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Within-session Practice Eliminates Age Differences in Cognitive Control

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Abstract

Previous research employing short-term practice and long-term training have been successful in reducing cognitive control deficits in the elderly. The goal of this study was to examine the effect of practice within session on a demanding cognitive control task. Nineteen older adults and 16 young adults performed 720 trials of a cued version of the Stroop task, in which an instructional cue is presented before each individually presented Stroop stimulus. Statistical analyses focused on the most difficult color-naming condition in task-switching blocks. Overall, participants showed faster reaction times and decreased errors with practice, particularly on incongruent trials. Older adults showed a greater reduction in errors with practice than young adults. Moreover, older adults, but not young adults, showed a reduction in errors and reaction times with practice on incongruent trials. Findings further suggest that practice reduces age-related differences in cognitive control. Improvements in cognitive control functioning has implications for treating functional deficits in older adults.

Keywords

Aging; Cognitive Control; Practice; Stroop task

Age-related cognitive deficits are well documented and are particularly salient for “cognitive control” tasks (Eppinger, Kray, Mecklinger, & John, 2007; Jimura & Braver, 2010; Paxton, Barch, Racine, & Braver, 2008; West, 2004), a set of higher-order cognitive processes supported by pre-frontal and anterior cingulate cortices and critical to such functions as working memory, response inhibition, and conflict processing (MacDonald, Cohen, Stenger, & Carter, 2000a; Miller, 2000; Miller & Cohen, 2001). Older adults are particularly susceptible to cognitive control deficits when strong pre-potent response tendencies must be inhibited, such as during the color-naming condition of the Stroop task, which requires participants to override and inhibit a strong pre-potent tendency to read the word in favor of the less pre-potent response of naming the printed ink color. A large body of literature has repeatedly found that older adults respond significantly more slowly and commit more errors on incongruent “conflict” conditions of the Stroop compared to young adults.

Cognitive control is considered to be crucial for successful adaptation to our complex world (Miller, Freedman, & Wallis, 2002). Indeed, age-related deficits in cognitive control and other frontal lobe functions are associated not only with an increased risk for dementia but also with difficulties performing activities of daily living (Hart & Bean, 2011). Consequently, it is not surprising that identifying methods to decrease age differences in cognitive control and other cognitive functions is a growing area of research. One focus of this area of research has been on practice effects. There is increasing evidence that suggests substantial neurobiological and behavioral changes can occur across cognitive domains with repeated task experience (Kelly & Garavan, 2005). Significant practice-related decreases in error-rates and response time (RTs) have been observed in older adults on various cognitive tasks, including measures of perceptual discrimination (R. Ratcliff, Thapar, & McKoon, 2006), dual-task performance (Sit & Fisk, 1999), and task-switching (Kramer, Hahn, & Gopher, 1999), as well as on the Stroop task (Dulaney & Rogers, 1994; Davidson, Zacks, & Williams, 2003). For example, Davidson et al. (2003) found that while both young and older adults showed a reduction in the interference effect on a single-item version of the Stroop, the overall effect of practice was larger in older adults. There is some evidence that performance gains can be maintained long-term, as Kramer and colleagues (1999) noted that task-switching costs (i.e., longer mean RTs) not only became similar for young and older adults after a moderate amount of practice but also remained equivalent at 2-month follow up.

Recent research has employed a cued version of the Stroop paradigm (Cohen, Barch, Carter, & Servan-Schreiber, 1999). In the cued-Stroop task, participants receive an instructional cue before each trial indicating whether the task is to read the word or name the color. This variation of the Stroop elicits a higher degree of cognitive control than non-cued paradigms, as the requirement to maintain the instructional cue across a brief delay adds a working memory or context maintenance component, and the requirement to shift between word-reading and color-naming tasks introduces a task-switching component. Previous research has shown that, as expected, older adults perform more poorly on this task compared to young adults (West & Moore, 2005) but did not address practice effects. The current study addresses this issue. Based on previous studies (Davidson, Zacks, & Williams, 2003; Dulaney & Rogers, 1994), we expected older adults to demonstrate increased behavioral improvement relative to young adults as a function of practice during cued-Stroop task completion, as evidenced by reduced error rates and shorter response times on later trials. This effect is predicted to be greatest on incongruent “conflict” color-naming conditions.

Methods

Participants

Thirty-five participants were included in the study. Participants were recruited from the University of Florida and surrounding community through local advertisement as part of a larger study examining the impact of aging and depression on cognitive and brain functioning. All participants were right-handed native-English speakers. Potential participants were excluded from the study for the following reasons: Axis I psychopathology other than Major Depression or Dysthymic Disorder, dementia or other neurological disease, severe or acute medical illness, current antiepileptic use, color blindness, visual acuity difficulties that would interfere with task performance, motor deficits that would interfere with the use of the dominant hand, and a score of less than 30 on the Telephone Interview for Cognitive Status (TICS; Brandt, Spencer, & Folstein, 1988), which was used to screen for dementia. All participants provided written informed consent according to procedures established by the University of Florida Health Science Center Institutional Review Board.

Demographic characteristics of study participants are provided in Table 1. Young adults ($n = 16$) were on average 24.19 ($SD = 4.49$) years of age and older adults ($n = 19$) were on average 76.16 ($SD = 5.89$) years of age. Groups were matched on gender, $\chi^2(1) = 1.18, p = .28$, education, $t(33) = -0.03, p = .97$, Full Scale IQ as estimated by the North American Adult Reading Test (NAART; Blair & Spreen, 1989; Nelson, 1982), $t(33) = -1.74, p = 0.092$, and depressive symptoms as measured by the Beck Depression Inventory, Second Edition (BDI-II; Beck, 1996), $t(33) = 0.27, p = 0.420$, and the Geriatric Depression Scale (GDS; Yesavage, et al., 1983), $t(33) = -0.61, p = 0.549$. Older adults reported more state, $t(33) = -14.19, p < .0001$, but similar levels of trait anxiety, $t(33) = 0.51, p = .61$. No participants included in the current analyses met criteria for Major Depression or Dysthymia.

Measures and Procedure

Participants attended two testing sessions within a one-week period. During the first testing session, all participants received the mood, psychotic disorders, substance abuse, and anxiety modules of the Structured Clinical Interview for DSM-IV-TR Axis I Disorders, Research Version (First, Gibbon, Spitzer, & Williams, 2001) to determine the presence of major psychiatric disorder that might be an exclusionary criterion. The BDI-II, GDS, and State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), were administered to assess the presence and severity of symptoms of depression and anxiety.

During the second testing session participants performed the cued-Stroop task, described in detail below, while electroencephalography (EEG) data were acquired. The present analyses include only the behavioral performance on the cued-Stroop task.

Cued-Stroop task

The cued-Stroop task was run on a Dell Dimension computer using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002). At the beginning of each trial, participants were presented with an instructional cue (the word “color” or “word” presented visually in 38-point Arial font) for 750ms, followed after a one-second delay by the Stroop stimulus, which was presented for a maximum duration of 2500ms or until participant response. Participants were instructed to respond manually to the stimulus, as designated by the cue, as quickly and accurately as possible. They responded by pressing one of three color-coded response keys (v, b, n) using the index, middle, and ring fingers of their right hand. Color-to-key mapping was counterbalanced across subjects. Three colors and words were used (red, green, blue) presented in each of two congruency conditions (congruent, incongruent). Congruent stimuli consisted of one of the three color names presented in its own color. Incongruent stimuli consisted of a color name presented in one of the two remaining colors. To increase the degree of conflict and error rates, 60% of trials were congruent and 40% incongruent. All stimuli were presented over a black background.

The task was presented in 8 blocks of 90 trials each, for a total of 720 trials distributed equally across tasks (color-naming, word-reading). Two color-naming and two word-reading blocks were presented (single-task blocks). Four mixed blocks were presented, in which the tasks of color naming and word reading were randomly distributed across trials, thus introducing a task-switching component. Color-naming and word-reading tasks were distributed equally in each mixed block. The task instruction cue was also presented in single-task blocks in order to make the blocks equivalent in terms of timing and perceptual characteristics; however, the context maintenance requirement was reduced because the same task instruction was presented for each trial and participants were instructed prior to starting the block to either read the word or name the color on each trial. Block order was

pseudorandomized, with the constraint that blocks of the same type (i.e., single-task color, single-task word, or mixed) did not occur consecutively. Participants were randomly assigned one of eight possible randomization sequences.

Data Analysis

Statistical analyses were carried out with JMP 7.0.2 (SAS Institute Inc., Cary, NC, USA). Median correct-trial RT (Roger Ratcliff, 1993) and error rates excluding non-responses (Neter, Wasserman, & Kutner, 1985) were analyzed separately using mixed-model REML analyses of variance (ANOVAs) with age group (young, older) as a between-subjects predictor and with congruency (congruent, incongruent) and time (mixed block numbers 1 through 4) as within-subjects predictors. We specifically focused our analyses on the color-naming condition in the mixed (i.e., task switching) blocks as these trials placed the heaviest demands on cognitive control.

Results

RTs and error rates for the cued-Stroop task were not significantly correlated for young $rs(15) < .39$, $ps > .14$, or older adults, $rs(18) < .44$, $ps > .06$, regardless of congruency condition. These results suggest that a speed/accuracy trade-off was not a significant factor in task performance for either group.

Verification of Stroop Interference

As expected, a robust Stroop interference effect was found for both errors, $F(1, 231) = 145.25$, $p < .0001$, and RT's, $F(1, 223.1) = 539.62$, $p < .0001$ (Figure 1), with longer RT's and more errors committed in the incongruent than congruent condition. An age group $\times$ congruency interaction was observed for both errors, $F(1, 231) = 24.12$, $p < .0001$, and RT's, $F(1, 223.1) = 8.05$, $p < .005$, reflecting a greater interference effect in older adults than in young adults.

Practice Effects

Significant block number effects for both errors, $F(3, 231) = 3.23$, $p < .025$, and RT's, $F(3, 222.9) = 10.54$, $p < .0001$, reflected improved performance over time. The practice effect was greater for the more difficult incongruent trials compared to congruent trials, error $F(3, 231) = 4.02$, $p < .01$, RT $F(3, 222.9) = 2.66$, $p < .05$, and for older adults compared to young adults for errors, $F(3, 231) = 3.50$, $p < .05$, with a trend for improvement in RT's, $F(3, 222.9) = 2.30$, $p = .078$. A block number $\times$ age group $\times$ congruency interaction was found for both errors, $F(3, 231) = 4.72$, $p < .01$, and RT's, $F(3, 222.9) = 4.38$, $p < .01$. As shown in Figure 2, older adults, but not young adults, showed a reduction in errors and RT's with practice on the incongruent trials.

Discussion The goal of this study was to verify age differences in cognitive control and to determine whether older adults showed greater practice effects on the most difficult cognitive control tasks compared to young adults. Results were consistent with our hypotheses.

As predicted, older adults showed clear behavioral evidence of impaired cognitive control, reflected in greater Stroop interference effects for both errors and RT's. This is consistent with numerous studies that have documented age differences in cognitive control (Eppinger, et al., 2007; Jimura & Braver, 2010; Paxton, et al., 2008; West, 2004) and specifically on the Stroop task (West & Moore, 2005). Our task placed even greater demands on cognitive control than traditional Stroop paradigms. The instructional cue before each trial requires context maintenance, and the mixed-task blocks used in our analyses introduced a task-

switching component since the task (color naming and word reading) changed randomly across trials. There is evidence that both context maintenance and task switching are mediated by frontal brain regions (MacDonald, Cohen, Stenger, & Carter, 2000b; Madden, et al., 2010). As such, the results are consistent with the frontal deficits that are consistently observed in normal aging (Fjell & Walhovd, 2010).

Analysis of performance changes across blocks allowed us to examine the effect of within-session practice on task performance. We found overall improvements in performance with practice as assessed by both errors and RT's. As expected, practice effects were greater on the more difficult incongruent trials. Moreover, older adults showed a greater practice effect than younger adults. In fact, a three-way interaction revealed improved performance with practice in older adults for incongruent trials, while young adults did not show practice effects. These results are consistent with research documenting the benefits of practice on cognitive task performance (Davidson, et al., 2003; Dulaney & Rogers, 1994; Kelly & Garavan, 2005; Kramer, et al., 1999; R. Ratcliff, et al., 2006; Sit & Fisk, 1999) and with evidence that practice effects may be greater in older adults than in young adults (e.g., Davidson, et al., 2003). The disproportionate benefit of practice in older adults is likely due in part to older adults starting off at a lower level of performance and thus having more potential for change in performance with experience. However, it is also possible that older adults developed strategies for successful performance with experience on the task or that performance improved as neural networks involved in task performance became increasingly primed over time. We were not able to test those possibilities with the present data.

The ability of older adults to improve cognitive control performance with practice on the cued-Stroop task is important as it suggests a possible strategy for reducing age-related differences on other cognitive control tasks, and perhaps in other cognitive domains. Given the association of cognitive impairment in older adults with negative sequelae, including functional impairment (Hart & Bean, 2011), reducing these age differences has important practical consequences. This is especially true because there is evidence that performance gains may be maintained long-term (Hart & Bean, 2011). The finding of performance improvements within a testing session are complemented by research providing evidence that practice is also associated with performance improvements across repeated sessions. Indeed, cognitive training research has suggested that repeated experience across multiple sessions is associated with improvements in cognitive performance (Ball, et al., 2002; Tardif & Simard, 2011) and these changes are associated with improved functional outcomes (Willis, et al., 2006). Our results suggest that the benefits of cognitive training may begin within the first session, with further practice promoting more sustained changes in functioning.

A few limitations of our study should be noted. First, the sample size is relatively small and may limit our ability to detect significant effects. However, the repeated measures design increases our statistical power, and the high number of trials per person increases the reliability of measurement for our dependent variables. Moreover, we were able to detect significant effects even with a relatively small sample size. The high education level of participants in our sample could limit our ability to generalize our results. However, a number of studies suggest that higher educational attainment has a protective effect on cognitive aging (Albert, et al., 1995; Lee, Kawachi, Berkman, & Grodstein, 2003); thus, age-related differences in cognitive performance should be smaller in highly educated samples. It is likely that we would have similar findings in a less educated sample. Finally, the gender bias in our sample, which comprised primarily women, limits our ability to generalize results to older men. Examining potential sex differences in the impact of practice on cognitive performance is an important area of future research.

In conclusion, our findings are consistent with a growing body of literature demonstrating that practice reduces age-related differences in cognitive performance, particularly in cognitive control. Improvements in cognitive control functioning are particularly important given their association with functional deficits in older adults. Future research aimed at integrating the benefits of practice with other cognitive interventions, such as aerobic exercise, will help to translate these research findings into practical benefits for older adults.

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Figure 1.
Cued-Stroop error rates and reaction times for congruent and incongruent trials as a function of age group.

Figure 2.
Cued-Stroop error rates and reaction times in young and older adults across block number (i.e., practice) as a function of congruency.

Table 1

Mean (+standard deviation) demographic and neuropsychological test data for younger and older adults.

	Young Adults (<i>n</i> =16)		Older Adults (<i>n</i> = 19)	
	N	%	n	%
No. of Women	11	68.75	16	84.21
	Mean	SD	Mean	SD
Age (yrs) *	24.19	4.5	76.16	5.9
Educational Level (yrs)	15.81	2.2	15.79	2.8
NAART FSIQ (raw score)	110.35	7.3	114.70	7.5
TICS (raw score) *	36.50	2.0	34.05	1.9
BDI-II (raw score)	6.31	7.7	6.95	6.3
GDS (raw score)	5.75	5.6	4.58	5.8
STAI – State (raw score) *	28.19	9.7	63.68	4.6
STAI –Trait (raw score)	32.94	13.4	31.00	9.1

Note : NAART = North American Adult Reading Test; FSIQ = Full Scale Intelligence Quotient; TICS = Telephone Interview for Cognitive Status; GDS = Geriatric Depression Scale; BDI-II = Beck Depression Inventory; STAI = State Trait Anxiety Inventory; FSIQ = Full-scale IQ; TMT = Trailmaking Test

* Groups significantly different at $p < .001$.