

Prior Experience Supports New Learning of Relations in Aging

Melanie L. Ostreicher,¹ Sandra N. Moses,^{1,2,3} R. Shayna Rosenbaum,^{1,4} and Jennifer D. Ryan^{1,5,6}

¹Rotman Research Institute, Baycrest, Toronto, Ontario, Canada.

²Hospital for Sick Children, Toronto, Ontario, Canada.

³Department of Medical Imaging, University of Toronto, Ontario, Canada.

⁴Department of Psychology, York University, Toronto, Ontario, Canada.

Departments of ⁵Psychology and ⁶Psychiatry, University of Toronto, Ontario, Canada.

This work examined whether semantically relevant schemas could facilitate learning in the transverse patterning (TP) task, which requires participants to learn the value of each stimulus in relation to the stimulus with which it is paired (e.g., A wins over B, B wins over C, C wins over A). Younger and older adults received the standard TP in isolation (alone condition), with additional sessions (practice condition), or with 2 TP sessions, which used familiar stimuli with known relations (e.g., rock–paper–scissors, semantic condition). Accuracy improved when training was provided within the context of a previously known relational framework, beyond the benefits obtained with extended practice with the task. When levels of education and vocabulary scores were considered as covariates, age-related deficits in accuracy were observed in the alone and practice conditions but were eliminated in the semantic condition. Extended practice and appealing to prior knowledge improved explicit awareness for the stimulus contingencies for each age-group. Thus, age-related deficits in learning relations among items may be remediated using existing relational information within semantic memory as an analog for new learning.

Key Words: Aging—Cognition—Memory—Relational binding.

OLDER adults often demonstrate difficulties in learning the relations among items (Naveh-Benjamin, 2000; Ryan, Leung, Turk-Browne, & Hasher, 2007). For instance, a series of studies conducted by Naveh-Benjamin and his colleagues (Naveh-Benjamin, Guez, Kilb, & Reedy, 2004; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003) illustrated that although older adults were similar to their younger counterparts in learning and remembering single items, they were impaired at learning and remembering the relations among the items, such as determining which combinations of faces and names were previously presented. Additional work has revealed an age-related deficit in relational learning using the transitive inference (TI) paradigm, in which participants were required to infer a linear hierarchical relationship among six stimuli (A>B>C>D>E>F) based on the presentation of overlapping premise pairs (AB, BC, CD, DE, EF) in which one stimulus had to be selected over the other (e.g., A wins over B; Ryan, Moses, & Villate, 2009). Older adults were less accurate relative to younger adults in correctly choosing the winning stimulus within the premise pairs, suggesting an age-related deficit in the acquisition of orderly relations (Ryan et al.). Similar age-related deficits have been observed on the transverse patterning (TP) task, in which individuals must learn the value of each stimulus in relation to the stimulus with which it is paired (A wins over B, B wins over C, C wins over A; Driscoll et al., 2003). In the TI task, responses could be based on the relative reward value of a single item (e.g., A is always rewarded, F is never rewarded), although this strategy leads to less accurate performance

(Moses, Villate, Binns, Davidson, & Ryan, 2008). By contrast, in the TP task, accurate responses can only be made by evaluating one item with respect to another item. That is, accurate responses must be made based on the evaluated relationship between the items and cannot be made based on the reward value of a single item. Thus, findings from the TP task in particular demonstrate that older adults may have difficulty integrating relations among stimuli. This is consistent with work that demonstrates that older adults have difficulty reordering and integrating pieces of knowledge when the information is discontinuous in presentation (Copeland & Radvansky, 2007) and is supported by a meta-analysis of 90 studies that revealed a disproportionate deficit in older adults for remembering the relations among items versus remembering single items (Old & Naveh-Benjamin, 2008).

However, there is an emerging suggestion that age-related relational learning deficits can be improved when prior knowledge is used as an analog for new learning. Previous studies have found that recognition performance is improved in older adults when the to-be-remembered items are semantically related (Hannon & Craik, 2001; Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003) or when participants can invoke semantically relevant, and preexperimentally known, items and associations (Castel, 2005, 2007; Hannon & Craik; Howard, 1983; Troyer, Hafliger, Cadieux, & Craik, 2006). For instance, Miller and Stine-Morrow (1998) demonstrated benefits for older readers for the maintenance and recall of verbal passages when passage titles were presented that clarified the meaning of the passage. Therefore, age-related

Table 1. Demographic Information (*M*s and *SD*s) for Younger and Older Adults for Each Experimental Condition

Variable	Condition		
	Alone	Semantic	Practice
Age			
Younger adults	23.50 (3.14)	22.38 (3.28)	19.50 (1.21)
Older adults	71.38 (7.87)	69.13 (7.18)	70.00 (6.87)
Years of education			
Younger adults	16.69 (2.63)	16.12 (1.86)	13.50 (1.37)
Older adults	15.41 (2.26)	15.50 (3.31)	16.09 (3.31)
Extended Range			
Vocabulary Test			
Younger adults	17.70 (8.48)	13.85 (10.10)	10.84 (5.78)
Older adults	30.55 (9.75)	26.86 (10.40)	25.22 (11.67)

learning deficits may be alleviated if relations are formed among objects for which there are existing associations in memory, or if the learning of novel relations is presented within the context of existing knowledge. Prior knowledge provides a schema or framework into which new information can be incorporated rapidly (Tse et al., 2007).

Learning of a new set of relations in the context of previously acquired knowledge may effectively allow for the analogical transfer of one set of relations to a new problem set, even in the absence of awareness for such transfer (Gross & Greene, 2007). However, other research has suggested that analogical transfer may be impaired, or at least slowed, in older adults (Clark, Gardner, Brown, & Howell, 1990; Salthouse, 1987). Therefore, questions remain regarding whether the learning of new relations can be supported in younger and older adults alike through the use of preexisting knowledge.

In the current work, we examined whether learning could be improved for both younger and older adults by training new relations in the context of existing knowledge and whether such training conferred advantages beyond that which could be gained with additional exposure or experience with the task demands. To achieve this, we used the TP task, for which older adults have previously demonstrated impairments relative to younger adults (Driscoll et al., 2003). Because incorporating new relations into existing knowledge can quickly establish new representations (Tse et al., 2007), we hypothesized that providing individuals with a TP task in which the stimuli consisted of known objects and relations would improve TP performance when new relations must be learned, surpassing the benefits observed through extended practice alone. Furthermore, we examined whether general practice and/or training on the use of existing knowledge can reduce the age-related deficits observed on TP.

To this end, older and younger adults were presented with one of the following three learning conditions. In the alone condition, participants were presented with the standard TP task in which novel relations must be learned among either novel or familiar objects. In the semantic condition, the standard TP task was preceded by two TP blocks, which used preexperimentally familiar stimuli with known relations (i.e.,

rock–paper–scissors [RPS] and playing cards; Moses, Ostreicher, Rosenbaum, & Ryan, 2008). Finally, in the practice condition, the standard TP task was preceded by two additional standard TP blocks in which new relations must be learned. The inclusion of the practice condition allowed us to determine whether any improvements in performance on the semantic condition were merely a result of extended training on the TP task. If the use of existing knowledge regarding relations can enhance new relational learning in younger and older adults, we should see improved performance for older (and younger) adults in the semantic condition compared with either the alone or practice conditions.

Furthermore, requiring older and younger adults to learn new relations among preexperimentally known objects, in addition to novel objects, may help to determine whether preexisting knowledge of the objects leads to more accurate learning of new relations among the objects. The possibility of improved accuracy and/or a reduction of age-related memory deficits would have implications for programs directed at cognitive rehabilitation by revealing the optimal conditions under which to acquire new relations.

METHODS

Participants

Forty-eight younger adults (15 men, 33 women; age range = 18–31 years) and 48 older adults (11 men, 37 women; age range = 60–84 years) with no known pathology participated in exchange for monetary compensation. Sixteen of the participants received additional testing on the same day, on separate experimental paradigms, either prior to or following the study reported here; however, receiving additional testing prior to the current study did not significantly alter accuracy compared with those participants who received additional testing following the current study ($F_s < 1$); and order of testing did not interact with performance for either stimulus condition (geometric shapes, abstract objects; $F_s < 1$). All participants gave informed written consent; the rights of the participants were protected, and the guidelines of the Toronto Academic Health Science Council were followed.

Using random assignment, one third of the participants in each age-group participated in one of three different learning conditions (alone, practice, semantic). Therefore, 16 older participants and 16 younger participants were assigned to each condition. There was no difference in age across the three learning conditions, $F(2, 90) = 1.92$, mean squared error (MSE) = 30.75, $p > .10$, $\eta^2 = .04$, and the interaction of learning condition by age-group was not significant ($F < 1$; see Table 1).

Younger and older adults did not differ on years of education ($F < 1$), and there was no difference in years of education across learning conditions, $F(2, 90) = 2.16$, $MSE = 6.53$, $p > .10$, $\eta^2 = .05$. However, there was a significant interaction of age-group and learning condition, $F(2, 90) = 5.27$,

$MSE = 6.53$, $p < .01$, $\eta^2 = .11$; younger participants in the practice condition had fewer years of education than the older participants (see Table 1).

Each participant completed a background information sheet and the Extended Range Vocabulary Test (ERVT; Educational Testing Service, 1976) prior to the commencement of the experiment. ERVT scores were not obtained for 4 younger participants (3 in the semantic condition, 1 in the alone condition). Older participants exhibited higher ERVT scores than younger participants, $F(1, 86) = 45.21$, $MSE = 90.97$, $p < .001$, $\eta^2 = .35$ (see Table 1), similar to previous reports (e.g., Rahhal, May, & Hasher, 2002; Ryan et al., 2007). ERVT scores also differed significantly across learning conditions, $F(2, 86) = 3.26$, $MSE = 90.97$, $p < .05$, $\eta^2 = .07$; participants in the alone condition had higher ERVT scores than participants in the semantic and practice conditions (see Table 1). Since a significant interaction was found between learning condition and education, as well as a significant main effect of learning condition on ERVT scores, analyses have been included which examine differences in performance on the TP task across conditions using education and ERVT scores as covariates.

Stimuli and Design

The stimuli and design of the various TP learning conditions were similar to the conditions used in the study by Moses and colleagues (2008). Three stimuli (A, B, C) were used in each TP session and were grouped into three completely overlapping pairs (A+B-, B+C-, C+A-). These overlapping pairs require learning about the relations between the stimuli as each stimulus is equally rewarded/unrewarded, in contrast to elemental or linear problems in which some stimuli are always/never rewarded and the problems can be solved without acquiring relations (for further discussion, see Driscoll, Howard, Prusky, Rudy, & Sutherland, 2005; Reed & Squire, 1999; Rickard & Grafman, 1998; Rickard, Verfaellie, & Grafman, 2006; Sutherland & Rudy, 1989). The alone condition consisted of two separate TP sessions, which used either familiar geometric shapes or novel abstract objects with arbitrary relations that were not known to the participants prior to the experiment. The order of the geometric shapes and abstract objects sessions was counterbalanced across participants. The geometric shapes and abstract objects TP sessions also served as the final two blocks in the semantic and the practice conditions, with the same counterbalancing procedures applied in each condition. The semantic condition consisted of four separate TP sessions defined by the stimuli used: (a) RPS (familiar stimuli with known relations: rock crushes scissors, scissors cut paper, paper covers rock), (b) playing cards (A,K,2; familiar stimuli with known relations in which the Ace may act as "high" or "low": Ace beats King, King beats 2, 2 beats the Ace), (c) geometric shapes, and (d) abstract objects. In the semantic condition, participants were always presented

with RPS first, followed by playing cards. The practice condition also consisted of four TP sessions: Two sessions used unique sets of abstract objects and two sessions used unique sets of geometric shapes. The additional geometric shapes and abstract objects sessions were presented first and second with order counterbalanced across participants. Therefore, geometric shapes and abstract objects TP sessions were presented for every participant; the only difference was in whether participants received no additional training prior to these sessions (alone), received previous TP training using familiar stimuli with known relations (semantic), or received previous TP training using (familiar and novel) stimuli with arbitrary relations (practice; see Figure 1).

Procedure

A pair of stimuli was presented on each trial using E-prime 1.1. Presentation of a stimulus on the right and left sides was counterbalanced across trials such that each stimulus appeared equally often on each side for each problem. Participants were required to select one stimulus over another by using keys "p" and "q" on a standard keyboard. A 19-inch monitor was used and was set at 1,024 × 768 pixel resolution and 24-bit high color. Participants were not informed of any relationships among the stimuli and were required to learn the correct response by trial and error. Correct responses were rewarded with a happy-face cartoon and the caption "Good Job!!!" and incorrect responses were followed by an angry-face cartoon and the caption "Wrong!!!"

Procedures were identical to those used in our previous TP study (Moses, Ostreicher et al., 2008) and consistent with our prior training procedures on other relational learning problems (e.g., Moses, Villate, & Ryan, 2006). Training for each experiment within each condition (alone, practice, semantic) involved five stages. In Stage 1, participants were presented with 10 trials of each of the problem pairs (10 × AB, 10 × BC, 10 × AC). Stage 2 consisted of five presentations of each of the pairs in consecutive order (5 × [AB, BC, AC]). Stage 3 was divided into three blocks and each block was composed of three presentations of each pair in consecutive order (3 × [AB, BC, AC]). Stage 4 was composed of nine presentations of each pair in consecutive order (9 × [AB, BC, AC]). Stage 5 included two blocks in which each problem was presented 18 times in pseudorandom order, for a total of 108 trials. If participants did not obtain an accuracy of 50% correct on any of the training blocks, the block was repeated. Following training, participants underwent a no-feedback test block of 12 trials (four of each pair).

Postexperimental questionnaires were administered to each participant to assess awareness of the relationships among the stimuli. Although the questionnaires also elicited responses regarding the participants' subjective strategies for learning the win-loss relationships, for the current purposes, awareness was determined by the ability to correctly report

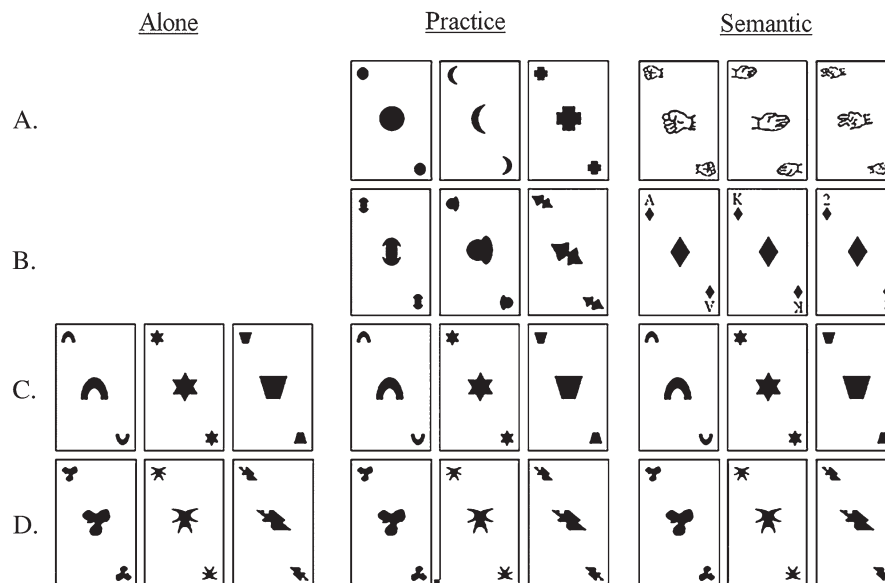


Figure 1. Stimuli used in the alone, practice, and semantic conditions. For participants in each condition, the final two experiments used geometric shapes (C) or abstract objects (D) as the stimuli, with the order counterbalanced across participants. For participants in the semantic condition, the geometric shapes and abstract objects experiments were preceded by variants of the transverse patterning (TP) task that used depictions of rock–paper–scissors (A) or playing cards (B). For participants in the practice condition, the geometric shapes and abstract objects experiments were preceded by additional experiments of geometric shapes (A) or abstract objects (B), the order of which was counterbalanced across participants. Participants in the alone condition received no training prior to performing TP using geometric shapes (C) and abstract objects (D). For all conditions, all possible pairings of two stimuli from the three-stimulus set were presented across trials.

the relations among the pairs of stimuli. Specifically, each of the three possible pairs of stimuli within each condition was presented (AB, BC, AC) and participants were asked to identify which stimulus in the pair would “win” over the other.

RESULTS

Mean accuracy for the two TP sessions that provided additional training in the practice (i.e., one session of geometric shapes and one session of abstract objects) and semantic (i.e., RPS and playing cards) conditions are presented in Table 2. Because the stimulus types were unique for the first two TP sessions of the semantic and practice conditions, separate repeated measures mixed-factor analyses of variance (ANOVAs) were conducted for accuracy for each condition. The ANOVAs consisted of the within-subjects factor of experimental stimulus type (for practice: geometric shapes, abstract objects; for semantic: RPS and playing cards) and one between-subjects factor of age-group (younger, older). *MSEs* and partial η^2 are noted. For the semantic condition, the main effect of age-group, stimulus type, and the interaction between age and stimulus type were each nonsignificant (all $F_s < 1$). For the practice condition, the main effect of stimulus type and the interaction between age-group and stimulus type were each nonsignificant ($F_s < 1$). The main effect of age-group was of marginal significance, $F(1, 30) = 2.87$, $MSE = 0.11$, $p = .10$, $\eta^2 = .09$.

In the following, we report findings for the subsequent geometric shapes and abstract objects sessions that were the same across all participant conditions (alone, practice,

semantic). The following findings report performance for the test blocks only; separate test blocks assessed TP performance when the geometric shapes versus the abstract objects were used as the stimuli. To assess TP performance, a repeated measures mixed-factor ANOVA was conducted for accuracy. The Huynh–Feldt correction was used to accommodate sphericity assumption violations. The ANOVA consisted of the within-subjects factor of experimental stimulus type (geometric shapes, abstract objects) and two between-subjects factors of learning condition (alone, practice, semantic) and age-group (younger, older). In an additional analysis, covariates of education and ERVT scores were included. *MSEs* and partial η^2 are noted.

Accuracy

There was no main effect of stimulus type ($F < 1$). As well, there were no significant interactions of learning condition by stimulus type ($F < 1$); stimulus type by age-group,

Table 2. Mean Accuracy, and Standard Deviations, for Younger and Older Adults for the Initial Two Transverse Patterning Variants in the Practice and Semantic Conditions

	Condition			
	Practice		Semantic	
Age	Geometric shapes	Abstract objects	Rock–paper–scissors	Cards
Young	0.80 (0.28)	0.83 (0.22)	0.97 (0.04)	0.96 (0.08)
Old	0.67 (0.28)	0.69 (0.26)	0.95 (0.09)	0.94 (0.11)

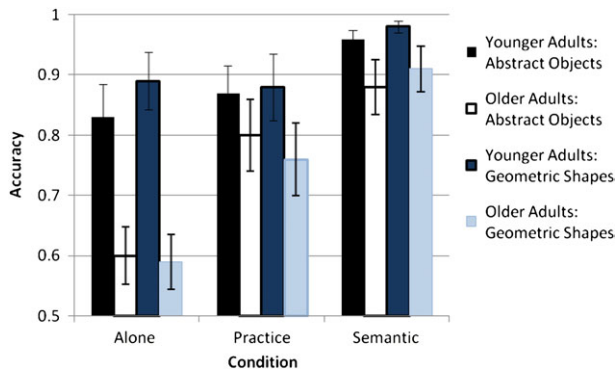


Figure 2. Mean accuracy and standard errors depicted for older and younger adults on the transverse patterning task under alone, practice, and semantic conditions, when geometric shapes or abstract objects were used as stimuli.

$F(1, 90) = 1.28$, $MSE = 0.013$, $p = .260$, $\eta^2 = .013$; or learning condition by stimulus type by age-group ($F < 1$). Therefore, there was no difference in accuracy as a result of differences in stimulus type; accuracy was similar for both the abstract objects and the geometric shapes sessions within each age-group, across conditions (alone, practice, semantic; see Figure 2).

Younger adults performed more accurately than older adults across the geometric shapes and abstract objects sessions for all three learning conditions, as illustrated by a significant main effect of age-group on accuracy, $F(1, 90) = 18.68$, $MSE = 0.06$, $p < .001$, $\eta^2 = .17$. There was a significant main effect of learning condition, $F(2, 90) = 12.35$, $MSE = 0.06$, $p < .001$, $\eta^2 = .22$. Post hoc contrasts revealed that across age-groups, accuracy was marginally greater in the practice condition versus the alone condition, $F(1, 62) = 3.55$, $p = .06$, and significantly greater in the semantic condition versus the practice condition, $F(1, 62) = 6.57$, $p = .01$ (see Figure 2). Older and younger adults alike showed similar trends for improvement: Accuracy for each age-group separately was marginally greater for those participants in the semantic condition versus the practice condition: older adults, $F(1, 30) = 3.39$, $MSE = 0.03$, $p = .08$, $\eta^2 = .10$; younger adults, $F(1, 30) = 3.61$, $MSE = 0.02$, $p = .07$, $\eta^2 = .11$.

There was a significant interaction of learning condition by age-group, $F(2, 90) = 3.23$, $MSE = 0.06$, $p < .05$, $\eta^2 = .07$, driven by the difference between groups for accuracy in the alone condition versus the practice condition. Younger adults in the alone and practice conditions did not significantly differ on accuracy ($F < 1$), whereas older adults in the practice condition were significantly more accurate than older adults in the alone condition, $F(1, 30) = 7.81$, $MSE = 0.04$, $p < .01$, $\eta^2 = .21$. Older adults, $F(1, 30) = 37.87$, $MSE = 0.02$, $p < .001$, $\eta^2 = .56$, and younger adults, $F(1, 30) = 4.67$, $MSE = 0.02$, $p < .05$, $\eta^2 = .13$, in the semantic condition were more accurate than their counterparts in the alone condition.

Significant age differences were found in the alone condition, $F(1, 30) = 18.41$, $MSE = 0.03$, $p < .001$, $\eta^2 = .38$, but

not in the practice condition, $F(1, 30) = 1.81$, $MSE = 0.04$, $p > .15$, $\eta^2 = .06$. Although, as previously noted, accuracy was highest for both age-groups in the semantic condition compared with either of the other two conditions, age differences in accuracy were observed, $F(1, 30) = 4.87$, $MSE = 0.01$, $p < .05$, $\eta^2 = .14$ (see Figure 2).

The pattern of findings for the overall ANOVA as previously outlined remained similar when covariates of education and ERVT scores were included in the analysis. The covariate of education was not significant ($F < 1$). The covariate of ERVT score was significant, $F(1, 84) = 11.62$, $MSE = 0.05$, $p = .001$, $\eta^2 = .12$. The main effect of learning condition, $F(2, 84) = 14.98$, $MSE = 0.05$, $p < .001$, $\eta^2 = .26$; the main effect of age, $F(1, 84) = 30.04$, $MSE = 0.05$, $p < .001$, $\eta^2 = .26$; and the learning condition by age interaction, $F(2, 84) = 3.06$, $MSE = 0.05$, $p = .05$, $\eta^2 = .07$, remained significant as in the original analysis. However, the interpretation of this significant interaction is altered from the original analysis in which the covariates of education and ERVT were not considered. When each learning condition was assessed separately, with the inclusion of education and ERVT scores as covariates, significant age differences remained in the alone condition, $F(1, 27) = 17.33$, $MSE = 0.06$, $p < .001$, $\eta^2 = .39$, and in contrast to the original analysis, significant age differences were observed in the practice condition, $F(1, 28) = 12.69$, $MSE = 0.06$, $p = .001$, $\eta^2 = .31$; but no significant age differences were observed in the semantic condition, $F(1, 25) = 1.35$, $MSE = 0.02$, $p > .25$, $\eta^2 = .05$. Therefore, when considering the covariates of education and vocabulary scores, age-related deficits in learning new relations were present in the alone and practice conditions but were effectively eliminated in the semantic condition.

Awareness

For each experiment within each condition, participants in each age-group were classified as “aware” or “unaware” of the stimulus relations based on their ability to correctly report the win–lose relationship among each pair of stimuli as in our previous work (Moses, Ostreicher, & Ryan, in press; Moses, Ostreicher et al., 2008; Moses et al., 2006, 2009; Ryan et al., 2009). Figure 3 depicts the percentage of younger and older adults who were aware of the stimulus relations for each stimulus type (geometric shapes, abstract objects) and learning condition (alone, practice, semantic). Binary logistic regressions were computed to detail the factors that predict subsequent awareness. Effects of extended practice can be ascertained by contrasting the alone condition, which does not provide training prior to the geometric shapes and abstract objects sessions, against the combination of the practice and semantic conditions, each of which provided additional training. Effects of preexisting knowledge can be ascertained by contrasting the semantic condition, which provides exposure to a familiar schema, against the combination of the alone and practice conditions, which

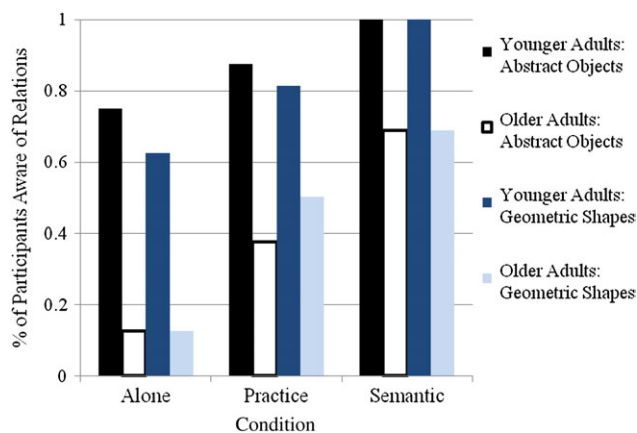


Figure 3. Proportion of older and younger adults who were aware of the correct stimulus relations in the transverse patterning task under alone, practice, and semantic conditions, when geometric shapes or abstract objects were used as stimuli.

do not provide additional semantic information. Binary categorical factors of age (old, young), stimulus (geometric shapes, abstract objects), extended practice (practice + semantic, alone), and preexisting knowledge (alone + practice, semantic) were entered into a logistic regression to assess the factors that significantly predict differences in awareness. Education and ERVT scores were also entered into the regression. As noted in Table 3, the factors of age, ERVT score, extended practice, and preexisting knowledge were significant predictors of subsequently assessed awareness. Younger adults were more likely to be aware of the relations among the stimuli than the older adults. The odds of becoming aware increased with extended practice (practice + semantic vs. alone). Likewise, the odds of becoming aware of the stimulus relations increased when an existing schema was presented prior to learning the new relations (semantic vs. practice + alone).

Table 4 shows the average accuracy for the final geometric shapes and abstract objects blocks across learning conditions for older and younger adults who were/were not subsequently considered aware of the relations among the stimuli. Inspection of the means reveals that participants who were subsequently considered aware of the stimulus relations tended to perform at/near ceiling across the learn-

ing conditions. To examine how the learning conditions (alone, practice, semantic) affected performance in situations where accuracy was not at ceiling, a univariate ANOVA, with learning condition as a between-subjects factor, was applied to the accuracy data from the unaware older adults. ANOVAs were conducted separately for the geometric shapes and abstract objects blocks given that not every participant was unaware of the relations among geometric shapes and the relations among the abstract objects. Data from the younger adults were not included in this analysis, as there were no younger adults who were unaware of the relations among either the geometric shapes or the abstract objects in the semantic condition.

When geometric shapes were used as the stimulus type, there was a significant effect of learning condition on accuracy, $F(2, 24) = 6.32$, $MSE = 0.03$, $p < .01$, $\eta^2 = .35$ (see Figure 4). Post hoc multiple comparisons (least significant difference) revealed significantly higher accuracy for the semantic condition compared with either the alone condition ($p < .01$) or the practice condition ($p < .05$). Accuracy on the practice condition was not significantly higher than that for the alone condition ($p = .19$). When abstract objects were used as the stimulus type, there was again a significant effect of learning condition on accuracy, $F(2, 26) = 3.96$, $MSE = 0.03$, $p < .05$, $\eta^2 = .23$ (see Figure 4). Post hoc multiple comparisons revealed significantly higher accuracy for the semantic condition compared with the alone condition ($p = .01$); the practice condition did not significantly differ from either the alone ($p = .10$) or the semantic condition ($p = .22$).

DISCUSSION

Relational representations can be created and stored more rapidly if prior knowledge regarding similar relations among items can be used as an analog for new learning (Tse et al., 2007). This is consistent with classic work in cognitive psychology showing that the relations among elements of a story narrative were more accurately remembered when participants were initially provided with an overall schema, as this provided a structure within which to organize the elements (Bartlett, 1932; Bransford & Johnson, 1972). Under this premise, we used the TP task to determine if relational learning for older and younger adults could be improved by

Table 3. Binary Logistic Regression Results Examining Predictors for the Proportion of Participants Considered Aware of the Stimulus Relations

Variable	<i>B</i> (<i>SE</i>)	Wald	<i>Df</i>	<i>p</i> Value	Odds ratio, exp <i>B</i>	95% CI for odds ratio	
						Lower limit	Upper limit
Age (old, young)	3.67 (0.61)	35.58	1	<.001	39.04	11.71	130.16
Education	0.02 (0.07)	0.11	1	>.70, <i>ns</i>	1.02	0.90	1.17
ERVT	0.08 (0.02)	10.13	1	.001	1.08	1.03	1.13
Stimulus (abstract objects, geometric shapes)	-0.08 (0.39)	0.04	1	.85, <i>ns</i>	0.93	0.43	1.99
Extended practice (practice + semantic, alone)	-1.92 (0.50)	15.03	1	<.001	0.15	0.06	0.39
Existing knowledge (alone + practice, semantic)	1.40 (0.52)	7.28	1	<.01	4.05	1.47	11.18

Note: $R^2 = .36$ (Cox & Snell), $.49$ (Nagelkerke). Model $\chi^2(4) = 81.90$, $p < .001$. CI = confidence interval; ERVT = Extended Range Vocabulary Test.

Table 4. Average Accuracy (*SE*) for the Final Geometric Shapes and Abstract Objects Blocks Across Conditions for Older and Younger Adults Who Were/Were Not Considered Subsequently Aware of the Relations Among the Stimuli

		Alone		Practice		Semantic	
		Geometric shapes	Abstract objects	Geometric shapes	Abstract objects	Geometric shapes	Abstract objects
Younger adults	Aware	0.99 (0.01)	0.94 (0.03)	0.98 (0.01)	0.92 (0.03)	0.98 (0.01)	0.96 (0.02)
	Unaware	0.71 (0.09)	0.52 (0.11)	0.44 (0.06)	0.54 (0.13)	N/A	N/A
Older adults	Aware	0.92 (0.08)	0.96 (0.04)	0.87 (0.07)	1 (0)	0.93 (0.05)	0.92 (0.04)
	Unaware	0.54 (0.03)	0.55 (0.04)	0.64 (0.09)	0.68 (0.07)	0.86 (0.07)	0.81 (0.10)

Note: NA = not applicable.

appealing to previously acquired semantic information and whether such improvements would be greater than what could be attained with practice. Across the age-groups, accuracy on the TP task improved when training was provided within the context of a previously known relational framework or “schema” (semantic), above and beyond the benefits obtained with extended practice with the task. Such learning of new relations was largely unaffected by whether the stimuli were preexperimentally familiar or novel.

We additionally examined whether age-related relational memory deficits (Naveh-Benjamin et al., 2003, 2004) could be reduced either through practice or through an appeal to existing knowledge. Older adults were less accurate compared with younger adults on the standard TP task with arbitrary relations, as reported by Driscoll and colleagues (2003, 2006). With extended practice, older adults performed more accurately, and, in effect, the age-related difference in accuracy was reduced. By contrast, accuracy was highest for each group in the semantic condition, but, despite the high performance, age differences were observed. When differences between the age-groups in education levels and ERVT were considered as covariates, significant age-related deficits were observed in learning new relations in the practice condition but were eliminated in the semantic condition. Thus, when controlling for nonequivalence among the groups on these demographic measures, the findings reveal that appealing to existing semantic knowledge may effectively reduce the age-related deficit in learning new relations. However, ceiling effects occurred for the

group of younger adults. It may be the case that age differences would be observed in all conditions, if performance could be brought down from ceiling. For instance, future research could implement similar conditions that require the learning of new relations among larger sets of stimuli and/or with fewer training stages. Nevertheless, within each group, accuracy improved for the semantic condition compared with the alone condition, and the incidence of conscious awareness for the acquired relations was significantly greater. Thus, although extended practice can confer some advantages for older adults, improvements were observed for both younger and older adults when new relations were trained within an existing relational framework.

Moreover, extended practice and the use of existing semantic knowledge each predicted the incidence of conscious awareness for the acquired relations. Age and scores on the ERVT were also significant predictors of conscious awareness. Taken together, these results suggest that although older adults are less likely than younger adults to become aware of the relations among the stimuli, those younger and older adults alike who have a more advanced vocabulary were also those who were more likely to be able to articulate the win–loss relations among the stimuli. Although the use of an existing relational framework improved accuracy and the incidence of conscious awareness for the stimulus relations, accuracy was greater in the semantic condition than in the practice or alone condition even for those older adults who were unaware of the acquired relations. Thus, the use of an existing relational framework reduces age-related deficits in learning new relations and increases the likelihood of being able to consciously introspect about those learned relations.

In the following, we discuss the current findings with respect to prior research on age-related deficits in relational binding and comment on the underlying neural mechanisms that may be invoked to improve performance. These findings support the design and use of strategies that capitalize on practice and the use of preexisting relational knowledge to help alleviate relational learning deficits that are typical of healthy aging.

Age-Related Deficits in, and the Use of, Relational Memory

Our findings from the alone experimental condition are consistent with those observed by Driscoll and colleagues

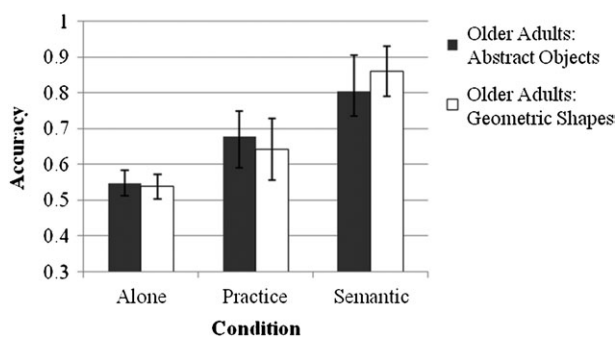


Figure 4. Mean accuracy and standard errors depicted for older adults who remained unaware of the relational contingencies on the transverse patterning task under alone, practice, and semantic conditions, when geometric shapes or abstract objects were used as stimuli.

(2003): Older adults had difficulty learning the relations among novel stimuli in the TP task, as indicated by decreased accuracy. This age-related relational learning deficit has been noted in prior studies that required pairs of words (Castel & Craik, 2003), pictures (Naveh-Benjamin et al., 2003), or combinations of face and name pairs (Naveh-Benjamin et al., 2004) to be remembered across a delay.

By contrast, older adults are comparable with younger adults for retaining relations among items that were already (semantically or otherwise) associated in memory (Hannon & Craik, 2001; Howard, 1983; Troyer et al., 2006). The findings here are unique in that we demonstrate highly accurate retention of novel, *arbitrary*, relations for older adults. That is, whereas previous work showed a memory advantage for one class of stimuli (stimuli with familiar/known relations) over another (stimuli with arbitrary relations), we showed that memory for the relations among one set of stimuli (stimuli with arbitrary relations) can be altered depending on prior training. Similarly, Castel (2007) showed higher recall of object and quantity relations for a group of older adults who had previously been employed as accountants or bookkeepers and had extensive prior semantic knowledge regarding numerical/object pairings, compared with older adults who had no such prior training. In the Castel study, prior knowledge was not explicitly used during the training session as an analog for new learning; rather, the groups differed on their prior expertise and information maintained within semantic stores. The advantages shown here were not due to differences in stimuli and/or in expertise of the participant groups; instead, prior exposure varied. Recent cognitive rehabilitation programs for healthy older adults have focused on techniques such as strategic processing, goal management (Winocur et al., 2007), and errorless learning (Kessels & de Haan, 2003), with reports of modest gains in cognition. Future programs that promote learning strategies by which new learning is incorporated into existing knowledge may improve day-to-day cognition in older adults.

Mechanisms Supporting Relational Memory

The deficits typically observed in healthy aging bear a resemblance to those observed in amnesic patients who have damage to the hippocampal/medial temporal lobe system and have deficits in the ability to form arbitrary relations among items (Eichenbaum & Cohen, 2001). This suggests that compromised hippocampal function may underlie the relational learning deficits observed in aging (Driscoll et al., 2003; Ryan et al., 2009).

Neuroimaging studies have demonstrated structural deficiencies in the hippocampi of older adults (Driscoll & Sutherland, 2005; Geinisman, deToledo-Morrell, Morrell, & Heller, 1995; Issa, Rowe, Gauthier, & Meaney, 1990; Jernigan et al., 1991), and markers of neuronal integrity in

the hippocampus have been correlated with accuracy on the TP task (Driscoll et al., 2003). Although the processing of known relations (e.g., RPS, playing cards) can be achieved in the absence of a functioning hippocampus, learning new relations among objects (geometric shapes, abstract objects) in the TP task appears to require contributions from the hippocampal system (Moses, Ostreicher et al., 2008; Reed & Squire, 1999; Rickard & Grafman, 1998; Rickard et al., 2006). Learning of new relations requires the hippocampus even when the new relations are trained within a stable known schema, although these new relational representations quickly become hippocampally independent (Tse et al., 2007; but see Rudy & Sutherland, 2008). Consequently, we suggest that the current findings of improved performance on the standard TP task in the semantic condition are likely not due to the *sole* use of extrahippocampal structures. Rather, the use of known relations (RPS, playing cards) in the present study may have either lessened the demand for new relational binding (geometric shapes, abstract objects) or facilitated relational memory binding capacities, allowing the learning of new relations to be bound by the hippocampus more rapidly than if no schema had been initially presented.

Although this discussion has focused on the hippocampus, dysfunction in other neural structures may also underlie the deficit observed in aging. Finding correspondences between the relations among distinct item sets, as required in analogical reasoning and transfer paradigms and in the present TP task, has been purported to require contributions from regions within the prefrontal cortex that serve to retrieve relations from semantic memory and integrate this information with the currently presented problem set (Bunge, Wendelken, Badre, & Wagner, 2005; Cabeza & Nyberg, 2000; Waltz et al., 2004). There is evidence of increased recruitment of the frontal lobes in normal aging during learning, suggesting either a functional decline in these regions or a redistribution of function (Grady & Craik, 2000), in the face of possible hippocampal decline. Frontal-hippocampal interactions may be the mechanism by which analogical transfer is mediated, thereby supporting the new learning of relations in the context of existing knowledge. Here, invoking prior semantic knowledge to learn novel arbitrary relations improved performance in both younger and older adults. These effects may be due to facilitation in hippocampal-dependent relational binding via recruitment of stored knowledge, as mediated by the frontal lobes, which is then applied to the current processing of relations.

FUNDING

This work was supported by funding from a Canadian Institutes of Health Research (CIHR) New Investigator Award to R.S.R. and funding from CIHR and the Canada Research Chairs Program awarded to J.D.R.

ACKNOWLEDGMENTS

The authors thank Christina Villate and Ella Pan for their assistance in data collection, and Malcolm Binns for statistical advice.

CORRESPONDENCE

Address correspondence to Jennifer D. Ryan, PhD, Rotman Research Institute, Baycrest, 3560 Bathurst Street, Toronto, Ontario, Canada M6A 2E1. Email: jrryan@rotman-baycrest.on.ca

REFERENCES

- Bartlett, F. C. (1932). *Remembering*. Cambridge, England: Cambridge University Press.
- Bransford, J. D., & Johnson, M. K. (1972). Contextual prerequisites for understanding: Some investigations of comprehension and recall. *Journal of Verbal Learning and Verbal Behavior*, *11*, 717–726.
- Bunge, S. A., Wendelken, C., Badre, D., & Wagner, A. D. (2005). Analogical reasoning and prefrontal cortex: Evidence for separable retrieval and integration mechanisms. *Cerebral Cortex*, *15*, 239–249.
- Cabeza, R., & Nyberg, L. (2000). Neural bases of learning and memory: Functional neuroimaging evidence. *Current Opinion in Neurology*, *13*, 415–421.
- Castel, A. D. (2005). Memory for grocery prices in younger and older adults: The role of schematic support. *Psychology and Aging*, *20*, 718–721.
- Castel, A. D. (2007). Aging and memory for numerical information: The role of specificity and expertise in associative memory. *Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *62*, 194–196.
- Castel, A. D., & Craik, F. I. M. (2003). The effects of aging and divided attention on memory for item and associative information. *Psychology and Aging*, *18*, 873–885.
- Clark, E., Gardner, M. K., Brown, G., & Howell, R. J. (1990). Changes in analogical reasoning in adulthood. *Experimental Aging Research*, *16*, 95–99.
- Copeland, D. E., & Radvansky, G. A. (2007). Aging and integrating spatial mental models. *Psychology and Aging*, *22*, 569–579.
- Driscoll, I., Hamilton, D. A., Petropoulos, H., Yeo, R. A., Brooks, W. M., & Sutherland, R. J. (2003). The aging hippocampus: Cognitive, biochemical and structural findings. *Cerebral Cortex*, *13*, 1344–1351.
- Driscoll, I., Howard, S. R., Prusky, G. T., Rudy, J. W., & Sutherland, R. J. (2005). Seahorse wins all races: Hippocampus participates in both linear and non-linear visual discrimination learning. *Behavioural Brain Research*, *164*, 29–35.
- Driscoll, I., Howard, S. R., Stone, J. C., Monfils, M. H., Tomanek, B., Brooks, W. M., et al. (2006). The aging hippocampus: A multi-level analysis in the rat. *Neuroscience*, *139*, 1173–1185.
- Driscoll, I., & Sutherland, R. J. (2005). The aging hippocampus: Navigating between rat and human experiments. *Reviews in the Neurosciences*, *16*, 87–121.
- Educational Testing Service. (1976). *Extended Range Vocabulary Test, version three (ERVT). Kit of factor-referenced tests*. Princeton, NJ: Educational Testing Service.
- Eichenbaum, H., & Cohen, N. J. (2001). *From conditioning to conscious recollection: Memory systems of the brain*. New York: Oxford University Press.
- Geinisman, Y., deToledo-Morrell, L., Morrell, F., & Heller, R. E. (1995). Hippocampal markers of age-related memory dysfunction: Behavioural, electrophysiological and morphological perspectives. *Progress in Neurobiology*, *45*, 223–252.
- Grady, C. L., & Craik, F. I. M. (2000). Changes in memory processing with age. *Current Opinion in Neurobiology*, *10*, 224–231.
- Gross, W. L., & Greene, A. J. (2007). Analogical inference: The role of awareness in abstract learning. *Memory*, *15*, 838–844.
- Hannon, B., & Craik, F. I. M. (2001). Encoding specificity revisited: The role of semantics. *Canadian Journal of Experimental Psychology*, *55*, 231–243.
- Howard, D. V. (1983). The effects of aging and degree of association on the semantic priming of lexical decisions. *Experimental Aging Research*, *9*, 145–151.
- Issa, A. M., Rowe, W., Gauthier, S., & Meaney, M. J. (1990). Hypothalamic-pituitary-adrenal activity in aged and cognitively unimpaired rats. *Journal of Neuroscience*, *10*, 3247–3254.
- Jernigan, T. L., Archibald, S. L., Berhow, M. T., Sowell, E. R., Foster, D. S., & Hesselink, J. R. (1991). Cerebral structure on MRI, part I. Localization of age related changes. *Biological Psychiatry*, *29*, 55–67.
- Kessels, R. P., & de Haan, E. H. (2003). Mnemonic strategies in older people: A comparison of errorless and errorful learning. *Age and Aging*, *32*, 529–533.
- Miller, L. M., & Stine-Morrow, E. A. (1998). Aging and the effects of knowledge on on-line reading strategies. *Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *53*, P223–P233.
- Moses, S. N., Ostreicher, M., & Ryan, J. D. (in press). Relational strategy bias improves transitive inference performance. *Psychological Research*.
- Moses, S. N., Ostreicher, M., Rosenbaum, R. S., & Ryan, J. D. (2008). Successful transverse patterning in amnesia using semantic knowledge. *Hippocampus*, *18*, 121–124.
- Moses, S. N., Ryan, J. D., Bardouille, T., Kivacevic, N., Hanlon, F. M., & McIntosh, A. R. (2009). Semantic information alters neural activation during transverse patterning performance. *NeuroImage*, *46*, 863–873.
- Moses, S. N., Villate, C., Binns, M. A., Davidson, P. S. R., & Ryan, J. D. (2008). Cognitive integrity predicts transitive inference bias and success. *Neuropsychologia*, *46*, 1314–1325.
- Moses, S. N., Villate, C., & Ryan, J. D. (2006). An investigation of learning strategy supporting transitive inference performance in humans compared to other species. *Neuropsychologia*, *44*, 1370–1387.
- Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 1170–1187.
- Naveh-Benjamin, M., Guez, J., Kilb, A., & Reedy, S. (2004). The associative memory deficit of older adults: Further support using face-name associations. *Psychology and Aging*, *19*, 541–546.
- Naveh-Benjamin, M., Hussain, Z., Guez, J., & Bar-On, M. (2003). Adult age differences in episodic memory: Further support for an associative-deficit hypothesis. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *29*, 826–837.
- Old, S. R., & Naveh-Benjamin, M. (2008). Differential effects of age on item and associative measures of memory: A meta-analysis. *Psychology and Aging*, *23*, 104–118.
- Rahhal, T. A., May, C. P., & Hasher, L. (2002). Truth and character: Sources that older adults can remember. *Psychological Science*, *13*, 101–105.
- Reed, J. M., & Squire, L. R. (1999). Impaired transverse patterning in human amnesia is a special case of impaired memory for two-choice discrimination tasks. *Behavioural Neuroscience*, *113*, 3–9.
- Rickard, T. C., & Grafman, J. (1998). Losing their configural mind. Amnesic patients fail on transverse patterning. *Journal of Cognitive Neuroscience*, *10*, 509–524.
- Rickard, T. C., Verfaellie, M., & Grafman, J. (2006). Transverse patterning and human amnesia. *Journal of Cognitive Neuroscience*, *18*, 1723–1733.
- Ryan, J. D., Leung, G., Turk-Browne, N. B., & Hasher, L. (2007). Assessment of age-related changes in inhibition and relational memory binding using eye movement monitoring. *Psychology and Aging*, *22*, 239–250.
- Ryan, J. D., Moses, S. N., & Villate, C. (2009). Impaired relational organization of propositions, but intact transitive inference, in aging: Implications for understanding underlying neural integrity. *Neuropsychologia*, *47*, 338–353.
- Rudy, J. W., & Sutherland, R. J. (2008). Is it systems or cellular consolidation? Time will tell. An alternative interpretation of the Morris group's recent Science paper. *Neurobiology of Learning and Memory*, *89*, 366–369.

- Salthouse, T. A. (1987). The role of representations in age differences in analogical reasoning. *Psychology and Aging, 2*, 357–362.
- Sutherland, R. J., Rudy, J. W. (1989). Configural association theory: The role of the hippocampal-formation in learning, memory, and amnesia. *Psychobiology, 17*, 129–144.
- Troyer, A. K., Haftiger, A., Cadieux, M. J., & Craik, F. I. M. (2006). Name and face learning in older adults: Effects of level of processing, self-generation, and intention to learn. *Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 61*, 67–74.
- Tse, D., Langston, R. F., Kakeyama, M., Bethus, I., Spooner, P. A., Wood, E. R., et al. (2007). Schemas and memory consolidation. *Science, 316*, 76–82.
- Waltz, J. A., Knowlton, B. J., Holyoak, K. J., Boone, K. B., Back-Madruga, C., McPherson, S., et al. (2004). Relational integration and executive function in Alzheimer's disease. *Neuropsychology, 18*, 296–305.
- Winocur, G., Craik, F. I. M., Levine, B., Robertson, I. H., Binns, M. A., Alexander, M., et al. (2007). Cognitive rehabilitation in the elderly: Overview and future directions. *Journal of the International Neuropsychological Society, 13*, 166–171.

Received December 16, 2008

Accepted September 8, 2009

Decision Editor: Dr. Elizabeth A. L. Stine-Morrow.