Category Learning and Adaptive Benefits of Aging

Angela Merritt (merri242@umn.edu)
University of Minnesota

Linnea Karlsson (karlsson@mpib-berlin.mpg.de)
Max Planck Institute for Human Development

Edward T. Cokely (cokely@mpib-berlin.mpg.de)
Max Planck Institute for Human Development &
Michigan Technological University

Abstract

We examined effects of normal aging on category learning, comparing performance and strategy choice on two learning tasks: one where a one-dimensional rule governed category membership and one where a multi-dimensional rule defined category structure. Paradoxically, we demonstrated that older adults can outperform younger adults in some types of complex category learning. In the current task—which required that multiple dimensions be integrated—simpler integration rules enabled more rapid achievement of reasonable levels of performance. As cognitive aging is associated with a reduction in working memory resources, older adults tended to adopt these simpler decision rules more often, facilitating complex category learning. Results provide some unique evidence highlighting potential adaptive benefits of cognitive aging. Implications are discussed.

Keywords: category learning, aging, rule-based, information-integration

Introduction

The learning of new categories is an important task throughout one's life span. While the literature investigating younger adults' category learning skill is vast, less is known about older adults' category learning competencies. In the current investigation, we sought to demonstrate that normal cognitive aging can confer cognitive performance benefits as older adults may favor simpler cognitive strategies known to facilitate learning and decision performance.

Previous research investigating aging and feedback-based category learning often draws the general framework of Ashby and colleagues (e.g. Ashby, Alfonso-Reese, Turken, & Waldron 1998). The framework involves contrasting two different task types that are assumed to be best solved by two distinct learning systems. The most basic difference between the tasks, as typically stated, is whether one or several dimensions of the probe determine category membership. In the so-called *rule-based tasks,* only one dimension of the probe determines category membership and these tasks are believed to rely on an explicit learning system capitalizing on simple verbalizable rules. In *information-integration tasks,* the values of several dimensions determines membership via a complicated combination rule. In these tasks, simple one-dimensional rules will not suffice for error-free performance. Learning in these tasks is thus said to be guided by an implicit learning system employing integration of dimensions at a "predecisional" stage. Moreover, it is suggested that there exists a *rule-bias*—a new learning endeavor will start off with the explicit learning system but compete with, and possibly lose against, the implicit system for determining the response.

The results with regard to older adults' learning in these tasks are mixed. Ashby, Nobel, Filoteo, Waldron and Ell (2003) demonstrated that older adults reached the learning criterion (10 correct consecutive responses, CCR) later than young adults in both a rule-based and an information-integration task. However, they did not investigate the cognitive processes used to guide categorization. Filoteo and Maddox (2004) compared younger and older adults on two versions of an information-integration task—one with a linear and one with a non-linear combination rule. Older adults were impaired compared to young adults on both versions. Via computational modeling the authors provided evidence suggesting that the age-related differences were less marked among individuals using simple one- or two-dimensional rules. In contrast, in a study comparing young and old adults on a probabilistic category learning task (the weather prediction task; Gluck & Bower, 1988) and an information integration task, age-related differences were only found in the probabilistic but not in the information integration task (Price, 2005).

Individual differences in working memory are known to influence cognitive task strategies and decision making performance (Cokely & Kelley, 2009; Cokely, Kelley, & Gilchrist, 2006). Furthermore, considerable evidence has documented declines and metacognitive changes associated with working memory during normal aging (e.g. Baltes, Staudinger, & Lindenberger, 1999; Herzog, Dixion, Hultsch, & MacDonald, 2003). Interestingly, individual differences in working memory have been shown to be a factor on success rates in category learning (DeCaro, Thomas, & Beilock, 2008). DeCaro et al. hypothesized that individuals with high working memory abilities should outperform individuals with low working memory abilities in rule-based tasks. In information-integration tasks it was hypothesized that low-capacity individuals would have a benefit: they may have less capacity to engage the explicit system in extensive hypothesis testing of the complex combination rule. Thus low ability individuals might switch to the implicit system earlier than high-ability individuals and show faster learning. DeCaro et al. showed that high-ability individuals reached the learning criterion faster than low-ability individuals in a rule-based task. In contrast, in an information-integration task, low-ability individuals reached the learning criterion faster—a benefit assumed to stem from an earlier switch to the implicit system. Of note, however, Tharp and Pickering (2009) demonstrated that the learning criterion used by DeCaro et al (i.e. 8 CCR) were insufficient for capturing learning of the information-integration combination rule and thus reaching that criterion is likely not a reliable indicator that implicit learning has taken place. Tharp and Pickering demonstrated that considerably fewer participants in an information-integration task were able to sustain performance long enough to reach the stricter criterion of 16 CCR. Further, the responses from around 40% of the individuals reaching the 8 CCR criterion could be well captured by one-dimensional categorization models, suggesting that it is possible to reach 8 CCR with explicit memory and simple one-dimensional rules. DeCaro, Carlson, Thomas and Beilock (2009) subsequently tested low- vs. high ability individuals again, using the stricter 16 CCR, and the interaction between tasks and abilities disappeared. Moreover, when assessing learning strategies in the two tasks for the two groups DeCaro et al found evidence suggesting that the low-ability individuals primarily used one-dimensional rules.

Might older adults also benefit from the use of simpler processes in the tasks used by DeCaro et al and Tharp and Pickering? Previous research suggests it is unlikely that that older adults would be able to proceed in learning the information integration task with the implicit learning system (see also Filoteo & Maddox, 2004). Previous research also suggests that in tasks similar to implicit category learning (i.e., implicit learning of new associations) age-related decline in performance is to be expected (Curran, 1997; Harrington & Haaland, 1992; Howard & Howard, 1997, 2001). Moreover, there is evidence that older adults prefer simpler strategies over complex strategies in various tasks, for example in mental arithmetic (Geary, Frensch & Wiley, 1993), in memory (Dunlosky & Hertzog, 1998, 2000) and decision making (Chen & Sun, 2003; Johnson, 1990; Mata, Schooler & Rieskamp, 2007). Thus, this leaves us with two nested hypotheses for the current study: (1) older adults will not address the information integration task with the implicit system, and (2) advantages demonstrated by older adults in an information-integration task will stem from older adults' use of simple, verbalizable rules, in contrast to a larger portion of younger adults who might attempt futile hypothesis testing with more complex rules.

Experiment

In the following experiment we tested younger adults and older adults on a categorization task. The stimuli consisted of pictorial drawings with four binary cues and the task was to learn to categorize the stimuli into two different categories with guidance by outcome-feedback. The task exactly followed DeCaro et al. (2008).

Method

Participants

Fifty eight participants were tested. Twenty nine of the participants were younger, aged 20-32 (m = 25.1, SD = 3.1), and the other 29 participants, were older, aged 64-79 (m = 69.9, SD = 3.3). Participants were recruited from the participant pool of the Max Planck Institute for Human Development, Berlin. All were compensated 10 € for participation.

Procedure

Participants completed a computer-based category learning experiment adapted from DeCaro, Thomas & Beilock (2008). During the experiment, the participant was shown colored geometric figures on a computer screen and asked to place each one into either category "A" or category "B" by pressing buttons on a keyboard. Immediate feedback was given after each trial. After 200 of such trials, the participant was informed that a new set was to begin and the rules had changed, but were not informed by which rule to sort. Participants completed 4 sets of 200 trials. There were two different sets of rule-based tasks and two sets of information integration tasks, rotated across participants in four different orders. In the rule-based tasks one dimension decided category membership (in one set it was symbol color and in the other set symbol shape). There were also two different sets of information-integration tasks. Three of the four dimensions were regarded as relevant (with background color respectively number of embedded symbols being irrelevant). The correct combination rule was given by assigning each binary value of the dimensions with 1 or -1 and then linearly combining those values:

If value (X) + value (Y) + value (Z) > 0 respond A, otherwise B.

In addition, participants completed a battery of cognitive ability measures. These results are not reported as they are beyond the scope the current paper.

Results

As a first step, to statistically investigate the extent to which we replicated DeCaro et al (2008), our initial analyses followed DeCaro et al. First, we log-transformed the number of trials to reach the criterion of 8 CCR, as the variable was positively skewed. Second, for the set of analyses directly aiming at comparing the results with DeCaro et al (2008) we only included participants who reached the criterion on all four task rules (two rule-based and two information-integration, of 200 trials each), and who were not higher than 2 *SD* above the mean in trials to criterion in each block.

First, we analyzed whether performance on any of the two different rules within each task differed and interacted with age. We performed one repeated measurement ANOVA per task, with rule type as within factor and age as between factor. In the rule-based task one rule was easier to learn than the other ($F(1,41) = 5.17$; $p = .03$) but this did not interact with age ($F(1,41) = .12$; $p = .73$). In the information-integration task rules did not differ in difficulty ($F(1,41) = .001$; $p = .97$) and there was no interaction with age ($F(1,41) = .26$; $p = .62$). Therefore, we averaged data across both rule types within each task.

Second, we investigated whether there was an effect of age on the ability to reach the 8 CCR criterion and if this interacted with task. We performed a repeated measurement ANOVA with task (rule-based vs. information-integration) as within-subjects factor and age as between-subjects factor. Overall, the age groups did not differ on the number of trials they took to reach the criterion ($F(1,41) = .07$; $p = .80$). The criterion was reached faster in the rule-based than the information-integration task ($F(1,41) = 9.96$; $p = .003$). Most importantly, there was a significant interaction between age and performance in the two tasks (Figure 1; $F(1,41) = 4.69$; $p = .04$). While the younger adults' ability to reach the criterion deteriorated significantly in the information-integration compared to the rule-based task ($F(1,15) = 28.05$; $p < 0.001$) the older adults reached it about equally fast across tasks ($F(1,15) = .25$; $p = .62$).

Following Ashby et al. (2003), DeCaro et al.(2008, 2009), and Tharp and Pickering (2009), and to further investigate the learning trajectories in the two tasks we next looked at the number of participants reaching the three different criteria used in those studies (8, 10 and 16 CCR) and the mean number of trials it took to reach the criterion (Table 1 and 2). All subsequent analyses included all participants.

It is evident that in the rule-based task most younger adults reached all three criteria while about 1/3 of the old adults did not reach the strictest criterion (Table 1). In the information-integration task on the other hand (Table 2), fewer older adults reached all criteria, but the number of learners dropped off proportionally in both age-groups as a function of how strict the criterion was. Critically, the older adults required fewer trials to criterion than the younger adults only when considering 8 CCR.

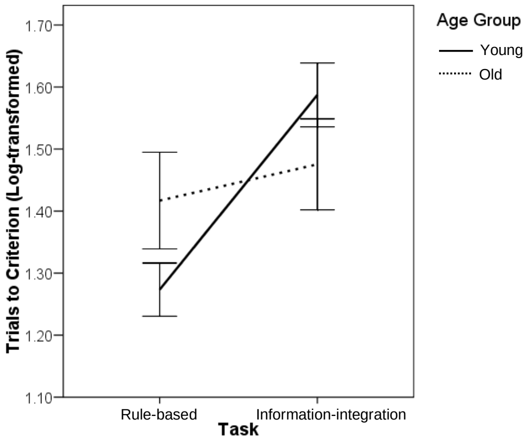

Figure 1. Average trials to reach the 8 CCR criterion as a factor of age group and task. Error bars represent +/- 1 SE.

Table 1. Rule-based task: number of learners and mean trials-to-criterion (TTC) as a function of age and criterion

	Number of learners (max 29 per group)		Mean TTC *(SD)*	
CCR	Young	Old	Young	Old
8	28	22	25.9 *(16.1)*	45.0 *(33.1)*
10	28	19	32.0 *(19.0)*	48.2 *(35.2)*
16	26	14	44.8 *(25.1)*	52.7 *(30.4)*

Table 2. Information-integration task: number of learners and mean trials-to-criterion (TTC) as a function of age and criterion

	Number of learners (max 29 per group)		Mean TTC *(SD)*	
CCR	Young	Old	Young	Old
8	27	19	53.9 *(32.2)*	47.5 *(31.3)*
10	21	15	69.0 *(25.1)*	77.9 *(33.8)*
16	4	2	91.0 *(21.6)*	155.8 *(2.48)*

To provide a more transparent impression of performance in the two tasks we next examined the proportion of correct responses as a function of task and age (Figure 2). First, performance on the two rule-types of each task did not interact with age, so we averaged the data across rule-types. In a repeated measurement ANOVA there were two main effects and one interaction. The younger adults performed better overall than the older adults ($F(1,56) = 14.74$; $p < 0.001$), and performance was better in the rule-based than in the information-integration task ($F(1,56) = 124.4$; $p < 0.001$). The interaction suggests that the impact of age on performance was different depending on the task ($F(1,56) = 4.04$; $p =.049$). The difference between the age groups was larger in the rule-based task ($m_{young} = 91.2\%$ vs. $m_{old} = 78.8\%$) than in the information-integration task ($m_{young} = 71.3\%$ vs. m_{old} 65.0%).

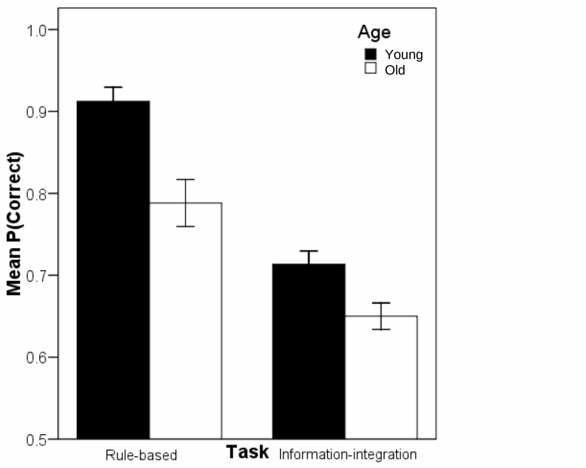

Figure 2. Proportion correct as a function of task and age-group. Error bars are SE +/- 1.

Next, to investigate whether the observed interaction reflected differences in the use of strategies we performed a rough strategy assessment for the information-integration task. The present task is limited when it comes to allowing reliable estimates of what model explains the data best and we thus refrain from sophisticated quantitative model assessments including parameter estimation. Indeed, several different models, including exemplar-models (e.g. Juslin, Olsson, & Olsson, 2003; Nosofsky & Johansen, 2000) and rule-plus-exception models (Nosofsky, Palmeri, & McKinley, 1994) are likely to give rise to a set of similar responses as one-dimensional and multi-dimensional rules under some values of the parameters. However, for the purpose of the present paper we were primarily interested in whether the age group differed in how many dimensions they utilized. A simplified means of assessing the correspondence between data and predictions from a model is to count the number of trials for which the data and the model gives the same answer (e.g. DeCaro et al., 2009). We defined the same set of 10 different strategies as DeCaro and colleagues (2009), including the correct three-dimensional rule, three different one-dimensional rules, and six different multi-dimensional rules (all of which could potentially be easily verbally described). Because we wanted to investigate what strategy accounted for participants responses when they had reached the 8 CCR criterion (and not what different strategies were at play early during learning), we used the responses containing the 8 CCR as well as the subsequent 8 x 3 responses and compared them to the different strategies' predictions (in total 32 trials). We reasoned that at that point the response strategy should be more stable than during the beginning of the task when the participants presumably tried out different ways of responding. The model comparison was done separately for each of the two different rule-types of the information-integration task. Next, we looked at which model had the lowest deviation between responses and model predictions for each individual and each rule-type of the information-integration task. We did not count individuals where there was a tie between two or more strategies (separately for the two rule-types of the task). This resulted in a total of 40 valid strategy assessments for the young adults and 30 for the old adults. We contrasted multi-dimensional with one-dimensional strategies and counted the number of times (max 2 per person since there were two versions of the task) where a one-dimensional model or a multi-dimensional model had the lowest deviation. The results (Figure 3) suggest that for younger adults about equally many of the information-integration tasks were best described by a one-dimensional strategy (52.5 %) as by a multi-dimensional strategy (47.5 %). However, for the older adults more were better described by a one-dimensional strategy (76.7 vs 23.3 %).

Discussion

With this study we sought to demonstrate potential adaptive benefits of aging. In a task where category membership was governed by the integration of several dimensions (in the present paradigm denoted an *information-integration task*) younger adults performed better than older adults overall (Figure 2). Importantly, however, older adults were able to produce reasonable levels of performance (i.e. to reach the 8 CCR criterion) somewhat faster than young adults (Figure 1). To investigate one potential mechanism underlying this advantage we did a simplified strategy assessment in the information-integration task. For the younger adults about equally many were best fit by one-dimensional as by multi-dimensional strategies. In contrast, for the older adults the larger proportion were best fit by one-dimensional strategies (Figure 3).

The results are intriguing in that they imply two important facets of age-related effects on the ability to acquire new categories. First, we find no evidence that the older adults engage an implicit learning system when trying to master the information-integration task. Had that been the case we should have observed sustained levels of performance independent of the learning criterion. Instead we observed the opposite (Table 2). Further, we ascribe the reasonable levels of performance produced by the older adults in the information-integration task mainly to their adoption of simple, one-dimensional rules. For this particular task, such rules are able to lead to performance well above chance. Thus, while the younger adults presumably tried different versions of multi-dimensional rules, performance might have suffered initially from erroneous responses, while in the meantime the older adults could sustain reasonable performance by not doing that.

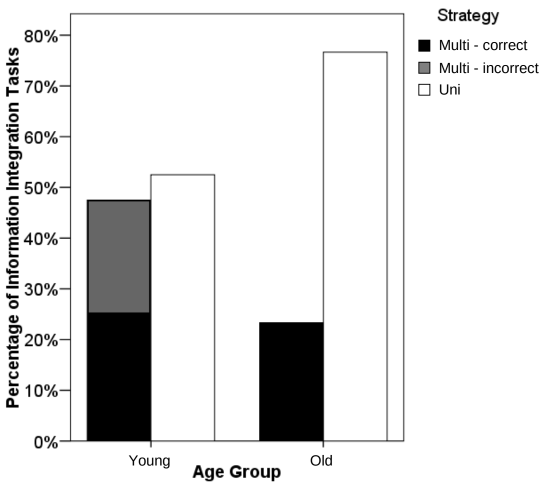

Figure 3. The proportion of information-integration tasks (with two different rule types) per age group where responses were best captured by a multi-dimensional (correct) multi-dimensional (incorrect) or a one-dimensional strategy.

The data presented in the current study replicates and extends the performance differences reported by Ashby et al (2003) who used the 10 CCR criterion. Our contribution extends the data presented by Ashby et al (2003) by demonstrating that older adults adopt one-dimensional rules to a larger extent than younger adults. Moreover, on the assumption that older adults represent a population with lower working memory capacities than younger adults we replicate DeCaro et al (2008, 2009), providing converging evidence on the influence of individual differences on the ability to acquire new categories.

Nevertheless, the data does not allow us to claim that younger adults engaged the implicit system in the information integration task. Performance dropped off as a function of learning criterion (Table 2). Further, nothing in the fit of a multi-dimensional strategy per se can tell us whether it was executed by an explicit or an implicit system. Unfortunately, there is some debate regarding whether the present set of stimuli are most suitable for studying the implicit system, as they may not be sufficiently complex (i.e. they involve binary stimuli dimensions). Rather, it has been suggested that the more complex Gabor patches are better for that purpose (e.g. Maddox, Ashby, & Bohill, 2003).

A number of interesting follow-up studies would help in clarifying some questions. First of all, it would be interesting to replicate the same experiment as reported here with the Gabor patch stimuli in order to investigate whether the ability to learn the tasks as well as the best performing strategies reveals the same pattern as reported here, even though the stimuli are more complex. Furthermore, follow-up experiments specifically designed for reliable quantitative model comparisons could provide a more detailed picture regarding the cognitive processes at play. Such experiments could for example aim at contrasting predictions by one- two- and three-dimensional rules with predictions by exemplar-models and rule-plus-exception models.

Results provide some new and unique data on potential benefits of cognitive aging. A large body of research has converged to reveal the benefits of simple decision strategies - in some cases *"less can be more"* (e.g. Gigerenzer, Todd, & the ABC Research Group, 1999). To the extent that cognitive aging biases older adults toward the use of simpler decision processes, there may be many benefits of cognitive aging that are currently underappreciated.

Authors' Note

We thank Gregor Caregnato and Paula Parpart for assistance in data collection. We thank DeCaro and colleagues for their experiment materials.

References

Ashby, F.G., Alfonso-Reese, L.A., Turken, U. & Waldron, E.M. (1998). A neuropsychological theory of multiple systems in category learning. *Psychological Review, 105,* 442-481.

Ashby, F.G., Noble, S., Filoteo, J. V., Waldron, E.M. & Ell, S.W. (2003). Category learning deficits in Parkinson's disease. *Neuropsychology,17,*115-124.

Baltes, P.B., Staudinger, U.M., & Lindenberger, U. (1999). Lifespan psychology: Theory and application to intellectual functioning. *Annual Review of Psychology, 50,* 471-507.

Cokely, E.T., & Kelley, C.M. (2009). Cognitive abilities and superior decision making under risk: A protocol analysis and process model evaluation. *Judgment and Decision Making, 4,* 20-33.

Cokely, E.T., Kelley, C.M., & Gilchrist, A.H. (2006). Sources of individual differences in working memory: Contributions of strategy to capacity. *Psychonomic Bulletin & Review, 13,* 991-997.

Chen, Y. W., & Sun, Y. L. (2003). Age differences in financial decision-making: Using simple heuristics. *Educational Gerontology, 29*, 627-635.

Curran, T. (1997). Effects of aging on implicit sequence learning: Accounting for sequence structure and explicit knowledge. *Psychological Research-Psychologische Forschung, 60*, 24-41.

DeCaro, M.S., Thomas, R.D., & Beilock, S.L. (2008). Individual differences in category learning: Sometimes less working memory capacity is more. *Cognition*, *107*, 284-294.

DeCaro, M.S., Carlson, K. D., Thomas, R.D., & Beilock, S.L. (2009). When and how less is more: a reply to Tharp and Pickering. *Cognition, 111*, 415-421.

Dunlosky, J., & Hertzog, C. (1998). Aging and deficits in associative memory: What is the role of strategy production? *Psychology and Aging, 13*, 597-607.

Dunlosky, J., & Hertzog, C. (2000). Updating knowl edge about encoding strategies: A componential analysis of learning about strategy effectiveness from task experience. *Psychology and Aging, 15*, 462-474.

Filoteo, J. V., & Maddox, W. T. (2004). A quantitative model-based approach to examining aging effects on information-integration category learning. *Psychology and Aging, 19*, 171-182.

Geary, D. C., Frensch, P. A., & Wiley, J. G. (1993). Simple and Complex Mental Subtraction - Strategy Choice and Speed-of-Processing Differences in Younger and Older Adults. *Psychology and Aging, 8*, 242-256.

Gigerenzer, G., Todd, P. M., & the ABC Research Group (1999). *Simple heuristics that make us smart*. New York: Oxford University Press.

Gluck, M. A., & Bower, G. H. (1988). From Conditioning to Category Learning - an Adaptive Network Model. *Journal of Experimental Psychology-General, 117*, 227-247.

Harrington, D. L., & Haaland, K. Y. (1992). Skill Learning in the Elderly - Diminished Implicit and Explicit Memory for a Motor Sequence. *Psychology and Aging, 7*, 425-434.

Herzog, C., Dixion, R.A., Hultsch, D.F. & MacDonald, S.W.S. (2003). Latent change models of adult cognition: Are changes in processing speed and working memory associated with changes in episodic memory? *Psychology and Aging, 18*, 755-769.

Howard, D. V., & Howard, J. H. (2001). When it does hurt to try: Adult age differences in the effects of instructions on implicit pattern learning. *Psychonomic Bulletin & Review, 8*, 798-805.

Howard, J. H., & Howard, D. V. (1997). Age differences in implicit learning of higher order dependencies in serial patterns. *Psychology and Aging, 12*, 634-656.

Johnson, M. M. S. (1990). Age-Differences in Decision-Making - a Process Methodology for Examining Strategic Information-Processing. *Journals of Gerontology, 45*, P75-P78.

Juslin, P., Olsson, H., & Olsson, A. C. (2003). Exemplar effects in categorization and multiple-cue judgment. *Journal of Experimental Psychology-General, 132*, 133-156.

Maddox, W. T., Ashby, F. G., & Bohil, C. J. (2003). Delayed feedback effects on rule-based and information-integration category learning. *Journal of Experimental Psychology-Learning Memory and Cognition, 29*, 650-662.

Mata, R., Schooler, L.J., & Rieskamp, J. (2007). The aging decision maker: Cognitive aging and the adaptive selection of decision strategies. *Psychology and Aging, 22*, 796-810.

Nosofsky, R. M., & Johansen, M. K. (2000). Exemplar-based accounts of "multiple-system" phenomena in perceptual categorization. *Psychonomic Bulletin & Review, 7*, 375-402.

Nosofsky, R. M., Palmeri, T. J., & McKinley, S. C. (1994). Rule-Plus-Exception Model of Classification Learning. *Psychological Review, 101*, 53-79.

Price, A. L. (2005). Cortico-striatal contributions to category learning: dissociating the verbal and implicit systems. *Behavioral Neuroscience, 119*, 1438-1447.

Tharp, I. J., & Pickering, A. D. (2009). A note on DeCaro, Thomas, and Beilock (2008): Further data demonstrate complexities in the assessment of information-integration category learning. *Cognition, 111*, 410-414.