs may eliminate the interference effect in the color version, but we believe that it is more likely that the color version has characteristics that are particularly difficult for attentional selection. Specifically, as Spieler et al. (2000) demonstrated, the color version of the interference task has integrated color and word features (i.e., they are spatially integrated within the same stimulus) that produce a qualitatively different effect compared with other interference tasks (e.g., flanker, local/global processing, and Simon tasks), wherein the features are spatially segregated. Importantly, the effect of spatial integration versus segregation becomes even more dramatic in the slower portions of the RT distribution, precisely as Spieler et al. reported. Additionally, the difference in interference between the color and spatial versions of Stroop-type tasks corroborates work from other researchers (Castel et al., 2007; Pratte et

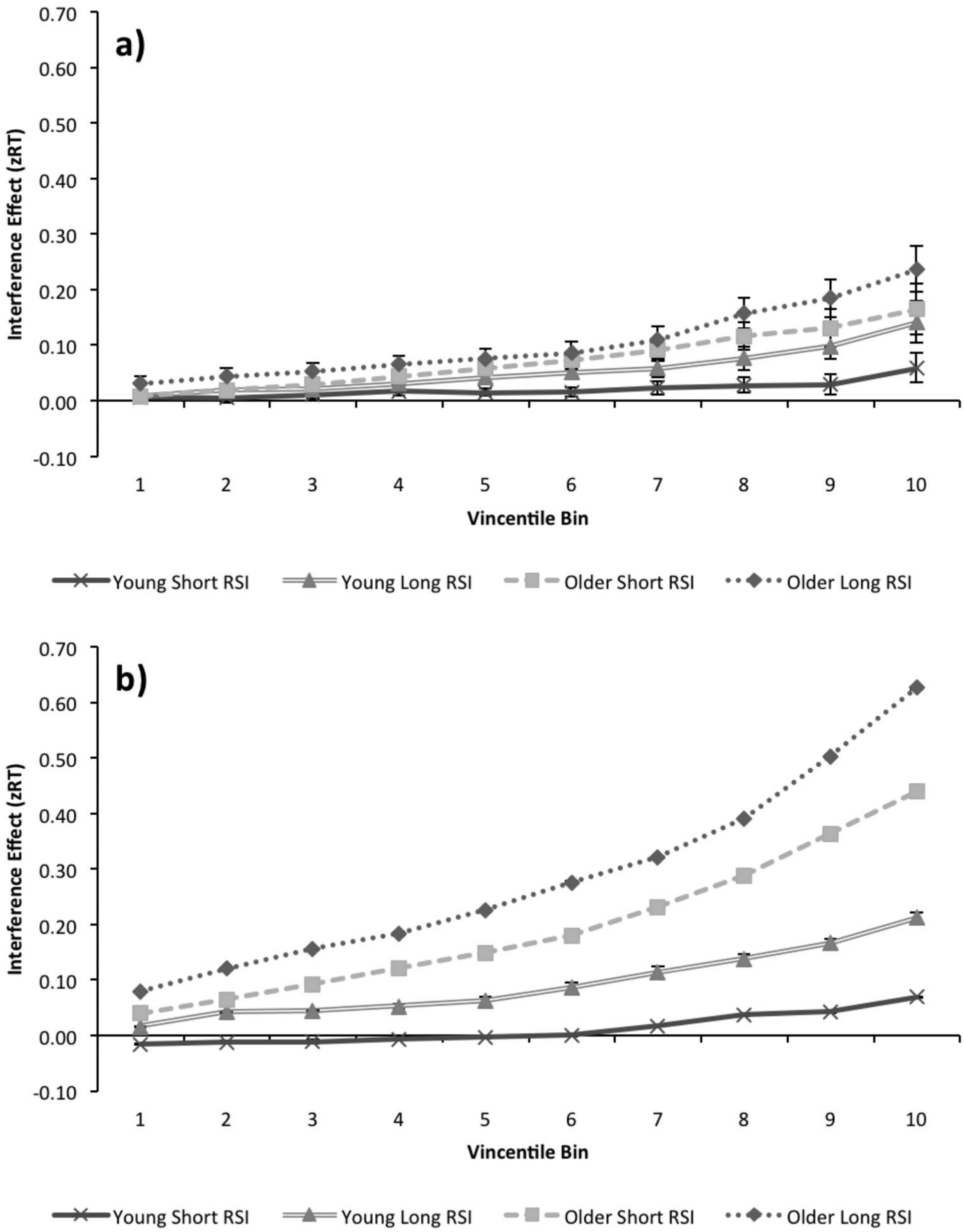

Figure 2. Standardized interference effect as a function of Vincentile (in 10% bins), age, and RSI. Displayed are (a) the spatial task and (b) the color task.

al., 2010). This may be at least partially due to increased prepotency of the word dimension in classic Stroop (Spieler et al., 1996, 2000), which may be more difficult to inhibit relative to a spatially based Stroop-type task (Pratte et al., 2010).

In addition to replicating and extending the original De Jong et al. (1999) study, a major goal of the present study was to examine age-related differences in the nature of attentional control. We considered two possibilities to account for performance decrements often seen in attentional selection tasks (see De Jong, 2001; Faust & Balota, 2007, for reviews). On the one hand, task sets may be of equal quality between age groups initially, but across time, the task set may degrade more quickly for older adults than for younger adults. On the other hand, older adults may simply have a less-robust task set irrespective of time, with similar declines across time for both groups. Following the logic of De Jong et al. (1999) and work by West (West & Baylis, 1998; West & Schwarb, 2006), the RSI manipulations in the present study allowed us to decouple these two possibilities. Specifically, both groups decreased the interference effect at the short RSI compared with the long RSI, replicating the De Jong et al. pattern suggesting an influence of task maintenance. Moreover, older adults produced a larger interference effect than younger adults at both the short and long RSIs. However, there was no hint of an interaction among age, RSI, and congruency in either experiment. Hence, we conclude that an age-related difference in the maintenance of task set is not the primary mechanism underlying the present age-related differences in Stroop-type interference.

It is important to note the utility of the RT distributional analyses in the current study. Specifically, the present results clearly indicated larger age-related and RSI differences in the slower Vincentiles. Although one must be cautious in attributing portions of the RT distribution to underlying mechanisms, there is accumulating evidence that, in some tasks, the slow tail is more related to attentional control mechanisms, as reflected by working-memory measures. In particular, Schmiedek, Oberauer, Wilhelm, Suß, and Wittmann (2007) and Tse, Balota, Yap, Duchek, and McCabe (2010) have used structural equation modeling to demonstrate a unique relation between working memory and the exponential estimate (τ), related to skewing, from an ex-Gaussian analyses of the RT distribution. Possibly, the present results provide further support for the notion that the slower trials reflect increasing demands on attentional selection mechanisms. However, converging evidence from modeling of these specific tasks would be necessary to provide compelling evidence for this hypothesis. At the very least, these data provide further evidence regarding the utility of RT distributional analyses for better understanding the locus of effects of targeted variables.

Finally, it is important to note a potential limitation of the current design. We closely followed the De Jong et al. (1999) design of using a button-press response, instead of a voice-key response often used in Stroop tasks, in which the interference effect is typically larger (MacLeod, 2005; Redding & Gerjets, 1977). These results, therefore, may not generalize to the more traditional Stroop color-naming task, in which responses are spoken aloud. Moreover, again following De Jong et al. and in an attempt to minimize complexity of the response, we only included two response options. There is clear evidence that the Stroop-type interference effect changes as a function of the number of response alternatives (see MacLeod, 1991, for a review). A more robust design might incorporate four-color alternatives to promote a more typical Stroop interference effect and multiple RSIs. Thus, as always, one needs to consider the limits of the experimental paradigm explored.

In summary, the present experiments suggest that a Stroop-type interference effect can indeed be modulated by the RSI between trials, replicating an important finding by De Jong et al. (1999). This suggests that task maintenance plays a role in Stroop-type interference effects. Importantly, although older adults produced a disproportionately larger interference effect, there was no evidence of an interaction with RSI. Thus, the disproportionate age-related interference observed in the present paradigm does not appear to be due to differences in the maintenance of task set, but rather due to age-related differences in the quality of the task set.

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