Aging, Neuropsychology, and Cognition, 13:411–434, 2006

ISSN: 1382-5585/05 print; 1744-4128 online
DOI: 10.1080/13825580600574377

Psychology Press
Taylor & Francis Group

The Effect of Age on Rule-Based Category Learning

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ABSTRACT

An explicit, rule-based, category-learning task with abstract visual stimuli was administered to 50 healthy older adults and 48 younger adults. Accuracy and reaction time (RT) were examined for the effects of age, perceptual abilities, rule memory, rule complexity, stimulus novelty, and response competition. Older adults performed at equivalent levels to younger adults when applying a simple rule, but showed performance decrements when applying a more complex rule. The age effect interacted with both stimulus novelty and response competition, and was not eliminated after controlling for basic perceptual abilities and rule memory. The authors suggest that older adults show category learning deficits in conditions that require enhanced cognitive control. These results are discussed in reference to the growing body of literature regarding age-related change in executive abilities and frontal lobe function.

Growing evidence within the cognitive aging literature suggests that cognitive functions supported by frontal cortex show decrements with age (e.g., Anderson & Craik, 2000; Moscovitch & Winocur, 1995; West, 1996). In addition, studies have suggested that executive functions supported by frontal cortex may show relatively earlier decline than other areas of cognition (Braver et al., 2001; Prull et al., 2000; Raz, 2000). One area of cognition in which executive function may play an important role is explicit categorization. Prior research has shown that tasks requiring the use of explicit rules or strategies (including category learning) are sensitive to prefrontal damage (Burgess & Shallice, 1996; Milner & Petrides, 1984; Petrides, 1997; Shallice & Burgess, 1991a). As such, we might expect age-related deficits in explicit

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categorization if cognitive aging reflects, at least in part, a decline in prefrontal function. However, the effect of age on explicit category learning tasks remains relatively unexplored. The goal of the current study is to begin to examine age-related changes in explicit category learning using a novel but carefully controlled rule-based category learning task.

To provide relevant background, there are several hypotheses regarding the processes by which people categorize information. One dichotomous view of categorization is that individuals can use either rule or exemplar-based processing to categorize stimuli (for a general discussion, see Estes (1986) and Nosofsky (1988); for a discussion of rule-based category learning see Nosofsky et al. (1989, 1994)). Rule-based strategies require selective attention to critical attributes as defined by a rule and the integration of several pieces of information to determine category membership. Exemplar-based categorization has been hypothesized to rely largely on memory (or perhaps familiarity) for exemplars similar to those items that are to be categorized. Experimental conditions can be created in which these two categorization strategies compete for control of a given response (Erickson & Kruschke, 1998). Recent studies have provided empirical support for the hypothesis that individuals can use either rule- or exemplar-based processes to categorize stimuli (Allen & Brooks, 1991) (see also Smith et al. (1998) for evidence that rule-based processes are related to frontal lobe function).

Briefly, there is significant evidence that the frontal lobes are important for the use of rule-based strategies. In particular, evidence for a frontal contribution to rule use comes from the Wisconsin Card Sorting Task (WCST) (Milner, 1963). The WCST has long served as a measure of frontal function in the neuropsychological literature and requires the development of appropriate rules. Though these rules are never explicitly provided to participants, it is likely that the majority of individuals who perform this task could state the appropriate rules at the end of the experiment (e.g., “sort by shape”). Evidence from frontal lesion patients suggests that damage to the frontal cortex impairs performance on the WCST (e.g., Lombardi et al., 1999; Milner, 1964; Stuss et al., 2000) (but see Mountain & Snow (1993)), consistent with the hypothesis that the application of explicit rules during categorization is supported, at least in part, by the frontal cortex.

Results from cognitive aging studies using the WCST and similar paradigms also provide evidence of specific age-related impairment in rule use (e.g., Isingrini & Vazou, 1997; Parkin & Lawrence, 1994; Ridderinkhof et al., 2002) and further the link between age-related changes in rule use and prefrontal cortex function. In particular, Ridderinkhof et al. found that on a WCST-like task, older adults continued to demonstrate significant perseverative errors, even when provided with explicit cues (i.e., nonspecific = “shift categories”; specific = “shift to color”) (Ridderinkhof et al., 2002). These results suggest that older adults may demonstrate difficulties using rules appropriately, even when provided with explicit rule information.

Researchers have also examined the effects of age on non-WCST tasks that require the use of explicit rules. In particular, early work on concept acquisition (see Kausler (1991) for review) suggested that older adults are slower at acquiring appropriate concepts/rules and may fail to use appropriate concepts/rules under certain circumstances. Additional early work by Hess on prototype abstraction during categorization (e.g., Hess & Slaughter, 1986a, 1986b; Hess & Wallsten, 1987) suggested that older adults are able to use prototype information to categorize information similarly to younger adults. However, Hess' studies suggested that during category learning, only the younger adults learned additional explicit information in the form of specific exemplars and related concepts in addition to prototypical information. Thus, Hess' work suggests that older adults may demonstrate impairments in categorization due to impaired retention of specific exemplar details. Overall, these results suggest that age affects both rule acquisition and the quality of rule representations.

More recently, Chasseigne et al. (1997) used a task that required younger and older adults to learn probabilistic relationships between cues and events to make inferential judgments. Individuals performed similarly when the cue had a direct relationship with later events. However, during a task in which the cue and event were inversely related, older adults showed decreased performance compared to younger adults. The authors hypothesized that this age-related impairment might be due to the increased working memory requirements of "figuring out" the inverse relationship (i.e., developing an explicit rule). Therefore in an additional task, they explicitly told the participants about this inverse relationship. The provision of explicit rule information benefited the performance of the young-old participants (65–75 years old). However, the performance of the old-old participants (76–90 years old) was still impaired even with the provision of the rule. Thus, this study is consistent with the hypothesis that older adults may demonstrate difficulty using explicit rules in certain circumstances, and that working memory may be a factor that contributes to performance declines.

The studies reviewed above suggest that older adults demonstrate difficulties using explicit rules during cognitive tasks. In addition, there is also a large literature suggesting that older adults have difficulty with other tasks that rely heavily on frontal function (for a review see West (1996)). Similar to frontal patients, older adults have been found to show impairments in recall paradigms that require strategic encoding (Sanders et al., 1980; Witte et al., 1993) and/or strategic retrieval (Craik & McDowd, 1987; Rogers & Gilbert, 1997). In addition, age-related deficits have been noted on other tasks hypothesized to represent frontal lobe function, including the Tower of Hanoi task (Davis & Klebe, 2001; Head et al., 2002), Stroop (West & Baylis, 1998), prospective memory (Vogels et al., 2002), inhibition (Persad et al., 2002), and context representation (Braver et al., 2001). Specifically, Braver et al. (2001) found that context processing was impaired in healthy older adults during a continuous performance task. Age-related deficits in context representation were thought to lead to a more general deficit in cognitive control, which was theorized to negatively impact multiple domains including attention, inhibition, and working memory. In concert with this theory, our presentation of the concepts of working memory and cognitive control within this article reflect a set of interdependent mechanisms, rather than mutually exclusive phenomenon (see Braver and Barch (2002) for further discussion). In summary, the literature on cognitive aging provides strong evidence for age-related declines on cognitive tasks thought to depend on frontal lobe function, including tasks that may require older adults to develop and/or apply explicit rules.

The goal of the current study was to begin a quantitative analysis of age-related effects on explicit category learning. As reviewed earlier, there is a substantial history of work that suggests that older adults show difficulties in tasks requiring the use of rules or strategies. This study was designed to expand on previous research in three ways. First, in order to exclude the effects of age-related difficulties in rule acquisition, we used a rule-based category learning task that allowed us to train all participants on an explicitly provided "correct" rule. Second, this task allowed us to quantitatively examine the ability to use the "correct" rule, rather than relying on self-reported or assumed rule/strategy use. Third, we were interested in examining the specific nature of age differences in rule/strategy use. To do this, we included parameters in the design that allowed us to investigate the effects of episodic memory, cognitive control/working memory, and automatic perceptual bias on age differences in rule-based categorization.

In the current study we used a modified category-learning task developed by Noelle and Cottrell (2000). Noelle created a category set of simple abstract shapes that varied on two dimensions (i.e., circle size and line angle) and had four possible values within each dimension, for a total of 16 possible stimuli. During the training phase, participants were provided with a verbal rule with which to categorize the stimuli and underwent extensive practice with 7 of 16 possible items from the category set. Noelle found that after training, younger adults showed impairment in the use of rule-based strategies on critical test items. For these items, the similarity relationship of the item to those practiced during the training phase led to a categorization bias that conflicted with that required by the explicit rule. This conflict between exemplar-similarity and explicit rule use was hypothesized by Noelle to produce exemplar-based interference that was reflected in poorer performance. As Noelle demonstrated, interference trials exhibit maximal sensitivity to rule use because the rule must effectively compete with, and overcome the perceptual bias induced by practice-related perceptual familiarity.

The same study also suggested that participants were less able to utilize the explicit rule, as this rule became more complex (i.e., involved more stimulus attributes, conjunction vs. disjunction), leading to increased exemplar-based interference. It is possible that an increase in rule complexity places a greater demand on both maintenance and manipulation processes in working memory, leaving fewer cognitive resources available for the successful implementation of the appropriate rule. Noelle's results suggest that the exemplar-based interference task is effective for examining the ability to use rules during categorization and that manipulating rule complexity provides a potential tool with which to investigate the relationship between cognitive resources and categorization in older adults.

Noelle also examined younger adults' ability to use rules to categorize stimuli in a neutral condition, in which there were no perceptual biases to compete with rule-based strategy use. Subsequent individual difference analyses revealed that younger adults who were "good" rule-based strategy users in the neutral condition demonstrated better performance in the interference condition than did "poor" rule-users. Thus, his findings suggest that younger adults who are better able to use rules or strategies in a neutral condition also do better at applying those rules under interference conditions. Based on these findings, we would predict that if older adults are "poor" rule-users they should demonstrate greater levels of interference than do younger adults. In summary, the Noelle study provides evidence of the effectiveness of using a category-learning task to more objectively examine rule use during categorization.

Our primary goal was to assess the ability of older and younger adults to use explicit rules during a novel category-learning task. Based on the literature described earlier relating both categorization and age-related cognitive deficits to frontal lobe function we predicted that in comparison to younger adults, older adults would show evidence of impaired rule use as demonstrated by higher levels of interference (decreased accuracy and increased RTs). Additionally, we were interested in exploring several specific hypotheses as to why older adults might demonstrate impairments in rule use. One hypothesis is that decreased rule use in older adults is due to rule-forgetting. We examined potential rule-forgetting as a between-subjects factor. Participants in the prompt condition received intermittent rule prompts during the test phase, while participants in the no-prompt condition were required to maintain the appropriate rule on their own. If older adults' deficits in rule use are simply due to an increased tendency to forget the rule, then participants in the prompt condition should show less interference than no-prompt participants. A second hypothesis is that increased demands on cognitive resources affect rule use in older adults. To test this hypothesis, all participants performed the categorization task at two levels of rule complexity (high memory load vs. low memory load). Based on previous evidence that suggests an age-related decrement in the ability to effectively allocate executive control under conditions that require increased working memory load, we predicted that older adults would show greater impairment during the high rule complexity condition.

METHOD

Participants

Participants in the study were 57 younger adults and 61 older adults. Younger adults were recruited from the Washington University community via posted fliers and a departmental subject pool. Older adults were recruited via the Washington University Older Adult Subject Pool. All participants underwent a brief telephone screening prior to entry into the study. Exclusion criteria included neurological or psychiatric disorders; current psychotropic medication or recent illicit drug use; uncontrolled hypertension, diabetes, or thyroid disease; bypass surgery; history of alcoholism and/or substance abuse; and colorblindness, cataracts, or glaucoma. Participants reporting a score of 11 or higher on the Beck Depression Inventory (Beck et al., 1961) were also excluded from the study. Additionally, as a gross dementia screen, older adults were required to achieve a score of five or less on the Blessed Orientation-Memory-Concentration Test (BOMC) (Katzman et al., 1983). Our exclusion criteria for medical conditions and our use of a formal dementia screen constitute stricter guidelines for participant inclusion than used in a number of prior studies with older adults (i.e., Balota & Duchek, 1991; Burke et al., 1987; Hay & Jacoby, 1999; May et al., 1999; Sommers, 1999; West & Baylis, 1998). Informed consent was obtained in accordance with the institutional review board. All participants received a cash payment for their participation.

Eleven younger adults and 11 older adults were removed from the final analyses due to the endorsement of exclusion criteria or computer error. All further descriptions of participants were based on the 48 younger adults (15 male, 33 female) and 50 older adults (15 male, 35 female) who successfully completed the study and met all of the previously described screening criteria (see Table 1 for demographic details). Older adult participants were slightly more educated ($t(96) = 1.86$, $p = .066$) and had higher scores on the Beck Depression Inventory (BDI) ($t(96) = 3.25$, $p = .0016$), though both age groups were well within the non-depressed range.

Materials

Category Learning Task

All participants performed two conditions of the category-learning task developed by Noelle (Noelle & Cottrell, 2000): high rule-complexity and

TABLE 1. Subject Demographic Information

	Younger[a]			Older[b]		
	M	SD	Range	M	SD	Range
Age	20.5	2.0	18–27	74.6	4.1	66–82
Yrs. of education	13.4	1.6	12–20	15.2	2.4	12–20
BDI score	2.5	2.7	0–11	4.2	2.6	0–11

[a] $n = 48$
[b] $n = 50$

low rule-complexity. Each of these two conditions contained three parts that were administered in the following order; 1) perceptual match control condition, 2) training phase, and 3) test phase. In all conditions, participants viewed sequences of abstract shapes measuring ~ 2.5 in.^{2} that were presented one at a time within a 3 in.^{2} white box on a black computer display. Stimuli consisted of two sets of abstract visual shapes, each of which varied on two object dimensions. One set (Figure 1a) consisted of a centrally located star that varied in color (“DARK” blue to “LIGHT” blue) and a small red circle that varied in distance from the middle of the star (3 mm = “NEAR,” 6 mm, 9 mm, 12 mm = “FAR”). The other set (Figure 1b) consisted of a centrally located triangle that varied on the degree of rotation (0° = “UP,” 30°, 60°, 90° = “RIGHT”) and the density of the texture pattern inside (“LARGE” density grid to “SMALL” density grid). There were four possible values of each dimension and a total of 16 members in each stimuli set. Participants viewed one set of stimuli in the low complexity condition, and the other set in the high complexity condition. The sets used for high vs. low complexity were counterbalanced across participants. In the remaining descriptions below, the star set (Figure 1a) will be used as the example.

Perceptual Match

This phase was designed as a practice condition to ensure that participants could accurately distinguish the perceptual features of the stimuli prior to performing the category-learning task. Participants were shown members of a set and were told that they should refer to only the darkest color of star as “DARK,” only the lightest color of star should be “LIGHT,” only the closest circle as “NEAR” and only the furthest circle as “FAR.” They were instructed that prior to each block, they would see a prompt on the screen such as “DARK” and that their task was to decide whether each subsequent object was “DARK.” Participants pressed one button for a “match” and another button for a “non-match.” Participants had no time limit in which to respond and received auditory feedback regarding their accuracy performance. The next

FIGURE 1A. "Star" category set during high-complexity rule condition ("A" = DARK, LIGHT, or FAR; "B" = all others). Squares surround items in category "A" that were studied during training. Circles surround training items that belong to category "B." The item "X" in the hexagon is an interference item due to its classification in "A" according to the rule, but its perceptual similarity to items in category "B."

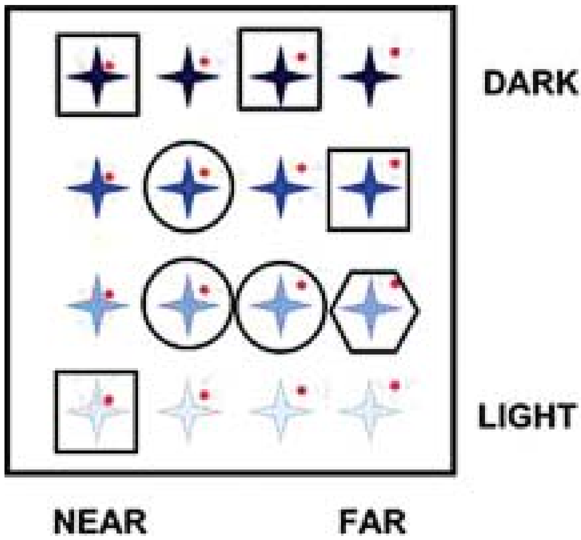
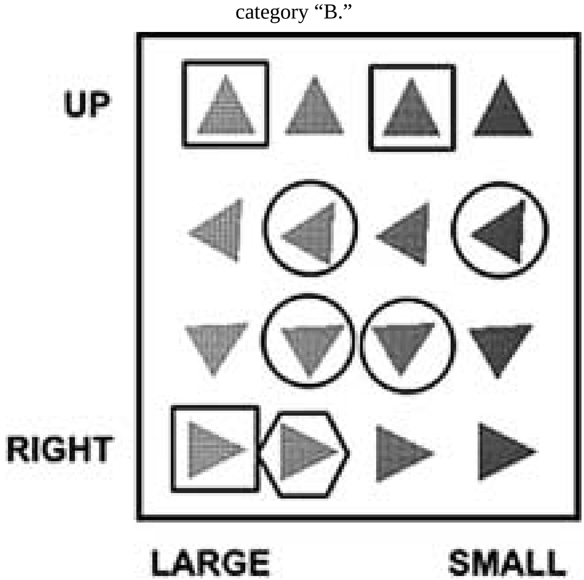


FIGURE 1B. "Triangle" category set during low-complexity rule condition ("A" = UP or RIGHT; "B" = all others). Squares surround items in category "A" that were studied during training. Circles indicate training items that belong to category "B." The item "X" in the hexagon is an interference item due to its classification in "A" according to the rule, but its perceptual similarity to items in category "B."



item appeared following a 500 ms inter-stimulus interval. This phase consisted of eight blocks of 16 trials, for a total of 128 trials. In 4 of the 8 blocks, subjects were asked to attend to only one attribute of one dimension (i.e., DARK?). We considered performance on these single attribute blocks to provide a (rough) estimate of perceptual identification and discrimination of test stimuli. We also administered four blocks in which participants were asked to attend to one attribute on each of the two dimensions (i.e., DARK & FAR?). We included these two-attribute trials to give participants practice attending to both dimensions of a stimulus. However, the two-attribute trials may involve some of the same cognitive processes required to perform the categorization task and therefore these blocks were not included in any analyses.

Training Phase

Participants were shown the same stimuli and verbal labels as seen during the perceptual match phase. Participants were instructed that their task would be to categorize subsequent stimuli into categories "A" and "B" according to a given rule. In the high-complexity condition the rule was a three-part conjunctive rule as follows: Any star that is DARK, regardless of circle distance is in category "A." Any star that is LIGHT, regardless of circle distance is in category "A." Any star with a FAR circle, regardless of star color is in category "A." Anything else is in category "B." Therefore, anything that is DARK, LIGHT, or FAR is in category "A"; everything else is in "B." The low-complexity condition rule was a two-part conjunctive rule as follows: Any star that is DARK, regardless of circle distance is in category "A." Any star with a FAR circle, regardless of color is in category "A." Anything else is in category "B." Therefore, anything that is DARK or FAR is in category "A"; everything else is in "B." Participants pressed one button for items in category "A" and another for items in category "B." Participants had unlimited time in which to respond and received auditory feedback regarding their accuracy performance. Participants received 36 blocks of 7 trials for a total of 216 trials. Each block of seven trials consisted of the same four items from category "A" and three items from category "B" with items presented in a new random order for each of the 36 blocks. As described in further detail below, the seven training items were selected to create a bias toward specific perceptual features of the stimulus category. This perceptual bias is essential in creating exemplar-based interference during the test condition.

Test Phase

Participants were told to continue using the same rule and response keys to categorize subsequent items. They were informed that they would no longer receive feedback about their performance, but they continued to have unlimited time in which to make their response. Each of the 16 possible category members was presented once during each of eight blocks in a new random order. Participants were randomly assigned to either a PROMPT or NO-PROMPT condition during the test phase. This manipulation was designed to examine the possibility that increased interference could be due to increased forgetting of the rule rather than an inability to successfully use the appropriate rule. During the NO-PROMPT condition, the procedure during the test phase was exactly that as described above. In the prompt condition, participants received a prompt that served as a reminder of the correct rule (i.e., "DARK, LIGHT or FAR") at the beginning of each task block for both the low and high complexity conditions.

Identification of "Interference" Items

We defined items as likely to show effects of interference if they belonged to one category according to the rule, but were perceptually similar to studied items from the other category. Specifically, we selected the four items predicted to demonstrate interference effects during the test condition in the following manner. An "interference score" was calculated for each item in the category. A particular item's score was determined by assigning number values to perceptually similar studied items, (i.e., nearby in feature space) that were in the same category vs. those that provided a perceptual bias toward the incorrect category. An illustration of this calculation is provided for the item enclosed in the hexagon in Figure 1a (hereafter referred to as item "X"). For example, if item "X" was viewed during the test phase, it would belong in category "A" according to the rule "DARK, LIGHT, or FAR = Category A; everything else = Category B". During training, participants studied one "A" item directly adjacent to "X" in feature space (enclosed in the square above). Thus, item "X" received three positive points for studying a directly proximal item in the same category. However, there were also two studied items perceptually similar to "X" (the two circles to the left of "X") but that biased responding towards the incorrect Category "B." Item "X" would receive three negative points for the studied "B" item directly adjacent, and two negative points for the studied "B" item one space away. After totaling three positive points and five negative points, the item "X" is assigned an interference score of −2. This negative score indicates a greater bias toward the incorrect category than toward the correct category. Interference scores were calculated in the same manner for all other items, and the four items demonstrating negative scores were classified as interference items. Three of the interference items were nonstudied (i.e., not viewed during training) and one item was studied (i.e., trained). Predicting that an item studied intensively during training will show effects of perceptual interference from nearby items may seem counterintuitive. However, in this case, the studied item (enclosed in the square above item "X") has no proximal studied items providing information towards the correct rule-based category, and has a distant studied item driving it in the incorrect direction. Therefore, it is possible that there is still enough perceptual bias from the incorrect studied item so as to exert a negative influence on the classification of the studied interference item.[1] Interference values were also calculated using several other coding schemes, including using diagonal relationships; however, in all schemes, the same items were predicted to show interference during the test condition.

Procedure

The order in which participants completed the high- and low-complexity conditions was counterbalanced. To determine whether participants were able to correctly report the appropriate rule, participants were asked to verbally report the categorization rule at the end of each rule-complexity condition. All tasks were run on an Apple Macintosh computer using Psyscope software for stimulus presentation and data collection (Cohen et al., 1993). Response reaction time and accuracy were collected using a button box designed specifically for the Psyscope software.

Data Analysis

Trials with incorrect responses were excluded from the analyses of the RT data. For the RT data, outliers were removed by excluding any trials in which the participant's RT was greater than two standard deviations (SD) above or below that participant's mean RT for the condition in which the trial occurred (Ratcliff, 1993). For each condition of interest, accuracy was calculated as the proportion correct across all trials. The distributions of the accuracy data were somewhat non-normal, violating the assumptions of our analyses. Thus, the accuracy data were normalized using an arcsine transformation (Neter et al., 1990). Data were subjected to repeated-measure analyses of variance (ANOVAs), as described below. Planned comparisons were used to follow-up on main effects and interactions predicted by specific hypotheses.

[1] We were concerned that the studied interference item could potentially bias the results. Thus, we also performed an additional set of analyses on the test session data after excluding all studied items (both interference and noninterference). Accuracy and RT data for nonstudied items was examined in a three-factor ANOVA with interference (interference vs. noninterference) and complexity (high-complexity vs. low-complexity) as within-subject effects and age (young vs. old) as a between-subject effect. For accuracy, the results were essentially the same as the analyses on the complete data set. For reaction time, the main effects of age, complexity, and interference continued to be significant. Although the expected age by interference interaction was not significant, the means were in the predicted direction. In addition, a significant age by complexity interaction was present (with older adults showing greater negative effects of increased complexity than young adults). The results of the nonstudied items analyses are extremely similar to the results from the full data set; thus we will present the analyses including both studied and nonstudied items.

RESULTS

Training

In order to confirm that older and younger adults demonstrated similar levels of learning during the training period, the accuracy and RT data during training were analyzed using a 2-factor ANOVA with age (young vs. old) as a between-subject factor, and complexity (high vs. low) as a within-subject factor. The accuracy ANOVA indicated no main effect of age, $F(1,96) = .46$, $p > .4$, or complexity, $F(1,96) = 1.48$, $p > .2$. There was no age by complexity interaction, $F(1,96) = .63$, $p > .4$. The RT ANOVA indicated an expected significant main effect of age, $F(1,96) = 97.79$, $p < .0001$, with older adults responding overall more slowly than younger adults. The main effect of complexity, $F(1,96) = 10.44$, $p = .002$, was also significant, with both groups of participants responding more slowly in the high rather than low complexity condition. There was no significant age by complexity interaction, $F(1,96) = .08$, $p > .8$. Thus, the results of the training data suggest that older and younger adults demonstrated equivalent levels of learning during the training period (see Table 2).

Test

In order to examine the effects of the prompt manipulation, the accuracy and RT data from the test phase were initially analyzed using a 5-factor ANOVA with age (young vs. old) and prompts (prompts vs. no prompts) as between-subject factors, and interference (interference vs. noninterference), study (studied vs. nonstudied), and rule complexity (high-complexity vs. low-complexity) as within-subject factors. The accuracy ANOVA revealed no main effect of prompts, $F(1, 94) = .24$, $p > .6$, or any interactions of prompts with age and/or any other factors (all p's $> .10$). The RT ANOVA revealed no main effect of prompts, $F(1, 94) = .64$, $p > .4$, and no further interaction between prompts and age, $F(1,94) = .01$, $p > .9$, or prompts with any of the other variables (all F's < 3.04). Additionally, the majority of older adults were able to state the appropriate rule at the end of the low- (96%) and

TABLE 2. Mean Accuracy and RT Performance During the Training Phase

	Accuracy		RT	
Condition	M	SD	M	SD
Young				
Low complexity	.951	.037	723	135
High complexity	.953	.066	802	185
Older				
Low complexity	.947	.054	1149	291
High complexity	.964	.026	1243	344

high-complexity (92%) conditions.[2] Taken together, these results suggest that older adults do not differentially forget the rule. Since we did not find any significant results with respect to the prompt manipulation, all of the subsequent analyses of the test phase data have been collapsed across the prompt manipulation for ease of presentation.

The accuracy and RT data from the test phase were analyzed using a 4-factor ANOVA with age (young vs. old) as a between-subject factor, and complexity (high vs. low), interference (interference vs. noninterference) and study (studied vs. nonstudied) as within-subject factors. The accuracy ANOVA revealed no main effect of age, $F(1,96) = .003$, $p > .9$, or study, $F(1,96) = 2.44$, $p > .12$, but significant main effects of complexity, $F(1,96) = 4.72$, $p = .03$, and interference, $F(1,96) = 76.49$, $p < .0001$. These main effects were modified by a significant interaction between complexity and interference, $F(1,96) = 17.29$, $p < .0001$. There was also a two-way interaction between study and interference, $F(1,96) = 10.52$, $p = .002$. Simple effects tests to follow up on the study by interference interaction indicated that participants were equally accurate for both studied (M = .979, SE = .003) and nonstudied (M = .977, SE = .002) noninterference items, $F(1,97) = 2.03$, $p > .16$. However, accuracy was worse for nonstudied (M = .920, SE = .009) than studied interference items (M = .938, SE = .006), $F(1,97) = 7.49$, $p = .007$.

Importantly, there was an additional significant interaction between complexity, study, and age, $F(1,96) = 6.32$, $p = .01$. To determine the source of the 3-way interaction in accuracy, we performed 2-way ANOVAs separately for the high- and low-complexity conditions, with age and interference as factors. The 2-way interaction of age and study was not significant for the low complexity condition, $F(1,96) = 1.38$, $p > .24$, but was significant for the high complexity condition, $F(1,96) = 5.03$, $p = .03$. Simple effect tests for the high-complexity condition revealed a significant effect of study in older adults (studied M = .961, SE = .006; nonstudied M = .935, SE = .010), $F(1,97) = 8.85$, $p = .004$, but not younger adults, (studied M = .955, SE = .006; nonstudied M = .955, SE = .010), $F(1,97) < 1$, $p > .8$. These

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[2] In the low-complexity condition, 2 of the 50 older adult participants did not report the correct rule—one in the prompt condition and one in the no-prompt condition. In the high-complexity condition, there were four "rule-forgetting" older adults, all in the no-prompt condition. To examine whether "rule-forgetters" showed performance declines relative to the other older adults, we performed unpaired *t*-tests on the accuracy data for each item type in the high complexity condition. There were no significant group differences in accuracy for nonstudied noninterference items, studied noninterference items, and studied interference items (all t's$(48) < 1$, p's $> .35$). Counter-intuitively, there was a trend for the "rule-forgetters" to show *less* interference on nonstudied interference items ($t(48) = 2.003$, $p = .051$). There were no significant group differences in reaction time for any of the four item types during the high complexity condition (all t's$(48) < 1.75$, p's $> .09$). Thus, although all four of the "rule-forgetting" older adults were in the no-prompt, high-complexity condition, their performance did not appear to be disproportionately impacted relative to the other older adults.

results reflect the fact that older adults' show a larger accuracy difference between studied and nonstudied items in the high-complexity condition in comparison to younger adults.

There was also a trend toward a three-way interaction between complexity, interference, and age ($F(1,96) = 2.80$, $p = .10$). However, we had a clear *a priori* hypothesis that older adults should demonstrate particular difficulties with interference items in the high-complexity condition. As such, we felt justified in further exploring whether the data provided any support for this hypothesis. We performed 2-way ANOVAs separately for the high- and low-complexity conditions, with age and interference as factors. The ANOVA for low complexity indicated a nonsignificant age by interference interaction, $F(1,97) = .18$, $p > .67$, while the high complexity ANOVA revealed a significant age by interference interaction, $F(1,97) = 5.15$, $p = .025$. Simple effect tests to follow up on the age by interference interaction in the high-complexity condition indicated that accuracy was decreased for interference items among both older (interference M = .913, SE = .012; noninterference M = .983, SE = .004), $F(1,96) = 107.47$, $p < .0001$, and younger adults (interference M = .933, SE = .008; noninterference M = .977, SE = .004), $F(1,96) = 48.72$, $p < .0001$. However, the accuracy difference between interference and noninterference items tended to be larger in older (partial $\eta^2 = .68$) than younger adults (partial $\eta^2 = .52$).

Taken in sum, these results reflect the fact that older adults' show a larger accuracy difference between interference and noninterference items than do younger adults, but only in the high-complexity condition. In summary, the accuracy results from the test phase suggest that older adults have decreased accuracy for both nonstudied and interference items in the high-complexity condition when compared with younger adults. Although older adults' accuracy performance on high-complexity, nonstudied interference items (M = .892, SE = .134) was lower than that of younger adults (M = .930, SE = .064), the full age by complexity by study by interference interaction was not significant, $F(1,96) = .19$, $p > .67$.

The RT ANOVA revealed a main effect of age, $F(1,96) = 119.41$, $p < .0001$, reflecting slower RT performance among older adults. The RT ANOVA also revealed main effects of complexity, $F(1,96) = 9.77$, $p = .002$, study, $F(1,96) = 4.64$, $p = .03$, and interference, $F(1,96) = 20.90$, $p < .0001$. These main effects were modified by a significant age by study interaction, $F(1,96) = 7.33$, $p = .008$, and a trend level age by interference interaction, $F(1,96) = 3.39$, $p = .07$. There were no further higher-order interactions (all Fs < 1.02). Simple effect tests to follow up on the age by study interaction indicated that older adults were slower for nonstudied (M = 1199, SE = 28) than studied items (M = 1158, SE = 28), $F(1,97) = 12.17$, *p* = .001, but that younger adults were equally fast for studied (M = 752, SE = 29) and nonstudied items (M = 748, SE = 29), $F(1,97) = .13$, $p > .72$). Simple effect tests to follow up on the age by interference interaction indicated that RTs were slower for interference items among both older (interference M = 1232, SE = 33; noninterference M = 1125, SE = 26), $F(1,97) = 20.43$, $p < .0001$, and younger adults (interference M = 773, SE = 34; noninterference M = 727, SE = 27), $F(1,97) = 3.03$, $p = .09$. However, the RT difference between interference and noninterference items tended to be larger in older than younger adults. To address the issue of age-related slowing, we repeated the above analyses of after converting the RT data to z-scores (Faust et al., 1999). In the results of the z-score analysis the age by study interaction remained significant, but the age by interference interaction was not significant (see Table 3).

Perceptual Match

Accuracy and RT data from the perceptual match condition were analyzed using unpaired *t*-tests. Statistical results revealed a significant main effect of age on accuracy (young M = .952, SD = .04; old M = .914, SD = .07), t(96) = 18.04, p < .0001, reflecting older adults' decreased accuracy in comparison to younger adults during the perceptual match condition. Similar to accuracy performance, RT results revealed a main effect of age (young M = 845, SD = 254; old M = 1598, SD = 601), t(96) = 133.52, p < .0001, consistent with older adults' typically slower performance in comparison to younger adults (see Table 4).

TABLE 3. Mean Accuracy and RT Performance during the Test Phase

	Low Complexity				High Complexity			
	Studied		Nonstudied		Studied		Nonstudied	
Condition	M	SD	M	SD	M	SD	M	SD
Accuracy								
Young								
Interference	.951	.072	.928	.082	.936	.067	.930	.064
Noninterference	.977	.026	.983	.023	.974	.035	.981	.031
Older								
Interference	.933	.119	.929	.149	.934	.070	.892	.134
Noninterference	.970	.043	.976	.061	.988	.025	.978	.046
RT								
Young								
Interference	747	269	710	166	811	208	823	216
Noninterference	691	253	699	207	760	185	758	164
Older								
Interference	1154	445	1184	431	1268	353	1323	381
Noninterference	1059	242	1098	255	1149	253	1192	270

TABLE 4. Correlation Between Dependent Variables During High-Complexity Test Performance and One-Attribute Perceptual Match Performance

	High Complexity			
Condition	I	NI	S	NS
Perceptual Match Accuracy				
Young	.064	–.052	.006	.023
Old	.022	.203	.118	.075
RT				
Young	.597*	.620*	.595*	.620*
Old	.431*	.436*	.472*	.404*

Note: I = interference items; NI = non-interference items; S = studied items; NS = nonstudied items.
*Correlation is significant at the $p < 0.01$ level (2-tailed).

Relationship Between Perceptual Match Performance and Age-Related Differences at Test

One potential interpretation of the current results is that the significant group differences observed in the high complexity condition during the test phase simply reflect age-related differences in perceptual abilities, rather than in rule use. To address this question, we used a very conservative approach in which we conducted a series of hierarchical regressions to determine whether age continued to account for significant variance in the effects of interference and study on performance (in conditions showing significant group differences) once perceptual ability was covaried out. We began by examining the age by interference interaction in accuracy for the high-complexity condition. In step one of the hierarchical regression, we entered noninterference performance and perceptual match performance as predictors. These predictors accounted for a significant amount of variance in interference performance ($R^2 = .262$, $F(2,95) = 16.839$, $p < .0001$), due to noninterference (ß = .512, t = 5.788, $p < .0001$) rather than perceptual match (ß = –.009, t = –.098, $p > .9$) performance. This result suggests that worse perceptual match performance is not associated with increased susceptibility to interference. In step two, we entered age (young = “0” vs. old = “1”) as an additional predictor, which accounted for a significant increase in variance in interference performance ($R^2_{change} = .03$, $F(1,94) = 4.01$, $p = .05$). Importantly, the partial correlation between age and interference (pr = –.20) did not significantly change when perceptual match accuracy was added to the model (pr = –.20).

Next we examined the age by study interaction in accuracy for the high-complexity condition. In step one, we entered studied performance and perceptual match performance as predictors. These predictors accounted for a significant amount of variance in nonstudied performance (R^2 = .240, *F*(2,95) = 15.04, *p* < .0001), again due to studied (ß = .489, *t* = 5.454, *p* < .0001) rather than perceptual match (ß = .019, *t* = .211, *p* > .8) performance. Again, this result suggests that worse perceptual match performance is not associated with increased susceptibility to novelty. In step two, we entered age as an additional predictor, which accounted for a nearly significant increase in variance in nonstudied performance (R^2_{change} = .03, *F*(1,94) = 3.68, *p* = .06). Similar to the interference results, the partial correlation between age and study (pr = –.19) did not significantly change when perceptual match accuracy was added to the model (pr = –.19). Overall, these data suggest that age is a significant predictor of both interference and nonstudied performance during the high complexity condition, even after accounting for perceptual abilities.

Reaction time (RT) during the perceptual match condition was significantly correlated with RT across all high-complexity conditions for both young and older adults (.43 < r < .62). In order to further explore the nature of these first-order correlations, we then examined the age by interference interaction in RT for the high-complexity condition. In step one of the hierarchical regression, we entered noninterference and perceptual match performance as predictors. These predictors accounted for a significant amount of variance in interference performance (R^2 = .86, *F*(2,95) = 302.26, *p* < .0001), again due to noninterference (ß = .89, *t* = 15.74, *p* < .0001) rather than perceptual match (ß = .05, *t* = .84, *p* > .40) performance. In step two, we entered age, which provided no additional predictive information above and beyond that accounted for by noninterference and perceptual match RT (R^2_{change} = .001, *F*(1,94) = .79, *p* > .38). We next examined the age by study interaction in RT for the high-complexity condition. In step one, we entered studied and perceptual match performance as predictors. These predictors accounted for a significant amount of variance in nonstudied performance (R^2 = .89, *F*(2,95) = 397.76, *p* < .0001), due to studied (ß = .91, *t* = 18.19, *p* < .0001) rather than perceptual match (ß = .05, *t* = .1.03, *p* > .3) performance. In step two, we entered age, which marginally accounted for an increase in variance in nonstudied performance (R^2_{change} = .003, *F*(1,94) = 2.29, *p* = .13). Overall, it is probable that the strong prediction of interference RT by noninterference performance (and nonstudied by studied) reflects global, age-related differences in processing speed.

DISCUSSION

The goal of this study was to use a category-learning task to explicitly examine rule-based categorization in older adults. The results support the hypothesis that as cognitive demands increase, older adults show performance declines in rule-based categorization. The age-related changes in performance that we found were relatively subtle in some conditions. However, the older adults' included in the current study were extremely high functioning due to the strict and conservative exclusion criteria that we used. Thus, we believe that the fact that these very high functioning older adults still showed evidence of categorization declines in theoretically predicted conditions suggests that a less-screened population of older adults would show even more severe impairments. Further, the data suggest that age-related declines in rule-based categorization are not solely due to increased forgetting of the rule. Rather, age-related categorization deficits were most apparent in conditions with strong working memory and/or processing resource demands (high-complexity rule condition), novel information (nonstudied items), and high levels of response competition (interference items). These results will be discussed in more detail later.

One might argue that a potential limitation of the current study was that accuracy performance was very good overall in both younger and older adults, and that some ceiling effects might have been present for younger adults in some conditions (e.g., the noninterference conditions). However, analyses of just the younger adult data suggested that accuracy performance was sensitive to the experimental manipulations of interference as well as the combined influence of study and interference. Thus, although accuracy levels were relatively high in younger adults, performance was still differentially affected by predicted experimental variables.

One of our initial hypotheses was that increased rule-forgetting might contribute to older adults' difficulties using rules during categorization. We argued that if older adults have deficits in rule use because of an increased tendency to forget the categorization rule, they should demonstrate enhanced performance when given external rule reminders in the prompt condition. In this study, older adults did not demonstrate any benefit of prompts on either accuracy or RT, nor were there any significant interactions between prompts and any of the other study variables. Additionally, the majority of older adults were able to report the appropriate rule at the end of the session. Together, these results suggest that in this task, age-related impairments in rule-based categorization are not due to forgetting of the rule (i.e., potentially due to impaired episodic memory).

Although older adults could correctly report the rule at the end of testing, they demonstrated performance declines during specific conditions of the category-learning task. As predicted, older adults demonstrated greater difficulties on interference than noninterference items. This finding suggests that under conditions of high-response competition (between rule-based and exemplar-based categorization decisions), older adults may have difficulty using a rule appropriately. Additionally, older adults demonstrated poorer performance on nonstudied than studied items, suggesting that they may have particular difficulty applying rule-based strategies to novel information. Further, these findings were observed more under conditions of high than low working memory load (high-complexity condition), particularly for the accuracy data. There are several possible frameworks for interpreting the data of the current study, a few of which are described below. Although we discuss these as different frameworks, there is clearly some overlap among the ideas, and the factors described below are not necessarily mutually exclusive.

Active Maintenance

The finding that older adults show some evidence for more impairment during the high-complexity than low-complexity condition suggests that one of the factors that influences effective rule use in older adults might be how much of a demand the rule itself places on cognitive resources (i.e., working memory load). As noted above, older adults do not appear to have difficulties with episodic memory for the rule. However, it is possible that this representation is not actively maintained in working memory in a manner that allows them to apply the rule quickly and accurately. An inability to have rule information easily accessible would make older adults slower and more error-prone, as we found in the study. This hypothesis is consistent with theories of age-related impairment in working memory (Craik et al., 1990; Salthouse, 1994) and/or contextual memory (Braver et al., 2001), which postulate that one factor that influences age-related cognitive deficits is an impairment in the representation of information relevant to the task goal. This hypothesis would also explain why older adults could still perform the task relatively well, although less accurately than younger adults. Even if the rule was not actively maintained in working memory, an available rule representation in episodic memory would allow older adults to retrieve the appropriate rule information as needed, though this method is likely less effective. One potential method for examining this hypothesis in future work would be to change the rule on a trial-by-trial basis. Under these conditions, active rule maintenance would be much more critical for performance, as the rapid changing of the rule would make it more difficult to develop a rule representation that could be stored in episodic memory. Under such conditions, we would predict that older adults would demonstrate much greater declines in explicit rule use than those found in the current study, if the maintenance of information in working memory is indeed a primary reason for age-related deficits in explicit rule use.

Transient Goal Neglect

Another possible framework for interpreting the observed results has been referred to as transient goal neglect in West's recent work (e.g., West, 2001; West et al., 2002). This hypothesis suggests that older adults experience only transient periods of active rule maintenance failures, rather than gross difficulties actively maintaining the appropriate rule. Periods in which the rule was not actively maintained could lead to situations of "goal neglect" and/or "intention lapse" in which rules or strategies are momentarily unavailable to bias performance appropriately (West, 2001). In the current study, if the appropriate rule was not immediately available during a "lapse," the participant might rely instead on the automatic or familiarity-based response, and incorrectly categorize items based on their perceptual similarity to previously studied items. Recent evidence suggests that this pattern of behavior may be particularly true in the case of older adults. Using a temporal analysis of behavior, West found that older adults had more frequent lapses of intention than did younger adults and that the older adults take longer to recover from a contextual lapse (West, 1999). Due to short block length we were not able to examine transient changes in performance that would be expected if older adults were to show evidence of goal neglect. However, future studies with longer blocks could examine fluctuations in older adult performance over time for results similar to those observed by West and colleagues.

Rule Application

An alternative hypothesis to the two described above is that older adults' are successful at actively maintaining the appropriate rule, but are unable to apply that rule to influence performance, which results in a disconnection between intended goal and observed behavior. Studies from both frontal lesion patients and child development lend evidence toward the hypothesis that the representation of rules and the ability to apply them may be independent phenomenon, with the latter being particularly dependent on the frontal cortex. For example, Shallice and Burgess have presented work suggesting that patients may show "strategy application" deficits following frontal damage, even when other executive abilities remain intact (Shallice & Burgess, 1991a, 1991b).

Interestingly, studies examining the development of rule and strategies in children have suggested that the first stage of learning a new rule consists of the ability to understand and remember rules, with the ability to successfully use that rule occurring later (e.g. Halford et al., 2002; Zelazo et al., 1996). It has been proposed that the age-related progression of neurobiological changes may follow the reverse course of those changes seen during development, particularly in frontal white matter (i.e., "retrogenesis," see Raz (2000) and Reisberg et al. (1999)). Applying this logic to rule use (thought to be dependent on frontal function), we might expect to see age-related decline in the ability to use rules initially, perhaps later followed by impairment in the ability to understand and recall rules. Our data is consistent with this hypothesis. The older adults could report what the rule was, but demonstrated difficulties applying the rule under conditions that had high cognitive control requirements. Future studies that more fully examine the individual cognitive components that contribute to rule and strategy use would prove useful in determining the underlying cause of age-related decline in rule use.

Perceptual Decline

Another hypothesis of interest was whether diminished perceptual abilities mediate older adults' difficulties with rule use. Contrary to this hypothesis, worse perceptual match performance was not associated with an increased susceptibility to the effects of either novelty (e.g., nonstudied items) or interference for accuracy or RT. Further, the covariate analyses revealed that that age continued to predict a significant amount of variance in accuracy performance after controlling for perceptual abilities. Thus, the fact that age predicted categorization accuracy over and above perceptual match performance suggests that basic perceptual abilities do not fully explain older adults' breakdown in rule-based category learning. However, the influences of perceptual abilities on age-related differences in rule use should be more closely examined in future studies.

In summary, we have demonstrated that although older adults are able to successfully recall appropriate rules, in certain conditions they are unable to successfully use those rules to guide behavior. Our results also suggest that the ability to actively maintain the appropriate rule influences the degree to which older adults are able to successfully apply rules or strategies. Working memory load, cognitive control, and transient "lapses of intention" are all potential factors that could influence older adults' performance on rule-based tasks. In future work, it will be important to design studies that help tease apart these different potential explanations. In addition, as noted in the introduction, performance on rule-based tasks may be dependent on intact frontal lobe function. Thus, an important next step will be determine the extent to which difficulties on rule-based tasks among older adults reflect changes in frontal lobe function with age.

ACKNOWLEDGMENTS

This study was supported by grants from the National Institute on Aging. The authors would like to thank S. Bongiolatti, E. Eisenberg, M. Fitzmeyer, B. Keys, and A. Satpute for assistance with data collection, D. Balota and S. Hale for helpful comments, and M. Storandt for providing us with access to the Washington University Older Adult Subject Pool and valuable statistical advice.

REFERENCES

Allen, S. W., & Brooks, L. R. (1991). Specializing the operation of an explicit rule. *Journal of Experimental Psychology: General, 120*, 3–19.

Anderson, N. D., & Craik, F. I. M. (2000). Memory in the aging brain. In Tulving, E., & Craik, F. I. M. (Eds.), *The Oxford Handbook of Memory* (pp. 411–425). London: Oxford University Press.

Balota, D. A., & Duchek, J. M. (1991). Semantic priming effects, lexical repetition effects, and contextual disambiguation effects in healthy aged individuals and individuals with senile dementia of the Alzheimer type. *Brain and Language, 40*, 181–201.

Beck, A. T., Ward, C. H., Mendelson, M., Mock, J., & Erbaugh, J. (1961). An inventory for measuring depression. *Archives of General Psychiatry, 4*, 561–571.

Braver, T. S., & Barch, D. M. (2002). A theory of cognitive control, aging cognition, and neuromodulation. *Neuroscience and Biobehavioral Reviews, 26*, 809–817.

Braver, T. S., Barch, D. M., Keys, B. A., Carter, C. S., Cohen, J. D., Kaye, J. A., Jaonwsky, J. S., Taylor, S. F., Yesavage, J. A., Mumenthaler, M. S., Jagust, W. J., & Reed, B. R. (2001). Context processing in older adults: Evidence for a theory relating cognitive control to neurobiology in healthy aging. *Journal of Experiment Psychology: General, 130*, 746–763.

Burgess, P. W., & Shallice, T. (1996). Response suppression, initiation and strategy use following frontal lobe lesions. *Neuropsychologia, 34,* 263–272.

Burke, D. M., White, H., & Diaz, D. L. (1987). Semantic priming in young and older adults: Evidence for age constancy in automatic and attentional processes. *Journal of Experimental Psychology: Human Perception and Performance, 13*, 79–88.

Chasseigne, G., Mullet, E., & Stewart, T. R. (1997). Aging and multiple cue probability learning: the case of inverse relationships. *Acta Psychologia (Amst), 97*, 235–252.

Cohen, J. D., MacWhinney, B., Flatt, M. R., & Provost, J. (1993). PsyScope: A new graphic interactive environment for designing psychology experiments. *Behavioral Research Methods, Instruments and Computers, 25*, 257–271.

Craik, F. I. M., & McDowd, J. M. (1987). Age differences in recall and recognition. *Journal of Experimental Psychology: Learning, Memory and Cognition, 13,* 474–479.

Craik, F. I. M., Morris, R. G., & Gick, M. (1990). Adult age differences in working memory. In Vallar, G. & Shallice, T. (Eds.), *Neuropsychological Impairments of Short-Term Memory* (pp. 247–267). Cambridge, UK: Cambridge University Press.

Davis, H. P., & Klebe, K. J. (2001). A longitudinal study of the performance of the elderly and young on the Tower of Hanoi puzzle and Rey recall. *Brain & Cognition, 46*, 95–99.

Erickson, M. A., & Kruschke, J. K. (1998). Rules and exemplars in category learning. *Journal of Experimental Psychology: General, 127*, 107–140.

Estes, W. K. (1986). Memory storage and retrieval processes in category learning. *Journal of Experimental Psychology: General, 115*, 155–174.

Faust, M. E., Balota, D. A., Spieler, D. H., & Ferraro, F. R. (1999). Individual differences in information-processing rate and amount: Implications for group differences in response latency. *Psychological Bulletin, 125*, 777–799.

Halford, G. S., Andrews, G., Dalton, C., Boag, C., & Zielinski, T. (2002). Young children's performance on the balance scale: the influence of relational complexity. *Journal of Experimental Child Psychology, 81*, 417–445.

Hay, J. F., & Jacoby, L. L. (1999). Separating habit and recollection in young and older adults: Effects of elaborative processing and distinctiveness. *Psychology and Aging, 14*, 122–143.

Head, D., Raz, N., Gunning-Dixon, F., Williamson, A., & Acker, J. D. (2002). Age-related differences in the course of cognitive skill acquisition: the role of regional cortical shrinkage and cognitive resources. *Psychology & Aging, 17,* 72–84.

Hess, T. M., & Slaughter, S. J. (1986a). Aging effects on prototype abstraction and concept identification. *Journal of Gerontology, 41,* 214–221.

Hess, T. M., & Slaughter, S. J. (1986b). Specific exemplar retention and prototype abstraction in young and old adults. *Psychology & Aging, 1*, 202–207.

Hess, T. M., & Wallsten, S. M. (1987). Adult age differences in the perception and learning of artistic style categories. *Psychology & Aging, 2,* 243–253.

Isingrini, M., & Vazou, F. (1997). Relation between fluid intelligence and frontal lobe functioning in older adults. *International Journal of Aging and Human Development, 45*, 99–109.

Katzman, R., Brown, T., Fuld, P., Peck, A., Schecter, R., & Schimmel, H. (1983). Validation of a short orientation-memory-concentration test of cognitive impairment. *American Journal of Psychiatry, 140*, 734–739.

Kausler, D. H. (1991). *Experimental Psychology, Cognition and Human Aging* (2nd Ed.). New York: Springer-Verlag.

Lombardi, W. J., Andreason, P. J., Sirocco, K. Y., Rio, D. E., Gross, R. E., Umhau, J. C., & Hommer, D. W. (1999). Wisconsin Card Sorting Test performance following head injury: dorsolateral fronto-striatal circuit activity predicts perseveration. *Journal of Clinical & Experimental Neuropsychology, 21*, 2–16.

May, C. P., Zacks, R. T., Hasher, L., & Multhaup, K. S. (1999). Inhibition in the processing of garden-path sentences. *Psychology and Aging, 14*, 304–313.

Milner, B. (1963). Effects of different brain lesions on card sorting: The role of the frontal lobes. *Archives of Neurology, 9*, 100–110.

Milner, B. (1964). Some effects of frontal lobectomy in man. In Warren, J. M. & Akert, K. (Eds.), *The Frontal Granular Cortex and Behavior*. New York: McGraw Hill.

Milner, B., & Petrides, M. (1984). Behavioural effects of frontal-lobe lesions in man. *Trends in Neurosciences, 7*, 403–407.

Moscovitch, M., & Winocur, G. (1995). Frontal lobes, memory and aging. *Annals of the New York Academy of Sciences*, 119–151.

Mountain, M. A., & Snow, W. G. (1993). Wisconsin Card Sorting Test as a measure of frontal pathology: A review. *The Clinical Neuropsychologist, 7*, 108–118.

Neter, J., Wasserman, W., & Kutner, M. H. (1990). *Applied Linear Statistical Models*. Boston, MA: Irwin Press.

Noelle, D. C., & Cottrell, G. W. (2000). *Individual Differences in Exemplar-based Interference During Instructed Category Learning*. Paper presented at the 22nd Annual Conference of the Cognitive Science Society.

Nosofsky, R. M. (1988). Exemplar-based accounts of relations between classification, recognition, and typicality. *Journal of Experimental Psychology: Learning, Memory & Cognition, 14*, 700–708.

Nosofsky, R. M., Clark, S. E., & Shin, H. J. (1989). Rules and exemplars in categorization, identification and recognition. *Journal of Experiment Psychology: Learning, Memory and Cognition, 15*, 282–304.

Nosofsky, R. M., Palmeri, T. J., & McKinley, S. C. (1994). Rule-plus-exception model of classification learning. *Psychological Review, 101*, 53–79.

Parkin, A. J., & Lawrence, A. (1994). A dissociation in the relation between memory tasks and frontal lobe tasks in the normal elderly. *Neuropsychologia, 32*, 1523–1532.

Persad, C. C., Abeles, N., Zacks, R. T., & Denburg, N. L. (2002). Inhibitory changes after age 60 and their relationship to measures of attention and memory. *Journals of Gerontology B: Psychological Sciences & Social Sciences, 57*, 223–232.

Petrides, M. (1997). Visuo-motor conditional associative learning after frontal and temporal lesions in the human brain. *Neuropsychologia, 35,* 989–997.

Prull, M. W., Gabrieli, J. D. E., & Bunge, S. A. (2000). Age-related changes in memory: A cognitive neuroscience perspective. In Craik, F. I. M., & Salthouse, T. A. (Eds.), *The Handbook of Aging and Cognition* (2nd ed., pp. 91–153). Mahwah, NJ: Lawrence Erlbaum Associates.

Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychology & Aging, 114*, 510–532.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In Craik, F. I. M., & Salthouse, T. A. (Eds.), *Hand-*

book of Aging and Cognition (2nd ed., pp. 1–90). Mahwah, NJ: Lawrence Erlbaum Associates.

Reisberg, B., Fransen, E. H., Hasan, S. M., Monteiro, I., Boksay, I., Souren, L. E. M., Kenowsky, S., Auer, S. R., Elahi, S. & Kluger, A. (1999). Retrogenesis: clinical, physiologic and pathologic mechanisms in brain aging, Alzheimer's and other dementing processes. *European Archives of Psychiatry & Clinical Neuroscience, 249*, 28–36.

Ridderinkhof, K. R., Span, M. M., & van der Molen, M. W. (2002). Perseverative behavior and adaptive control in older adults: performance monitoring, rule induction, and set shifting. *Brain & Cognition, 49*, 382–401.

Rogers, W. A., & Gilbert, D. K. (1997). Do performance strategies mediate age-related differences in associative learning? *Psychology & Aging, 12*(4), 620–633.

Salthouse, T. A. (1994). The aging of working memory. *Neuropsychology, 8*, 535–543.

Sanders, R. E., Murphy, M. D., Schmitt, F. A., & Walsh, K. K. (1980). Age differences in free recall rehearsal strategies. *Journal of Gerontology, 35*, 550–558.

Shallice, T., & Burgess, P. W. (1991a). Deficits in strategy application following frontal lobe damage in man. *Brain, 114*, 727–741.

Shallice, T., & Burgess, P. W. (1991b). Higher-order cognitive impairments and frontal lobe lesions in man. In Levin, H. S., Eisenberg, H. M. & Benton, A. L. (Eds.), *Frontal Lobe Function and Dysfunction* (pp. 125–138). New York: Oxford University Press.

Smith, E. E., Patalano, A. L., & Jonides, J. (1998). Alternative strategies of categorization. *Cognition, 65*, 167–196.

Stuss, D. L., Levine, B., Alexander, M. P., Hong, J., Palumbo, C., Hamer, L., Murphy, K. J., & Izukawa, D. (2000). Wisconsin Card Sorting Test performance in patients with focal frontal and posterior brain damage: Effects of lesion location and test structure on separable cognitive processes. *Neuropsychologia, 38*, 388–402.

Vogels, W. W., Dekker, M. R., Brouwer, W. H., & de Jong, R. (2002). Age-related changes in event-related prospective memory performance: a comparison of four prospective memory tasks. *Brain & Cognition, 49*, 341–362.

West, R. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin, 120*, 272–292.

West, R. (1999). Age differences in lapses of intention in the stroop task. *Journals of Gerontology B: Psychological Sciences & Social Sciences, 54*, 34–43.

West, R. (2001). The transient nature of executive control processes in younger and older adults. *European Journal of Cognitive Psychology, 13*, 91–105.

West, R., & Baylis, G. C. (1998). Effects of increased response dominance and contextual disintegration on the Stroop interference effect in older adults. *Psychology & Aging, 13*, 206–217.

West, R., Murphy, K. J., Armilio, M. L., Craik, F. I., & Stuss, D. L. (2002). Lapses of intention and performance variability reveal age-related increases in fluctuations of executive control. *Brain & Cognition, 49*, 402–419.

Witte, K. L., Freund, J. S., & Brown-Whistler, S. (1993). Adult age differences in free recall and category clustering. *Experimental Aging Research, 19*, 15–28.

Zelazo, D. P., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development, 11*, 37–63.