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Distraction as a Determinant of Processing Speed

Cindy Lustig
University of Michigan

Lynn Hasher
University of Toronto and The Rotman Research Institute of Baycrest Centre

Simon T. Tonev
Duke University

Abstract

Processing speed is often described as a fundamental resource determining individual (e.g., I.Q.) and group (e.g., developmental) differences in cognition. However, most tests that measure speed present many items on a single page. Because many groups with slowed responding are also distractible, we compared younger and older adults on high- (i.e., standard) versus low-distraction versions of two classic speed tasks. Reducing distraction improved the performance of older adults while having little or no effect on younger adults, suggesting that the ability to limit attentional access to task-relevant information can affect performance on tests designed to measure processing speed.

Distraction and Processing Speed

The idea that "faster is better" is powerful in cars, computing, and cognitive psychology. Group differences, especially age differences, are often ascribed to the better-performing group's faster processing. We report two studies that assessed the contribution of an attentional-perceptual variable, visual distraction, in determining age differences in classic speed tasks.

Many standard speed tests use items that are individually simple, but fit many such items onto a single page, resulting in a cluttered, potentially distracting display. Many groups thought to have deficits in processing speed also have difficulties regulating attention, and thus might be especially vulnerable to distraction. These groups include children, older adults, poor readers, and young adults who score less well on intelligence tests (e.g., Casey, Giedd & Thomas, 2000; Dempster & Corkill, 1999, Engle, Tuholski, Laughlin, & Conway; 1999; Fry & Hale, 1996; Gernsbacher & Faust, 1991; Hasher & Zacks, 1988; Kail,1993; Salthouse 1996a, 1996b).

Address correspondence to: Cindy Lustig, Department of Psychology, University of Michigan, 530 Church Street, Ann Arbor, MI 48109-1043, Email: clustig@umich.edu.

Author Note

Cindy Lustig, University of Michigan , Lynn Hasher, University of Toronto and Rotman Research Institute at Baycrest Centre, Simon T. Tonev, Duke University.

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Portions of these data were previously presented at the 2000 Cognitive Aging Conference, Atlanta, GA. Those posters were later cited by Hasher, Tonev, Lustig, and Zacks (2001).

Correspondence should be addressed to Cindy Lustig, Psychology, University of Michigan, 530 Church Street, Ann Arbor, MI 48109-1043. Email: clustig@umich.edu or Lynn Hasher, Department of Psychology, University of Toronto, 100 St. George Street, Toronto, Ontario, Canada M5S 3G3. Email: hasher@psych.utoronto.ca

Our interest in distraction's potential role on tests of processing speed stems from a longstanding theoretical framework emphasizing inhibitory control mechanisms that, together with goals, determine what information enters the focus of attention (e.g., Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999) . Weakened inhibitory control allows distraction to impede the speeded performance of older adults in other settings, including well-practiced skills such as reading (e.g., Carlson, Hasher, Connelly, & Zacks, 1995; Duchek, Balota, & Thessing, 1998; Dywan & Murphy, 1996; Madden, 1983; Rabbitt, 1965).

To assess distraction's potential role on tests of processing speed, we computerized two standard speed tasks and administered them to younger and older adults in one of two formats. The "high-distraction" format resembled the standard, paper-and-pencil versions of these tasks, with many items presented at the same time. The "low-distraction" format reduced the opportunity for distraction by presenting items individually, so that only the currently relevant item was present on the screen.

Our hypothesis was simple: If vulnerability to distraction contributes to group differences in processing speed, then older adults should be faster on the "low- distraction" versions of processing tests than on the "high-distraction" versions that resemble the standard, but distraction should make little difference to young adults..

Experiment 1

The paper and pencil versions of the Letter Comparison and Pattern Comparison tasks (Salthouse & Babcock, 1991) are widely used as measures of processing speed (e.g., Hambrick & Oswald, 2005; Salthouse, 1993). Both meet our critieria for "high- distraction", with many items presented on a single page. We computerized the Letter Comparison task and presented it in either a high- or low-distraction format. Correlations between the computerized Letter Comparison tasks and the standard paper-and-pencil version of the Pattern Comparison task were examined to ensure that the high-distraction computerized task was representative of performance on standard measures of processing speed.

Method

Participants.—Strict exclusionary criteria helped ensure that any differences were the result of age and our distraction manipulation rather than extraneous problems with vision, health, or motor functioning. Participants' data were discarded if they (a) had health problems or were taking medications that might affect vision or motor functioning (e.g., attention deficit disorder, dyslexia, macular degeneration), b) made incorrect responses on more than one-third of the trials, or c) failed to meet criterion on either our vocabulary measure (a score of at least 13 out of 48 possible on the Extended Range Vocabulary Test (ERVT), Version 3, Educational Testing Service (ETS), 1976) or our dementia screen (a score less than 6 on the Short Blessed Test; Katzman et al., 1983). In both experiments, data from several other participants were discarded due to experimenter or computer error, or because the participant had completed one of the speed tasks in a previous session.[1]

In both studies, participants in each age group were randomly assigned to the low- or high-distraction condition (see Table 1 for demographics). As is common, older adults had more education and higher vocabulary scores than did young adults. Participants within an age group but in different distraction conditions did not differ in age, education, or vocabulary.

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[1] In both experiments, the critical Age X Distraction interaction and Distraction contrast for older adults remained statistically significant when all available data were included. Previous participation or computer error was the most common reason for exclusion, followed by medical conditions and failures to pass either the vocabulary or dementia screens. Vocabulary is used to screen out participants whose lower ability or education might influence results; the threshold (standardly used in our lab) is approximately 2 *SD* below the mean for either group.

Three hundred and twelve young adults and 239 older adults participated. After discarding data from participants who did not meet one or more of our exclusion criteria, the final sample had 146 young adults and 92 older adults in the low-, and 138 young adults and 99 older adults in the high-distraction condition.

Materials and Procedure.—In the paper-and-pencil version of the Letter Comparison Test, each of two pages has 21 pairs of letter strings with 3, 6, or 9 letters (e.g., RXL_____RXL) presented in a random order in a single column. Participants indicate whether the two strings are the same or different. Our computerized version consisted of 48 pairs of letter strings, with three, six, or nine letters per string. In the high-distraction condition, pairs were presented in two columns of 12 pairs each. Columns were separated by .6cm vertical space. A cursor directly under the first character in the string marked the participant's progress down the screen. The screen refreshed after the first 24 pairs. For participants in the low-distraction condition, each stimulus item was presented individually in the center of the screen.

All items were presented in black text on a white background. Participants adjusted the chair to sit at a distance most comfortable to them. The font (Turbo C graphics SMALL_FONT) had characters that up to .4cm wide and .5cm high, with .15 horizontal space between characters and a 1.2cm line separating the letter strings that made up a pair. Items in the high-distraction condition were separated by .6cm vertical space. Participants were to press one key (the "z" key, covered by a red sticker) if the strings were identical and a different key (the "/" key, covered by a blue sticker) if the strings were different. Reaction time (RT) was measured as the time between the cursor's movement to the stimulus (high-distraction) or the appearance of the stimulus (low-distraction) and the participant's keypress.

Participants first completed a health questionnaire and a practice test (30 single- digit pairs, e.g., 5_8) to familiarize them with the display and response mapping. Following practice, participants completed five additional trials using letter strings before beginning the 48 trials that constituted the Letter Comparison Test. Participants were instructed to respond as quickly as possible, but not so fast that they made mistakes.

Participants also completed a paper-and-pencil version of the Pattern Comparison Test (Salthouse & Babcock, 1991). Due to experimenter error, four young adults and one older adult were not given this task.

Results

Error and RT data from the Letter Comparison test were analyzed using 2 (Age: young, old) X 2 (Distraction: high, low) X 3 (Length: 3, 6, or 9 letters in a string) ANOVAs, followed by planned contrasts within each age group comparing the high- and low-distraction conditions. Within-subjects analyses used the Huyn-Feldt sphericity correction implemented in SPSS, resulting in non-integer degrees of freedom.

Error rates gradually increased as a function of string length, $F(1.97, 924.56) = 243.68$, $p < .0001$, but did not differ by group (all *p*s > .19; see Table 2). Within each string length, we computed the mean RT across correct trials for each participant first deleting outlying RTs that were more than 2.5 *SD* faster or slower than the participant's mean. Outlying trials made up 1.5% of the total, and all patterns in the data remain the same if these outlying RTs are included.

Mean RTs are shown in Figure 1. The three-way interaction was not significant, $F(1.30, 610.03) = 1.91$, $p = .16$, although Length interacted significantly with Age, $F(1.30, 610.03) = 86.93$, $p < .001$, and Distraction, $F(1.30, 610.03) = 12.77$, $p < .001$, and had an obvious main effect, $F(1.30, 610.03) = 2813.61$, $p < .0001$.

Of primary importance, the Age X Distraction interaction was reliable, $F(1, 471) = 8.58$, $p = .004$. Young adults were equally fast across conditions ($F(1, 471) = 1.13$, $p = .29$, $d = .15$), but older adults were significantly faster in the low-distraction condition than in the high-distraction condition, $F(1, 471) = 23.79$, $p = .0001$, $d = .58$. Similar patterns were found in separate analyses done at each string length, with the exception that at length 6, young adults showed a small benefit of reduced distraction $F(1, 471)$, = 4.15, $p = .04$, $d = .28$.

Performance on the paper-and-pencil Pattern Comparison speed task (Table 3) replicated standard findings of better performance by young adults (e.g., Salthouse, 1993;Salthouse, 1996a), $F(1,466) = 463.34$, $p < .0001$, and did not interact with group assignment (high- or low-distraction) for the Letter Comparison test, $F(1,466) = 2.55$, $p = .11$. Thus the Age X Distraction interaction found for the computerized Letter Comparison task is not an artifact of subject selection problems across the groups.

Correlations between Pattern Comparison and the different computerized versions of the Letter Comparison task helped to validate our manipulation. If distraction critically influences the speed of older adults, performance on the paper-and-pencil test should correlate more highly with the high- than the low-distraction version of the computerized test. A different speed test, Pattern Comparison, was chosen as the criterion task rather than a paper-and-pencil version of Letter Comparison to increase the probability that any correlations would reflect relations among speed tasks in general, rather than being idiosyncratic to Letter Comparison. For older adults, the high- distraction version of the Letter Comparison task tended to be a better predictor of performance on the paper-and-pencil task than was the low-distraction version (Table 3), although perhaps due to low power (.50) this medium-sized difference did not reach statistical significance ($q = 30$, Fisher's $Z = 1.76$). For young adults, the low- and high- distraction versions of the computerized Letter Comparison task were equally good predictors of performance on the paper-and-pencil Pattern Comparison test.

The relations between the computerized tasks and the paper-and-pencil test across age groups were compared in a post-hoc analysis using structural equation models implemented in LISREL. The first model served as a conceptual null hypothesis, constraining correlations between tasks to be equal for all groups, regardless of age or distraction condition. This model did not fit the data well, Chi-square ($df = 3$) = 7.30, $p = .06$. The second model constrained the between task correlations to be equal only for the two young adult groups and low distraction older adults. It fit the data well, Chi-square ($df = 2$) of 0.30. A Chi-Square difference test comparing these two models yielded a significant result ($df = 1$, Chi-Square difference = 7.00, $p < .01$). The contrast between these models supports the suggestion that correlations with the paper-and-pencil test were different (higher) for older adults tested with the high-distraction version of Letter Comparison than they were for young adults or older adults tested in low distraction.

Nearly identical results were found for a second paper-and-pencil task added later in data collection (Identical Pictures Test, ETS, 1976; completed by 63% of participants). (See Table 2.) Further, correlations between the two paper and pencil tasks ($r = .77$ for older adults, $r = .48$ for young adults) were in the same range as those between Letter Comparison and Pattern Comparison for older adults tested in high distraction, and for young adults overall. In other words, the variance shared between the high-distraction computerized task and the paper and pencil-and-pencil tasks was similar to that shared between the two paper-and-pencil tasks themselves. Letter Comparison string length did not systematically influence correlations with the paper-and-pencil tests.

Variability (standard deviation of RT) also showed an Age X Distraction interaction, $F(1,471) = 4.29$, $p < .05$; Figure 2. Results were generally similar to those on mean RT, with the following exceptions: Young adults also showed a significant effect of Distraction, $F(1,471) = 21.06$, $p < .0001$, and Length did not interact with Distraction, $F(1.69, 797.52) = 2.23$, $p = .12$. Variability did not show strong correlations with paper- and-pencil test performance for any group, all $r < .30$.

To examine whether effects on RT *per se* were greater than those on variability, each trial RT was transformed into a z-score based on the participant's mean RT and standard deviation of RTs for all correct trials across string lengths (Faust, Balota, Spieler, & Ferraro, 1999). Using the same ANOVA design as for the raw RTs, the two main effects of Length and Distraction were significant, as was their interaction, Length X Distraction ($F(1.74, 820.77) = 30.23$, $p < .0001$). The main effect of Age was not significant and did not enter interactions. At length 6, means were higher in high- (.14 young; .12 old) than low-distraction (.08 young, .05 old), but the reverse was true at length 9 (high distraction: .87 young, .90 old; low distraction: 1.02 young, 1.05 old).

These patterns are generally consistent with our hypothesis that distraction can lead to slowed and more variable performance, and that its effects are greater on older adults. In the following experiment, we ask whether the results found for this simple two-choice task would generalize to a more complex test.

Experiment 2

The Digit Symbol Substitution Test is included on the WAIS-R intelligence battery (Wechsler, 1981) as part of the fluid or performance intelligence quotient. This experiment computerized a simple reversal of this test (the Symbol Digit Substitution Test (SDST); Royer, Gilmore & Gruhn, 1981; Yerkes, 1921), and presented it under high- or low-distraction conditions. These tests present participants with a code table of the digits 1 to 9, with each digit paired with a symbol. For the SDST, each of the 90 test items consists of a symbol, to which participants respond with the corresponding digit. On the standard, paper-and-pencil version of the test, all test items are presented together on the same page.

Would the visual distraction effect found in the first experiment generalize to this more complex, 9-choice task used as a measure of fluid intelligence? To preview our results, the answer is "yes": While young adults were equally fast regardless of whether the test was given in the high- or low-distraction condition, older adults were much faster in the low-distraction version.

Method

Participants.—Sixty-four young adults and 59 older adults were randomly assigned to either the high-distraction or low-distraction conditions. Data from 14 young adults and nine older adults were excluded by our critieria. The final sample had 25 participants of each age group in each distraction condition.

Materials and Procedure.—Instructions and procedures for the health questionnaire, vocabulary, and dementia screens were identical to those for the first study. The primary measure used in this experiment was a computerized version of the Army Beta Symbol-Digit Substitution Task (SDST, Yerkes, 1921). For all participants, a code table of 9 symbols each matched with a single digit, appeared at the top of the screen (see Figure 3). There were seven practice items and 93 test items, each of which consisted of a single symbol above a blank box. Each symbol was up to $.6\text{cm}^2$ in area and centered in a 1.1cm^2 box. The blank box below the symbol was conjoined to the box containing the symbol and was also 1.1cm^2. The high-distraction version was presented in a format similar to the paper-and-pencil version, with all practice and test items simultaneously visible on the screen and arranged in a grid of 4 rows of 25 items each. For the low-distraction condition, each item was presented individually in the center of the screen.

Response was simplified by using a Gerbrands voicekey. The participant was to say aloud the digit that matched the symbol for the current trial, and the experimenter recorded (via key press) the response. We reduced the possibility that participants in the high-distraction condition would lose their place while moving their eyes and attention between the current test item and the answer key in three ways: (a) a question mark cursor to mark the current item; (b) for all previously completed items, a mask (#) filled in the blank box below the symbol; (c) a mask also obscured the three symbols following the current item. RT was measured from the cursor's appearance at the current item (high-distraction condition) or the appearance of the item (low-distraction condition) to the participant's voicekey response.

Results

Errors did not differ as a function of either Age or Distraction (*Fs* < 1), but there was a borderline Age X Distraction interaction, $F(1,96) = 3.94$, $p = .05$. (See Table 2). Older adults tended to make fewer errors in the low- than high-distraction condition, $F(1, 96) = 2.45$, $p = .12$, $d = .51$. Thus, any speed-accuracy tradeoffs would work against our prediction that reducing distraction would especially speed the performance of older adults.

Trimmed RTs were computed as before, deleting about 3% of correct trials. All patterns in the data remain the same if outlying RTs are included. The Age X Distraction interaction was reliable, $F(1,96) = 7.56$, $p = .007$. Young adults performed equally in the two distraction conditions ($F < 1$), but older adults were markedly slower in the high- distraction condition than in the low-distraction condition, $F(1, 96) = 21.97$, $p = .0001$, $d = 1.09$. (See Figure 3.)

The negative impact of distraction on older adults' performance was if anything larger for the SDST ($d = 1.09$) than for the Letter Comparison task ($d = .58$). The reasons for the larger distraction effect on SDST are not clear, but may be related to its greater demands on visual search, working memory, or reference memory (Gilmore, Royer, Gruhn, & Esson, 2004).

Variability showed similar patterns to mean RT, with a significant Age X Distraction interaction, $F(1,96) = 7.00$, $p < .01$. Young adults did not show a significant effct of Distraction, $F(1,96) = 1.01$, $p = .32$, but older adults did, $F(1,96) = 25.04$, $p < .001$. For the z-score transformed data, the Age X Distraction interaction was marginally significant , $F(1,96) = 3.53$, $p = .06$. Means were in a paradoxical direction, with older adults tested in high distraction showing the lowest and even slightly negative values (low distraction: 2.52×10^{-17} young, 5.25×10^{-17} old; high distraction: 6.52×10^{-17} young, -5.57×10^{-17} old). Comparison of Figures 1 and 2 suggests that for older adults, distraction increased variability even more than mean RT. These results vary somewhat from those of Experiment 1, but are generally consistent with the proposal that distraction is especially detrimental for older adults.

General Discussion

Does distraction influence tests of processing speed? The answer is clearly "Yes", at least for older adults. The presence of irrelevant information directly influenced estimates of their processing speed by over 15% in both experiments. Furthermore, for older adults the variance shared between the high-distraction computerized task and paper-and-pencil speed tasks approximated that shared between the paper-and-pencil tasks themselves. The most parsimonious explanation for this pattern of results is that our distraction manipulation tapped a factor that slows older adults on standard tests of processing speed.

What is this factor? We generated our hypotheses and interpret the data from the perspective of the inhibitory deficit framework, which proposes that many of the behavioral deficits exhibited by older adults (and other groups, Hasher & Zacks, 1988) stem from a reduced ability to keep irrelevant information from the focus of attention. However, these results might also have been predicted atheoretically, from a longstanding empirical literature demonstrating older adults' vulnerability to irrelevant information (e.g., Rabbitt, 1965). The slowdown due to irrelevant information could also be due to factors not directly linked to cognitive inhibition, such as acuity, eye movement control or visual crowding. Regardless, reducing irrelevant information clearly benefited the performance of older adults.

It is equally clear that substantial age differences remain even in single-item conditions, in these experiments and many others (Myerson, Hale, Wagstaff, Poon, & Smith, 1990). Further, the presence of irrelevant information also influenced variability in ways that were not entirely consistent across experiments. This brief report is only one step in understanding the factors that influence group differences on tests of processing speed (see discussions by Ecksenberger, 1973; Hertzog & Bleckley, 2001). We have experiments underway to better understand how information load (e.g., string length) may interact with distractibility to influence both mean RT and variability (see also Faust et al., 1999; Gilmore et al., 2004). Future studies including groups (e.g., children, people with low working memory spans) with intact sensory function but who are thought to have deficits in both inhibition and speed will be important for understanding the size and generality of the distraction effect on speed tests. It will also be important to establish the role that distraction may play in speed tests' ability to predict performance in other areas of cognition.

These broader issues will require more work to resolve, but the basic findings of this brief report are clear. Reducing distraction differentially improved older adults' performance on tests of processing speed that are widely used in both research literature and clinical settings. These results provide incentive for a better theoretical understanding of the link between inhibition and processing speed in groups commonly thought to show deficits in these abilities, and may prove useful in guiding the design of environments to maximize their performance.

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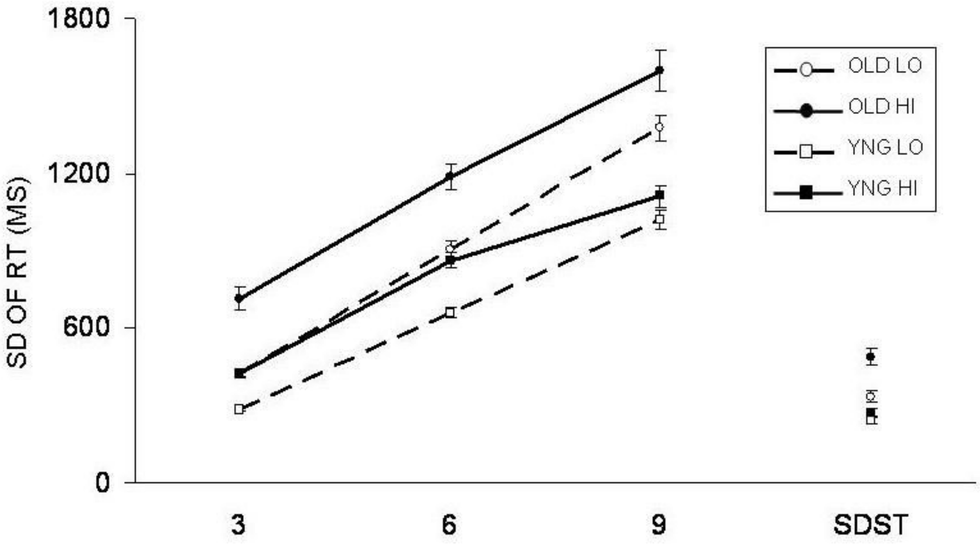

Figure 1.

Mean reaction times for each string length of the Letter Comparison task, and for the Symbol Digit Substitution Task.

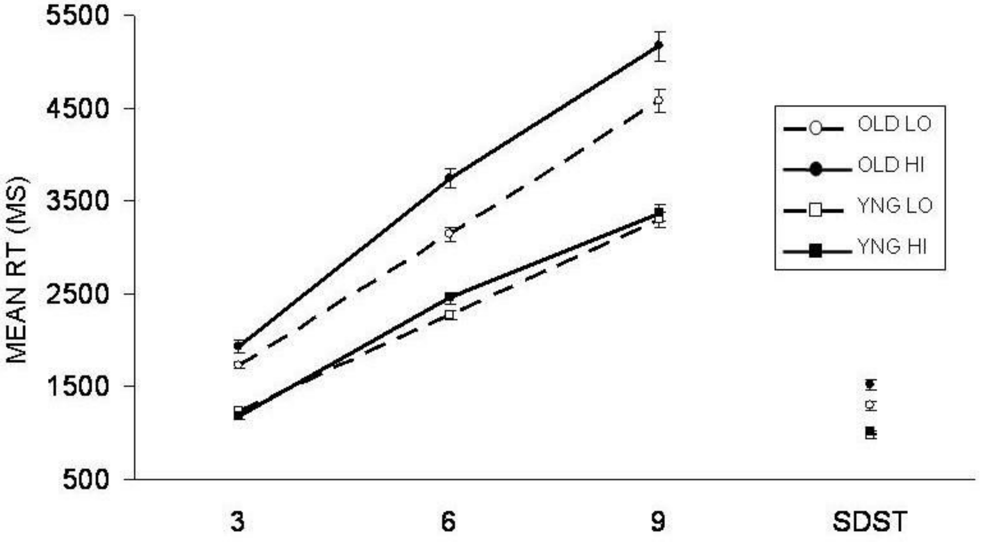

Figure 2.
Mean individual standard deviations for each string length of the Letter Comparison task, and for the Symbol Digit Substitution Task.

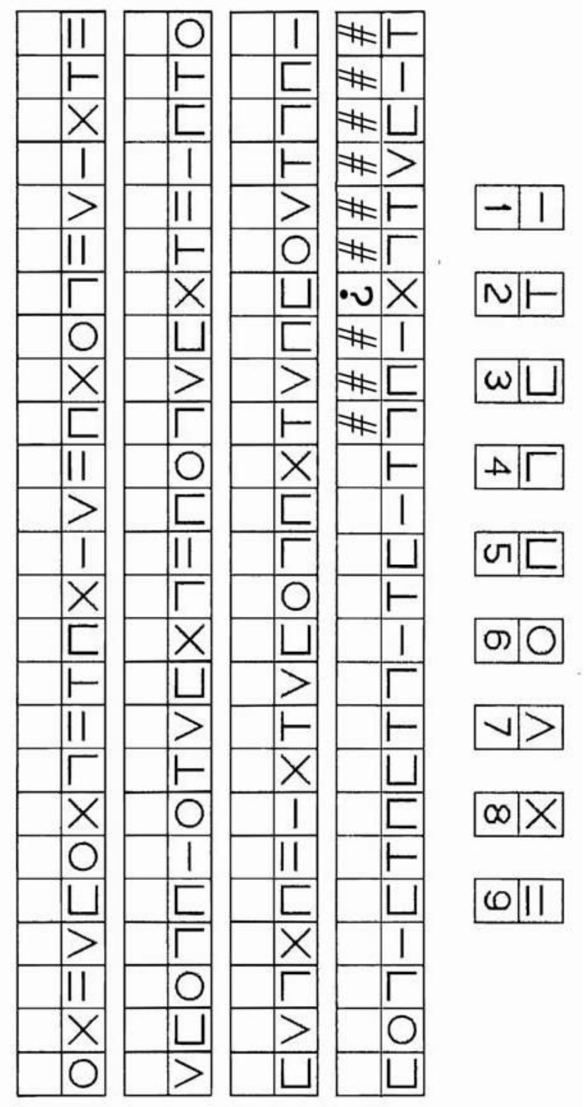

Figure 3.
Illustration of the high-distraction version of the Symbol Digit Substitution Task.

Table 1

Demographics by Age and Distraction Condition.

		Age		Education		Vocabulary	
Experiment 1: Letter Comparison							
Young		low-D	high-D	low-D	high-D	low-D	high-D
	M	19.20	18.90	13.00	12.80	25.70	26.20
	SD	1.50	1.20	1.20	1.10	6.60	6.40
Old							
	M	68.40	69.50	16.60	16.60	35.80	35.10
	SD	3.90	3.60	2.40	2.30	8.00	8.10
Experiment 2: Symbol-Digit Substitution							
Young		low-D	high-D	low-D	high-D	low-D	high-D
	M	18.40	19.00	12.40	12.60	23.40	25.40
	SD	0.60	1.30	0.60	0.80	5.50	7.20
Old							
	M	68.90	70.70	16.10	16.60	35.30	32.70
	SD	3.50	3.80	2.20	2.10	10.20	9.60

Table 2

Errors by Age, Distraction, and Length

Young			**Letter Comparison (Length)**			
	Low-D		3	6	9	SDST
		M	0.4	1.5	2.2	3.0
		SD	0.6	1.4	2.0	3.5
	High-D					
		M	0.5	1.4	2.2	2.0
		SD	0.8	1.5	1.9	2.5
Old						
	Low-D					
		M	0.3	1.5	2.0	1.6
		SD	0.7	1.5	1.6	2.0
	High-D					
		M	0.6	1.5	2.0	2.9
		SD	1.0	1.5	1.4	3.0

Table 3

Paper and Pencil Speed Tests: Means and Correlations with Low-Distraction and High-Distraction Computerized Letter Comparison.

		Pattern Comparison				**Identical Pictures**			
Young		M	SD	n	r	M	SD	n	r
	low-D	22.6	3.4	143	-0.35	38.7	6.7	86	-0.29
	high-D	21.5	3.3	137	-0.30	38.4	6.1	82	-0.27
Old									
	low-D	15.7	2.9	91	-0.37	24.1	6.1	57	-0.39
	high-D	15.5	2.9	99	-0.57	24.5	6.1	69	-0.60