# Age Differences in Strategic Behavior During a Computation-Based Skill Acquisition Task*

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## Abstract:
The development of cognitive skills often involves a transition from an effortful and slow rule-based process to a more fluent memory retrieval process, which occurs with repeated practice on relevant problems (Ackerman & Woltz, 1994; Logan, 1988; Rickard, 1997). As task discriminations become more familiar with practice, individuals can respond quickly and accurately on the basis of remembering the answers rather than having to compute them. In many current models of skill acquisition, transition to retrieval-based processing involves a parallel race between algorithm and memory retrieval (e.g., Logan, 1988; Nosfsky & Palmeri, 1997; Palmeri, 1999); in other models a fast, early strategy choice (algorithm vs. retrieval) is involved (Rickard, 1997, 2004) prior to retrieval of the correct solution (e.g., Reder & Ritter, 1992; Schunn, Reder, Nhouyvanisvong, Richards, & Stroffolino, 1997). In all these models, the rate of associative learning is a key factor in determining whether the problem is solved by retrieval versus algorithm. As items become better learned, the fluency of memory retrieval in accessing the solution increases, as does the fluency of a fast familiarity mechanism for problem recognition that is thought to be a principal influence on early strategic choice.

## Article:
It is no surprise, then, that age differences in the rate of acquiring skills have been attributed to associative learning deficits. Given that older adults require more learning trials to form new associations (Hertzog, Cooper, & Fisk, 1996; Kausler, 1994), one would expect their shift to memory retrieval in skill acquisition tasks to be slowed (Rogers, Hertzog, & Fisk, 2000). Some have argued that the associative learning deficit is a sufficient explanation of age differences in rates of skill acquisition (e.g., Cerella, Onyper, & Hoyer, 2006; Onyper, Hoyer, & Cerella, 2006). In contrast to this mechanistic, bottom-up explanation, other perspectives attribute slowing of skill acquisition to other factors in addition to slowed associative learning, including strategy choice and variables that govern it (e.g., Touron & Hertzog, 2004a, 2004b; Touron, Hoyer, & Cerella, 2001, 2004). In contrasting these explanations, Cerella and colleagues have suggested that top-down processes are trivial in accounting for age differences in skill acquisition (e.g., Cerella et al., 2006; Onyper, Hoyer, & Cerella, 2008). The current article examines the role of strategic factors in age differences in skill acquisition.

### Mechanistic Perspective
The mechanistic perspective argues that both the accuracy and the latency of recognizing associations influence use of memory retrieval in skill acquisition. For example, Cerella et al. (2006) compared older adults and young adults who completed either a paired associative learning task or skill learning task involving transition from a novel computation-based strategy to memory retrieval. Both tasks used the same stimulus set in an effort to test the hypothesis that retrieval use in the skill task is analogous to associative learning.

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Cerella et al. (2006) argued for a dual-process model of learning and retrieval, where stimuli with high associative strength lead to fast and confident retrieval, and stimuli with low associative strength lead to slow and uncertain retrieval. In the latter case, individuals in the skill acquisition task would compute rather than retrieve, as stipulated by race models. Older adults in each condition had more slow retrieval response times (RTs) than young adults. Furthermore, a lack of an age-by-task interaction was interpreted as evidence that age differences in strategy shift reflect only associative learning deficits. Onyper et al. (2006, 2008) reached a similar conclusion when examining the impact of explicit problem recognition testing or manipulations of item difficulty on retrieval shift.

With respect to item difficulty, Hoyer, Cerella, and Onyper (2003) had previously found that difficult items generate later retrieval shifts. Onyper et al. (2008) proposed that stimulus difficulty might influence retrieval strategy selection through two different mechanisms. Easy items might be retrieved earlier because they require less processing and can be learned more quickly (referred to as an "easy effect"), and more difficult items might be retrieved earlier if participants engage in a purposeful strategic approach to minimize processing effort (referred to as a "hard effect"). For a task that involved the processing and learning of novel arithmetic problems, Onyper et al. found that both young and older adults demonstrated easy effects, whereas young but not older adults demonstrated the hard effect. Touron and Hertzog (2004b) had previously demonstrated an analogous hard effect for older adults in the noun–pair lookup (NP) task; Onyper et al. (2008) explained the inconsistent findings as resulting from the greater resource demands inherent in the novel computation task; they interpreted their results as supporting the associative learning deficit hypothesis.

**Metacognitive Perspective**

A role of associative learning deficits in delaying older adults' retrieval shift is not in dispute. However, metacognitive factors might exaggerate age differences in rates of strategy shift. Various theoretical perspectives have been advanced to describe how strategic behavior influences age-related differences in cognitive performance, involving constructs such as strategy production, effective strategy use, response criteria, and task approach or mental model (see Hertzog & Dunlosky, 2004; Hertzog, Vernon, & Rypma, 1993; Thapar, Ratcliff, & McKoon, 2003). Age differences in strategy production and implementation affect performance of various simple and complex cognitive tasks, including associative learning, arithmetic computation, inductive reasoning, episodic memory, and mnemonic techniques (Dunlosky & Hertzog, 2001; Dunlosky, Kubat-Silman, & Hertzog, 2003; Hertzog & Dunlosky, 2004; Lemaire, Arnaud, & Lecacheur, 2004; Saczynski, Willis, & Schaie, 2002; Verhaeghen & Marcoen, 1996). Moreover, metacognitive beliefs about one's ability to control memory appear to affect strategy use in intentional memory tasks (Hertzog, Dunlosky, & Robinson, 2008; Hertzog, McGuire, & Lineweaver, 1998; Lachman & Andreoletti, 2006; Lachman, Andreoletti, & Pearman, 2006). Older adults often (but not always) show lower levels of perceived control over memory (e.g., Lachman, Bandura, Weaver, & Elliott, 1995; Lineweaver & Hertzog, 1998).

Older adults' slower rate of strategy shift in the NP task can be influenced by variables in ways that seem inconsistent with a simple associative learning deficit (e.g., Rogers & Gilbert, 1997; Rogers et al., 2000). Touron and Hertzog (2004a) showed that older adults' retrieval strategy choice lags their associative learning ability to a greater extent than occurs for young adults and that this delay is related to participants' reported confidence in being able to use the memory retrieval strategy. Older adults also appear to avoid the retrieval strategy even after learning items to a criterion (Touron & Hertzog, 2004a); they often show reversals of strategy use on a given item during a skill acquisition task, reverting to using the original strategy after successful retrieval use (Touron, 2006). Older adults' strategy choices are related to the perceived cost and benefit of available strategies (Touron & Hertzog, 2004b), as well as to the mental model and understanding of the task adopted during instructions and training. For example, older adults are more likely to transition to retrieval if they believe that using the retrieval strategy benefits task efficiency (Hertzog & Touron, 2006), or if they perceive a large RT discrepancy between the rule-based and retrieval strategies (Hertzog, Touron, & Hines, 2007).

Most of the evidence for metacognitive effects just cited involves the NP task, which involves a shift from visual search to memory retrieval. Previous results with novel arithmetic tasks that require a more difficult and effortful algorithm also produce effects that cannot easily be reconciled with a pure associative learning deficit. [1] Although Hoyer et al. (2003) found that easy items produced faster strategy shifts, recognition memory performance for problems did not vary by item difficulty. Furthermore, no age differences in the item difficulty effect were obtained, and performance on a recognition test did not vary between older adults who shifted to retrieval early versus late in training. These results appear to suggest that older adults vary in strategy selection effects. Likewise, White, Cerella, and Hoyer (2007) found that confusable items were learned more slowly but in a manner suggesting resistance to a retrieval strategy shift, because participants persisted in using the algorithm for some stimuli even after an extended training interval.

Compelling evidence for a metacognitive influence on retrieval shift in older adults comes from a recent study of monetary incentives in the NP task (Touron, Swaim, & Hertzog, 2007). Providing older adults with modest monetary incentives for fast RT (along with instructions indicating the use of the memory retrieval strategy was the best means of improving RT) produced much earlier retrieval shifts for older adults than in two other groups: those assigned to a standard NP task control condition, and those instructed to use the memory retrieval strategy to improve RT (but without incentives). Only the monetary incentive increased retrieval use, suggesting that the incentive motivated older adults to risk errors to achieve their rewards in a manner that mere instructions to respond faster did not accomplish.

Indeed, older adults are often more conservative in RT task response criteria (Brébion, 2001; Hertzog et al., 1993), preferring accuracy over speed. The demonstration that instructions and monetary incentives increase older adults' retrieval use indicates that retrieval choices in the NP task are volitional and under participant control. It is important to note that monetary incentives increased retrieval use without influencing performance accuracy, response confidence, and subsequent item recall in a surprise cued–recall test. This latter set of outcomes appears to rule out an explanation of the incentive effects as due to greater effort to memorize the pairings. Touron et al.'s (2007) findings therefore implicate metacognitive influences as factors in the rate of strategy shifts in the NP task.

Such effects call into question meta-theoretical assumptions about how to think about age differences in cognitive task performance (Hertzog, 2008). Rates of RT improvement in skill acquisition tasks have been interpreted as providing a straightforward and unambiguous measure of age impairments in rates of skill acquisition and the associative mechanisms that may underlie it. However, if older adults are likely to avoid the retrieval strategy—perhaps due to an aversion to risking errors, although they could in fact successfully employ the strategy—then studies that fail to account for such strategic differences overestimate the age effect on rates of associative learning and the magnitude of age deficits in skill acquisition resulting from those deficits (Rogers et al., 2000). Similar concerns about older adults' suboptimal response conservatism arise in other performance contexts (Botwinick, 1984; Thapar et al., 2003).

### Current Aims

An important distinction between available research supporting a mechanistic versus metacognitive account lies in the type of skill acquisition tasks that have been used. Whereas most work supporting the pure associative deficit hypothesis has used tasks involving a computation-based algorithm, most work supporting metacognitive influences on age differences has used a task involving a visual search algorithm. It is possible that greater resource demands in a computation-based skill acquisition task might serve to dampen purposeful strategy use and reduce retrieval reluctance effects obtained with the shift from visual search (Onyper et al., 2008). If resource demands indeed reduce strategic behavior, it is possible that metacognitive influences on age differences in skill acquisition do not generalize to more complex task environments. This argument makes it imperative to evaluate retrieval reluctance in a task involving a computation-based algorithm. We used a novel arithmetic task with the instructions and incentives conditions applied by Touron et al. (2007). If task difficulty influences metacognitive and mechanistic mechanisms tied to the retrieval shift, then incentives may not moderate rates of retrieval shift in the more demanding novel arithmetic task as they did in the NP task. If older adults are averse to shifting to a retrieval-based strategy in a novel arithmetic task, even when they could use memory as a basis for accurate responding, then monetary incentives should produce robust benefits for rates of retrieval shift.

## Method

### Design

The experiment was a 2 (age: young, old) × 3 (condition: control, instructions, incentives) × 30 (training blocks: 1–30) mixed design, with age and condition as between-subjects independent variables and training block as the within-subjects variable.

### Participants

Younger adult participants were undergraduates from Appalachian State University, who received course credit for their participation. Older adults were recruited from the nearby community and were compensated with a modest honorarium (approximately $10 per hr) for their participation. Seventy-two younger adults between 18 and 25 years of age (*M* = 19.4, 67% female) and 52 older adults between 60 and 75 years of age (*M* = 67.8, 54% female) participated. All participants were prescreened for basic health issues that could impede participation, and were required to have good corrected visual acuity (20/50 or better). Participants also completed a brief battery of cognitive ability tests. Group characteristics differed in expected directions and are reported in Table 1; comparisons involved a 2 (age: young, old) × 3 (condition: control, instructions, incentives) general linear model.

Table 1
*Means (and Standard Errors) of Participant Characteristics*

| Measure | $\text{Young}_{\text{control}}$ | $\text{Young}_{\text{instructions}}$ | $\text{Young}_{\text{incentives}}$ | $\text{Old}_{\text{control}}$ | $\text{Old}_{\text{instructions}}$ | $\text{Old}_{\text{incentives}}$ |
|---|---|---|---|---|---|---|
| Education | 12.9 (0.40) | 12.8 (0.40) | 13.0 (0.43) | 15.2 (0.48) | 15.4 (0.50) | 16.4 (0.50) |
| Medication[a] | 0.96 (0.30) | 0.88 (0.30) | 1.23 (0.32) | 2.44 (0.35) | 1.82 (0.36) | 2.82 (0.36) |
| Vocabulary[a] | 13.6 (1.11) | 13.4 (1.11) | 14.1 (1.18) | 19.9 (1.30) | 22.1 (1.34) | 20.1 (1.34) |
| Digit symb[a] | 66.1 (2.29) | 72.1 (2.29) | 67.7 (2.44) | 53.0 (2.69) | 48.1 (2.77) | 50.6 (2.77) |
| DS memory[a] | 7.68 (0.35) | 7.48 (0.35) | 7.55 (0.38) | 6.00 (0.42) | 5.88 (0.43) | 6.71 (0.43) |

*Note.* Education = number of years of education completed; medication = self-reported number of medications taken daily; vocabulary = number correct out of 40 on the Shipley Vocabulary Test (Zachary, 1986); digit symb = WAIS Digit–Symbol subtest (Wechsler, 1981); DS memory = symbol recall memory following the WAIS Digit–Symbol subtest (Wechsler, 1981).
[a] Age comparison $p < .05$. No comparisons of or interactions with the condition variable were significant. No comparison of education was made because of the interpretational ambiguity (young adults are currently enrolled at a university).
*Means (and Standard Errors) of Participant Characteristics*

### Materials and Procedures

A Visual Basic 6.0 program controlled stimulus presentations and response recordings. Stimuli were presented in 15-point Arial font on a 15-in. (38.1-cm) LCD monitor with a resolution of 1024 × 768. Seating and monitors were adjusted to a height and distance that optimized each participant's viewing and comfort.

The stimulus set consisted of 12 repeated novel ("pound") arithmetic equations (Rickard, 1997). Equations were presented as A # B = C, where *A* was a one-digit number and *B* and *C* were two-digit numbers, and had the computational form: [(B – A) + 1] + B = C. Problems were *true* if the solution conformed to the equation and were *false* if it did not conform. To eliminate participants' learning true–false associations to particular values of *C* rather than processing full equations, the six true equations used different values of *C*, and false equations were randomly constructed by the testing program for each trial using these six values.

All participants received general task instructions and practice via computer. Participants in the standard condition were told to equally focus on speed and accuracy. Participants in the instructions and incentives conditions received additional instructions emphasizing quick responses over accuracy and informing them that the best way to respond quickly is to retrieve the target stimulus from memory. Participants in the incentives condition received additional instructions about the incentive system: (a) one point worth 50¢ could be gained for each block of accurate memory retrieval, for a maximum total payout of $15; (b) the criteria to earn points would become more stringent over time; and (c) their goal should be to eventually achieve 100% retrieval use. Incentives instructions did not provide the precise criteria for receiving points, as this might have led to more vigilant task monitoring that could be resource depleting.

In actuality, the point-based system to earn a monetary bonus included the following criteria. Use of the retrieval strategy was indicated by strategy probe reports and confirmed by an accurate solution and RT slower than 200 ms and faster than either 5,000 ms (older adults) or 2,500 ms (younger adults). We used the lower RT boundary to account for possible guessing behavior, as choice RT tasks cannot generally be responded to in less than 200 ms (e.g., Wilding & Sharpe, 2004). We used the upper RT boundaries to ensure that participants were not reporting retrieval use on trials when they had actually computed the solution. Older adults generally take longer than 5,000 ms to compute equation solutions in the pound arithmetic task, and younger adults generally take longer than 2,500 ms to compute equation solutions (see Touron et al., 2004). To account for normative performance improvements, we increased the minimum percentage of retrieval trials required to earn bonus points from 50% (Blocks 1–10) to 75% (Blocks 11–20) to 90% (Blocks 21–30).

Before testing began, we required all participants to score perfectly on a series of review questions confirming their understanding of their condition instructions. If one or more review questions were answered incorrectly, we allowed participants to review the instructions before attempting the quiz again.

During training, participants trained on the stimulus set for 30 blocks; each block contained 24 trials (one true and one false for each stimulus). Participants were to press a key labeled *Y* if the equation was true or a key labeled *N* if the equation was false. Participants then reported the strategy used by pressing labeled keys: *C* if they used the computation strategy, *M* if they used the memory retrieval strategy, *B* if they used both strategies, or *O* (signifying *other*) if they used a strategy not listed. If participants responded to the equation trial incorrectly, the strategy report was followed by the presentation of the word *ERROR* in the center of the screen for 1 s.

A test phase followed training, during which all participants were shown self-paced instructions and then received 2 blocks of memory probes. Participants were instructed to use memory retrieval and no computation in solving these problems, and an *M* (analogous to the memory retrieval strategy report) was used as the fixation point prior to each trial as a reminder of the instructions. Memory trials used the same stimulus set and format as training trials, except that the equation disappeared at a response deadline determined by their individual retrieval responses during training, set at $m + 2(sd)$.

Following each memory probe, participants reported their level of confidence that their preceding answer was correct by pressing keys labeled *0%* through *100%* in increments of 10. If participants answered the memory probe incorrectly, the confidence judgment was followed by the word *ERROR* presented centrally on the following screen for 1 s, followed by the next trial. We did not use memory probes during training because they tend to increase retrieval use by older adults (Rogers & Gilbert, 1997; Touron & Hertzog, 2004a), which would reduce our opportunity to observe instructional effects.

Throughout the task, each block was followed by the opportunity to take a short break, and feedback on mean RT and accuracy was presented. During training, the program also presented participants with their average percentage of retrieval reports and let them know whether or not a bonus point was earned (for participants in the incentives condition only) for the preceding block. After every 10 blocks, participants took a mandatory 1-min break. At the breaks following Blocks 10 and 20, participants in the incentives condition were reminded that it would become more difficult to gain points and that they should continue to strive for 100% accurate retrieval.

The experimental task was followed by a debriefing session that included a posttask survey, including questions on task understanding and performance. Participants were asked questions regarding global task confidence ("How confident are you that you can recall the left-hand side [A#B] for each equation when prompted with the right-hand side or solution of the equation[?#?=C]?"; 0 = *definitely won't recall* and 100 = *definitely will recall*), estimated solution memorization ("What percentage of the equations did you memorize?"; 0 = *none of the equations* and 100 = *all of the equations*), rated effort for memorization ("How much effort did it require for you to memorize the equations and solutions?"; 1 = *automatic* and 5 = *effortful*), and perceived improvement gained from the retrieval strategy ("How much does using memory improve performance on this task?"; 1 = *very much* and 5 = *not at all*). Participants in the instructions and incentives conditions also rated perceived difficulty of adhering to instructions ("Did you find it difficult to conform to the instructions to respond quickly using retrieval?"; 1 = *very much* and 5 = *not at all*), and those in the incentives condition rated the value of the monetary incentive ("How much did you value the monetary inventive offered in this study?"; 1 = *very much* and 5 = *not at all*). Participants also provided judgments of learning (JOLs; "For each equation, how confident are you that you can recall the left-hand side (A#B) for each equation when prompted with the right-hand side or solution of the equation (?#?=C)?"; 0 = *definitely won't recall* and 100 = *definitely will recall*), and performed a cued stimulus recall task that required participants to write in the left-hand side of each equation when presented with a list of equation solutions.

## Results

Data were analyzed as follows unless otherwise specified. Group comparisons involved a 2 (age: young, old) × 3 (condition: control, instructions, incentives) × 30 (training block) repeated measures GLM on each dependent variable. Strategy use and RT data were examined for correct trials only. Participant median RTs were analyzed to reduce the influence of positive skew and outliers that occur infrequently due to fast guessing or attentional lapses; we report group means of the participant medians.

### Phase 1 Training

### Retrieval use

The mean percentage of reported retrieval strategy use is presented in Figure 1. Because retrieval use is not possible on first exposure to the stimuli, reported retrieval use is plotted starting with Block 2. Young adults reported retrieval more often than older adults, $F(1, 114) = 24.41$, $MSE = 15{,}047$, $p < .01$. Retrieval use also varied by condition, $F(2, 114) = 23.17$, $MSE = 15{,}047$, $p < .01$. Retrieval use increased with training, $F(28, 3192) = 77.83$, $MSE = 303$, $p < .01$. Increases were steeper for young adults, $F(28, 3192) = 4.70$, $MSE = 303$, $p < .01$, and varied by condition, $F(56, 3192) = 1.37$, $MSE = 303$, $p < .05$. These effects were most noticeable in the linear and quadratic trends for training (age: linear $p < .01$, quadratic $p = .02$; condition: linear $p < .01$, quadratic $p = .05$), indicating faster rates of retrieval shift as the source of the overall significant effects.

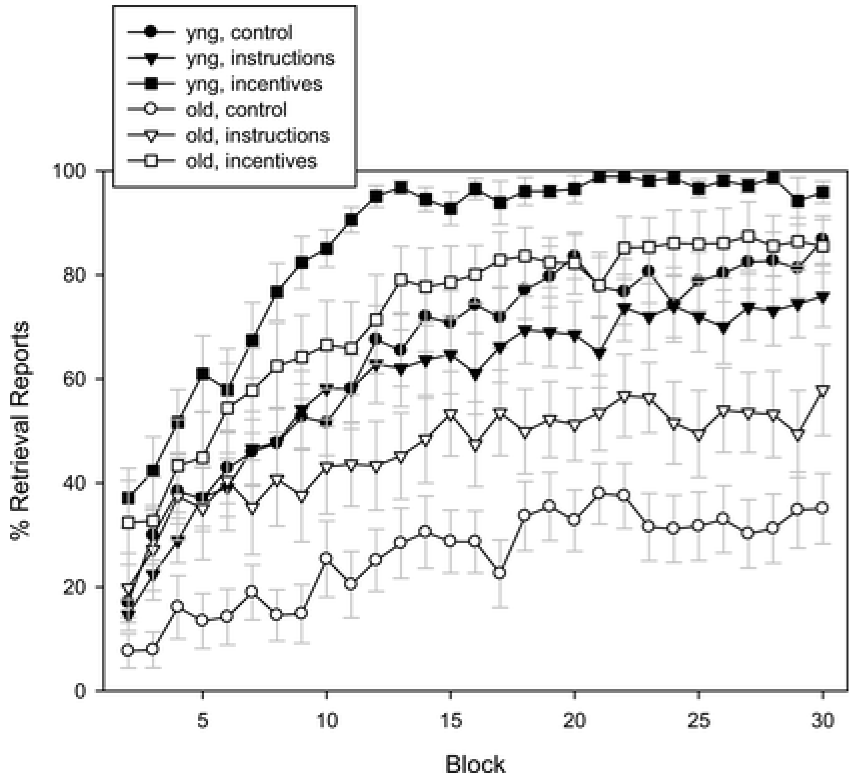


*Figure 1. Percentage of retrieval reporting and standard error bars by age, condition, and training block. Yng = young.*

Critical to the retrieval reluctance hypothesis, there was a robust age by condition interaction, $F(2, 114) = 4.66$, $MSE = 15{,}047$, $p < .01$, indicating greater retrieval shift by older adults after experimental intervention. An improvement in the retrieval instructions condition or retrieval incentives condition versus the standard control instructions may be taken as evidence favoring the metacognitive perspective over a simple mechanistic perspective. Focused comparisons further examined the pattern of outcomes and showed a reliably larger effect of incentives, relative to the control condition, for older adults compared to young adults, $F(1, 81) = 5.29$, $MSE = 422$, $p = .02$. On average, incentives increased overall retrieval use compared to the control condition by 42 % for older adults and 21 % for younger adults; for both groups, the increased retrieval use relative to the control condition was reliable, *p*s < .01. The focused comparison of instructions to control also showed a larger effect for older adults compared to young adults, $F(1, 84) = 4.91$, $MSE = 668$, $p = .02$. Instructions increased overall retrieval use compared to the control condition by 20% for older adults ($p = .03$), but the comparison was not reliable for younger adults ($p = .4$). The final focused comparison, of incentives versus instructions, did not show a reliable interaction with age, $F(1, 77) = .14$, $MSE = 0.84$, $p = .7$. This outcome suggests that retrieval instructions may have a similar but more subtle influence, compared to monetary incentives, on age difference in retrieval use for a novel computation task. This differs from findings for the NP task, where instructions had no discernable impact on retrieval, and also contrasts starkly with a perspective which advocates that the greater resource demands of novel computation should lead to less possibility of metacognitive strategy choice.

The overall condition by training interaction did not vary reliably by age ($p = .3$). However, focused comparisons showed that age differences in improvements were reliable when comparing the control and incentives conditions, $F(28, 2128) = 1.5$, $MSE = 319$, $p = .04$, although rates of improvement were similar between age groups when comparing the control and instructions conditions, $F(28, 2212) = 0.76$, $MSE = 292$, $p = .8$. Although instructions produced reliably faster retrieval shift for both young and older adults, incentives produced steeper retrieval shifts compared to the control condition for older adults versus young adults. This effect was confined to the linear trend (linear $p < .05$, quadratic $p = .9$), supporting an interpretation of faster retrieval shift for older adults with incentives. The age comparison for instructions versus incentives was again nonsignificant, $F(28, 2044) = .84$, $MSE = 297$, $p = .7$, again suggesting that instructions and incentives could each potentially influence age differences in shift.

Given that young adults in the incentives condition approach ceiling levels of performance, it is important to test these outcomes within early training blocks. Indeed, when analysis was confined to the first half of training, the age difference in improvements persisted when comparing the control and incentives conditions, $F(14, 1078) = 1.81$, $MSE = 214$, $p < .05$, and was not reliable past the quadratic trend (quadratic $p < .05$, cubic $p = .4$), again supporting an interpretation of faster retrieval shift for older adults with incentives. The age difference in improvements remained nonsignificant when comparing the control and instructions conditions, $F(14, 1078) = 1.06$, $MSE = 216$, $p = .4$, and when comparing the instructions and incentives conditions, $F(14, 1064) = .42$, $MSE = 214$, $p = .7$.

Furthermore, although the three-way interaction did not reach statistical significance, the experimental manipulations clearly demonstrated that older adults were not inevitably slower than younger adults in retrieval shift, supporting the metacognitive perspective. At the end of practice (i.e., the final training block), older adults in the incentives condition reported using retrieval more often than older adults in the control or instructions condition (*p*s < .01) and were not reliably distinct from younger adults, regardless of condition (*p*s > .13).

It is perhaps even more important that older adults in the incentives condition used retrieval at a similar rate to young adults throughout training. Indeed, focused comparisons of the older adults in the incentives condition with younger adults in the control condition showed greater retrieval use in Block 2 ($p < .01$) by older adults and equivalent retrieval use in Blocks 3–30 (all *p*s >.05). Furthermore, older adults in the incentives condition also showed greater retrieval use than older adults in the control condition throughout training (all *p*s <.01).

**Accuracy**

Response accuracy (scaled as percentage correct) is presented in Figure 2. Accuracy did not vary overall by age ($p = .5$). Given experimental instructions regarding the importance of accuracy relative to speed, the main effect of condition was expected, $F(2, 114) = 5.83$, $MSE = 3{,}337$, $p < .01$. However, despite the fact that both the instructions and the incentives conditions emphasized speed over accuracy, focused comparisons revealed that accuracy was equivalent for the standard control ($M = 88.2$) and instructions ($M = 88.2$) conditions but lower for the incentives condition ($M = 81.1$) compared to each (*p*s < .01). Thus, it appeared that the substantial shift to retrieval in the incentives condition (Figure 1) was accomplished at least in part by individuals sacrificing accuracy for speed by using retrieval. It is notable that accuracy in the incentives condition was lower but still reasonably high and well above chance, even early in training. The magnitude of the reduced accuracy in the incentives condition did not differ between the age groups, and accuracy in the young adult and older adults incentives groups was statistically equivalent ($p = .67$). Accuracy varied by training block, $F(29, 3306) = 1.7$, $MSE = 67$, $p = .01$, with slight increases by old and slight decreases by young, $F(29, 3306) = 5.63$, $MSE = 67$, $p < .01$, but no other interactions were significant.

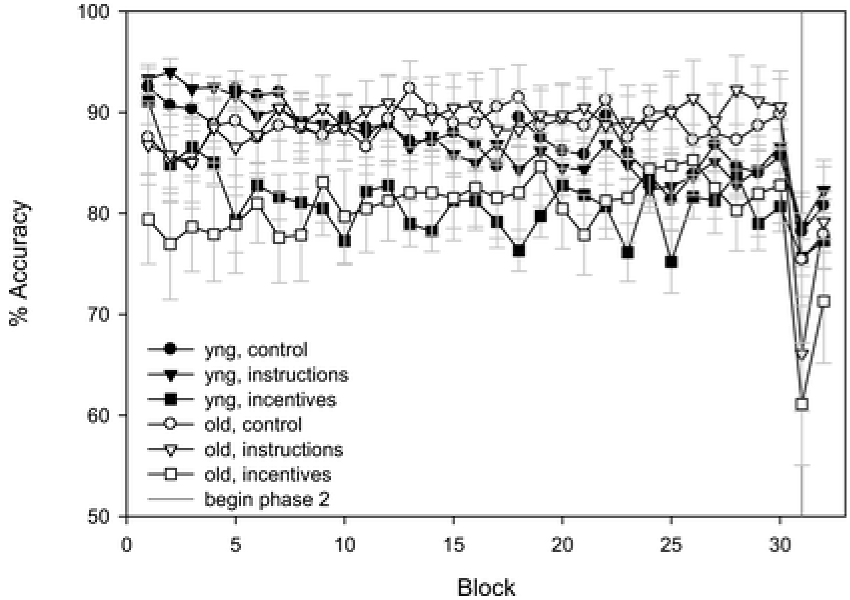


*Figure 2. Percentage of accuracy and standard error bars by age, condition, and training block. Yng = young.*

**RTs**

RT data are presented in Figure 3. Young adults responded more quickly than older adults, $F(1, 114) = 20$, $MSE = 47{,}971{,}911$, $p < .01$. RT also varied by condition, $F(2, 114) = 7.62$, $MSE = 47{,}971{,}911$, $p < .01$; participants in the incentives condition were faster than those in the standard or instructions conditions. This effect emerged early in practice and was consistent with the hypothesis that retrieval shift in this condition involved a speed–accuracy tradeoff accomplished by a greater use of the retrieval strategy early in training. Improvements occurred with training, $F(29, 3306) = 198.61$, $MSE = 1{,}099{,}202$, $p < .01$, and were steeper for young adults, $F(29, 3306) = 11.22$, $MSE = 1{,}099{,}202$, $p < .01$. Although the training by condition interaction did not reach significance ($p = .6$), the age by condition by training interaction, $F(58, 3306) = 2.12$, $MSE = 1{,}099{,}202$, $p < .01$, was associated with earlier RT benefits of the incentives condition for young adults. In contrast, incentives appeared to result in slower RTs and substantial variability in median RTs early in practice for older adults. This effect dissipates after Block 5; thereafter, older adults' RTs in the incentives condition are faster than older adults' RTs in the standard and instructions conditions. Moreover, older adults' RTs under monetary incentives approach the RT performance of young adults in the control and instructions conditions.

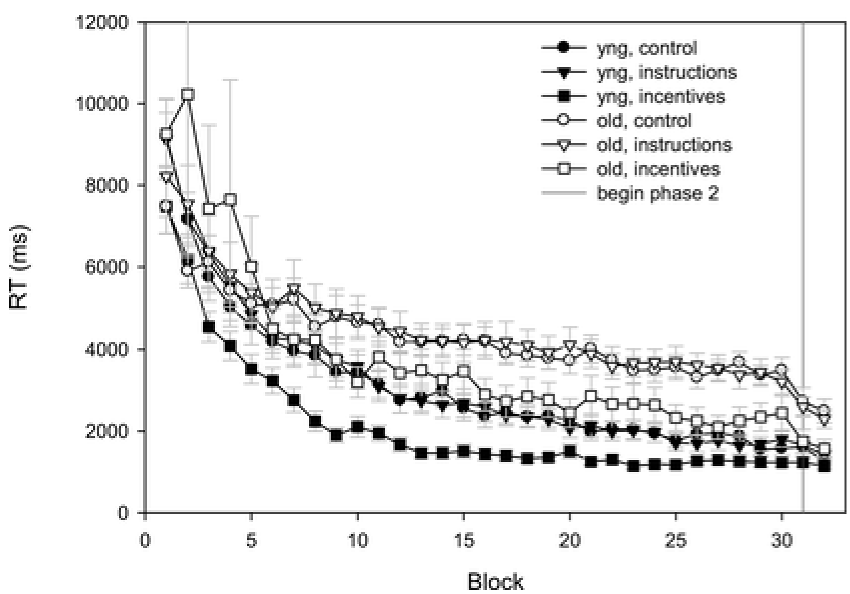

*Figure 3. Response times (RT) and standard error bars by age, condition, and training block. Yng = young.*

RTs were further examined by separating trials by reported strategy (see Figure 4, upper panel). Differentiating performance by strategy report typically validates the accuracy of strategy self-reports by showing widely separated RT distributions for trials reported to differ in strategy (e.g., Touron & Hertzog, 2004a). In the current study, it is also critical to establish that the inclusion of instructions and monetary incentives did not influence the RT difference, and hence the validity of strategy self-reports. As expected, trials with reported retrieval were faster than trials with reported computation, $F(1, 114) = 128.98$, $MSE = 6{,}414{,}313$, $p < .01$. This strategy difference did not interact with age, $p = .92$. On average, participants in the incentives condition showed a larger difference between retrieval and computation times, with faster retrieval RTs and slower computation RTs, $F(2, 114) = 3.47$, $MSE = 6{,}414{,}313$, $p = .03$. The mechanism of the effect differed by age, however, with young adults in the incentives condition showing faster retrieval and older adults in the incentives condition showing slower computation, $F(2, 114) = 3.79$, $MSE = 6{,}414{,}313$, $p = .03$.

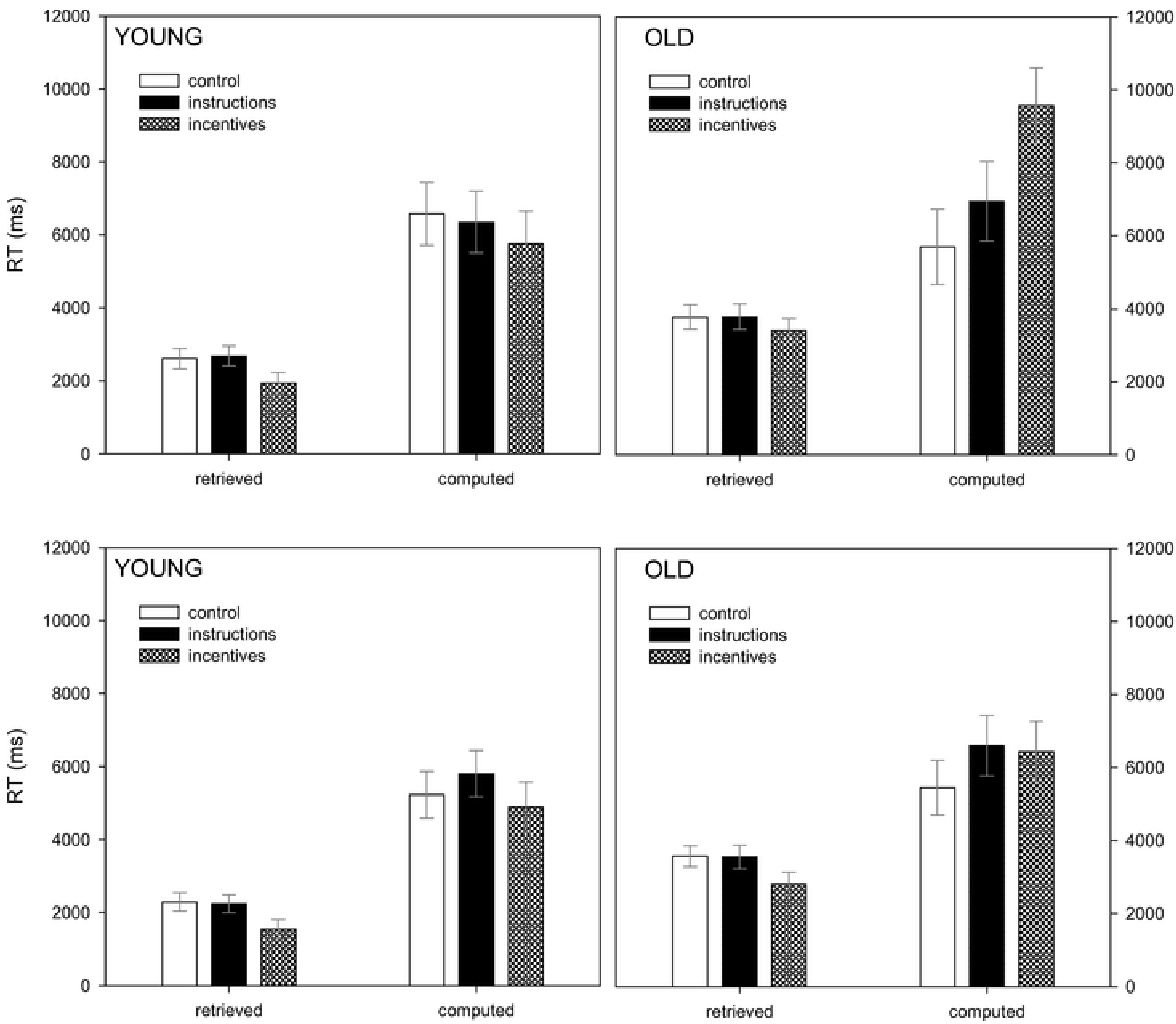


*Figure 4. Response times (RT) and standard error bars by age, strategy, and condition. Top panels provide data for the full training period. Bottom panels do not include the first five blocks of training.*

We performed further analyses to clarify any condition difference in older adults' computation RTs. As noted earlier, it appears that older adults in the incentives condition respond slowly and variably in the first five blocks of training, but thereafter respond more quickly than older adults in the control and instructions conditions. When the strategy-separated RT comparisons discard these early blocks (bottom panels of Figure 4), older adults in the incentives condition show computation times comparable to the other conditions, and the strategy variable no longer interacts with the age or condition variables (*p*s > .34). Nevertheless, RTs for reported retrieval trials were still substantially faster than RTs for reported computation trials.

This pattern of outcomes is inconsistent with the notion that incentives incite participants to falsely report retrieval despite having computed the solution; such an effect would result in longer RTs for false retrieval reports and less separation of the median RTs between reported retrieval and reported computation trials. These outcomes support the validity of the strategy self-reports. They are also consistent with effects demonstrated by Touron et al. (2007), who found no influence of instructions or incentives on the validity of strategy reporting for young or older adults.

**Phase 2 Memory Test**

In Phase 2, participants were instructed to respond using only memory retrieval instead of computation, and a subject-tailored fast response deadline was imposed in two blocks of trials to enforce these instructions. These test blocks were used to determine how individuals perform on the basis of memory use alone.

**Accuracy**

Memory test accuracy was higher overall for young compared to old, $F(1, 77) = 4.76$, $MSE = 294$, $p = .03$. Accuracy did not vary by condition and showed no evidence of an age by condition interaction (*p*s > .19; see Figure 2). Accuracy improved from the first to second test block, $F(1, 77) = 9.56$, $MSE = 89$, $p < .01$, with greater improvement for older adults compared to young adults, $F(1, 77) = 5.33$, $MSE = 89$, $p = .02$. When constrained to Block 2, the age comparison was nonsignificant ($M_{\text{young, block1}} = 77.5$, $M_{\text{old, block1}} = 67.5$, $M_{\text{young, block2}} = 78.8$, $M_{\text{old, block2}} = 76.1$). [2] In comparison with retrieval reports in Figure 1, it is apparent that the probability of correct item recognition exceeded the probability of retrieval use at the end of Phase 1 for older adults in the control and instructions conditions, consistent with retrieval reluctance. Critically, and in accordance with the retrieval reluctance hypotheses, this discrepancy between memory and retrieval use disappeared for older adults who were given monetary incentives to retrieve. Moreover, young adults did not manifest retrieval reluctance in any condition.

Studies of the NP task have demonstrated an age difference in the conditional probability of retrieval for an item given that they correctly solved the item in a preceding memory probe (e.g., Touron & Hertzog, 2004a). Because the novel arithmetic task does not lend itself to interpolated recognition memory probes, we could not compute the exact same index in this task. We instead computed the probability of retrieval for an item on Block 30 (the last standard block), given that they correctly recognized the item in the memory instruction condition (given in Block 31), assuming that accuracy in Block 31 reflects knowledge of item pairings available in Block 30. As with the NP task, older adults were less likely to have used the retrieval strategy for items that they then correctly recognized on the following memory probe ($M_{\text{control}} = .45$, $M_{\text{instructions}} = .52$, $M_{\text{incentives}} = .62$) compared to young adults ($M_{\text{control}} = .68$, $M_{\text{instructions}} = .65$, $M_{\text{incentives}} = .77$), $F(1, 77) = 10.63$, $MSE = 0.05$, $p < .01$. There was a trend for a condition difference, with sample means in the direction of participants in the incentives conditions being more likely to retrieve for items they knew, $F(2, 77) = 2.45$, $MSE = 0.05$, $p = .09$, but the effect did not reach statistical significance. However, when a focused comparison of incentives versus the other two conditions was evaluated, as recommended by Touron et al. (2007), the expected condition effect was reliable, $F(1, 79) = 4.99$, $MSE = 0.01$, $p < .03$. The Age × Condition interaction was not significant, $p = .69$, suggesting that both age groups were moved toward greater retrieval use for learned items by monetary incentives.

**Confidence**

No age or condition differences were found for probe response confidence ($M_{young}$ = 87.9, $SE_{young}$ = 2.13, $M_{old}$ = 87.2, $SE_{old}$ = 3.19; *ps* > .09). As shown previously for the NP task, response confidence exceeded obtained test accuracy for both younger adults and older adults. Gamma correlations of confidence judgments with associative recognition accuracy indicated reliable and equivalent resolution of confidence judgments across groups ($M_{young}$ = .68, $SE_{young}$ = .04, $M_{old}$ = .60, $SE_{old}$ = .06; *p*s > .24).

**RTs**

RT data for memory test trials are presented in Figure 3. It is important to note that the RT deadline did not appear to substantially constrain responding. Timeouts were rare, although somewhat more frequent for older adults (*M* = 2.9 % of responses) compared to young adults (*M* = 1.5 % of responses). This outcome suggests that participants were complying with retrieval instructions rather than attempting computation.

Young adults responded more quickly compared with older adults, $F(1, 77) = 25.61$, $MSE$ = 985,228, $p < .01$. RT also varied by condition, $F(1, 77) = 5.63$, $MSE$ = 985,228, $p < .01$. Participants in the incentives condition retrieved solutions more quickly than those in the standard or instructions conditions, and the interaction with age was not significant. Improvements occurred from Block 1 to Block 2, $F(1, 77) = 24.34$, $MSE$ = 77,307, $p <$ .01, but block did not interact with age or condition.

Cerella et al. (2006) suggested that age differences in the conditional probability index might be an artifact of older adults having more successful slow retrieves in memory probes that cannot occur in standard trials because, in those cases, the algorithm process results in successful discrimination prior to the completion of slow retrievals. We therefore compared conditional probabilities of retrieval by memory probe retrieval speed and confidence. Retrieval speed was separated into values below (fast) or above (slow) the participant's median retrieval RT. Given that confidence levels were generally quite high, confidence was separated into items with 100% (high) confidence or less than 100% (low) confidence. As shown above, the main effect of age on the conditional probability of retrieval was statistically reliable ($p < .01$). Conditional retrieval was greater for items that were retrieved quickly ($M_{young, fast}$ = .78, $M_{young, slow}$ = .65, $M_{old, fast}$ = .58, $M_{old, slow}$ = .50), $F(1, 77) = 13.58$, $MSE = 0.03$, $p < .01$, but the effect did not vary by age group, $p = .39$, or condition, $p = .61$. Critically, older adults' conditional probability of retrieval was lower even for items that were retrieved quickly, $p < .01$. We also found that conditional retrieval was greater for items with high memory probe confidence ($M_{young, high}$ = .81, $M_{young, low}$ = .51, $M_{old, high}$ = .64, $M_{old, low}$ = .37), $F(1, 58) = 29.47$, $MSE = 0.07$, $p < .01$, but the effect again did not vary by age group, $p = .78$, or condition, $p = .56$. Critically, again, older adults' conditional probability of retrieval was lower even for items that were retrieved with high confidence, $p = .03$. Notably, the sample means indicated smaller effects of retrieval speed and confidence on conditional retrieval for older adults, opposite to the prediction of the slow retrieval account. It appears that age differences in retrieval reluctance cannot be accounted for by retrieval speed or confidence.

We also considered the possibility that slow retrievals may not occur in strategy shift tasks because, from a race model perspective, the algorithm can be faster than slow retrievals (Cerella et al., 2006). We compared our slowest memory probe RTs from correct trials (those at the 75th percentile) with fast computation RTs from correct trials (those at the 25th percentile in Blocks 25–30). Even fast computation in standard trials took much longer than slow memory probe retrieves, $F(1, 42) = 7.3$, $MSE$ = 2,444,018, $p < .01$, and this pattern did not vary by age, $p = .25$ (younger: $M_{fast\ compute}$ = 2,374, $M_{slow\ retrieve}$ = 1,789; older $M_{fast\ compute}$ = 3,870, $M_{slow\ retrieve}$ = 2,693). Thus, it does not appear that slow retrievals would be routinely overridden by fast computations in the current task.

**Posttask Survey**

The posttask survey data provided useful clarifying information about age differences in metacognitive variables relevant to the strategy shift (see Table 2). After task experience, older adults showed lower global retrieval confidence, indicating that they did not feel as confident in relying on memory retrieval after practice on the novel arithmetic task. On average, older adults estimated less memorization of problem solutions. It is interesting, however, that older adults in the incentives condition estimated greater memorization of problem solutions compared to those in the control condition. Older adults also rated memorization as more effortful (less automatic) and perceived less task improvement from use of the memory retrieval strategy, although older adults in the incentives condition perceived greater task improvement from the memory retrieval strategy compared with the control condition. Older adults had lower mean JOLs than younger adults and also had reliably lower cued recall of problem solutions. Ratings for the difficulty of adhering to instructions and ratings of the value of monetary incentives did not vary by age.

Table 2
*Means (and Standard Errors) of Survey Responses*

| Measure | $Young_{control}$ | $Young_{instructions}$ | $Young_{incentives}$ | $Old_{control}$ | $Old_{instructions}$ | $Old_{incentives}$ |
|---|---|---|---|---|---|---|
| Confidence[a] | 56.8 (5.8) | 50.0 (5.8) | 47.3 (6.2) | 40.0 (6.8) | 36.5 (7.0) | 39.4 (7.2) |
| Memorization[a,b] | 64.8 (4.7) | 56.0 (4.7) | 65.9 (5.0) | 28.6 (5.5) | 27.1 (5.7) | 43.8 (5.9) |
| JOL[a] | 49.9 (5.6) | 37.2 (5.6) | 46.7 (6.0) | 23.4 (6.6) | 14.9 (6.8) | 26.7 (7.0) |
| Recall[a] | 20.3 (3.3) | 19.3 (3.3) | 11.7 (3.5) | 2.8 (3.9) | 2.9 (4.0) | 6.3 (4.2) |
| Effort[a] | 3.5 (0.2) | 3.6 (0.2) | 3.6 (0.2) | 4.6 (0.2) | 4.2 (0.3) | 4.3 (0.3) |
| Improvement[a,b] | 2.3 (0.2) | 2.0 (0.2) | 2.3 (0.3) | 3.5 (0.3) | 3.0 (0.3) | 2.6 (0.3) |
| Inst. difficulty | | 3.0 (0.2) | 2.9 (0.2) | | 2.5 (0.3) | 2.5 (0.3) |
| Inc. value | | | 3.6 (0.3) | | | 3.7 (0.3) |

*Note.* Confidence = global confidence rating; memorization = estimated stimulus memorization; JOL = average posttask recall judgment of learning; recall = post-JOL recall accuracy out of 100%; effort = rated effort for memorization; improvement = perceived improvement gained from the retrieval strategy; inst. difficulty = perceived difficulty adhering to instructions; inc. value = rated value of the monetary incentive.
[a] Age comparison $p < .05$. [b] Control versus incentives condition comparison $p < .05$ in the older adult sample. No other condition comparisons or interactions were reliable.

*Means (and Standard Errors) of Survey Responses*

Pearson correlations between retrieval use at the end of training (in the final block) and these metacognitive variables provide further insight into the relationship between strategy selection and metacognition. For both young adults and older adults, retrieval use was related to global retrieval confidence ($r_{young} = -.25$, $p_{young} = .04$; $r_{old} = -.33$, $p_{old} = .02$) and memorization estimates ($r_{young} = .28$, $p_{young} = .02$; $r_{old} = .52$, $p_{old} < .01$) but not to JOLs, recall, effort, instructions difficulty, or incentives value. For older but not younger adults, retrieval use was additionally related to the perceived task improvement from using retrieval ($r = -.44$, $p < .01$), indicating that the mental task model was more influential in older adults' strategy selection. Notably, this relationship was seen for older adults in the control and instructions conditions, but not in the incentives condition ($r_{control} = -.51$, $p_{control} = .03$, $r_{instructions} = -.48$, $p_{instructions} = .05$, $r_{incentives} = .21$, $p_{incentives} = .5$). Incentives may have eliminated variability in retrieval use for this group that is otherwise associated with task mental models that influence individuals' strategy use.

## Discussion

The present results demonstrate that retrieval use in a computation-based skill acquisition task involves a strategic choice mechanism. Older adults given retrieval instructions or monetary incentives and younger adults given monetary incentives used retrieval more often than individuals given standard instructions in the task. However, retrieval shift in the incentive condition was more pronounced for older adults from virtually the beginning of practice. The strong additional effect of retrieval instructions and monetary incentives for older adults indicates that the retrieval reluctance identified in the NP task operates in the novel arithmetic task as well. This inference is supported by the fact that older adults' use of memory retrieval for standard novel arithmetic problem solutions at the end of practice was lower than their memory probe performances when deadlines forced memory-based responding. Younger adults, in contrast, showed no such discrepancy. The pattern of results provides strong support for the argument that older adults choose not to base responses on retrieving problem solutions, even when they could effectively do so.

Despite similarity in outcomes, the incentives effects in this novel arithmetic task differed from findings of Touron et al. (2007) in the NP task in some important respects. First, incentives had a greater effect on older adults' retrieval shift in the novel arithmetic task. At the end of training in the NP task, older adults in the incentives condition showed about 80% retrieval use compared with 70% retrieval use in the control condition. At the end of comparable training in the novel arithmetic task, older adults in the incentives condition showed about 80% retrieval use compared to 35% retrieval use in the control condition. Second, retrieval instructions without incentives similarly influenced older adults' rates of strategy shift in the current data, arguing further against the notion that greater resource consumption in novel arithmetic tasks reduces metacognitive strategy choice. Further research should examine factors that determine the combined versus unique influence of incentives and instructions on strategy choice. Third, a major discrepancy between the two studies was that younger adults in this task also showed a robust incentives effect, which was not observed by Touron et al. (2007). Retrieval use by younger adults in the NP task rapidly rises to asymptote, perhaps because the associations are easier to learn between noun pairs than between problems with multiple operators and their solutions. The slower rate of retrieval shift by young adults in the current novel arithmetic task may create the opportunity for the incentives effect to emerge.

It is notable that memory test performance and confidence were not higher after experiencing monetary incentives, despite their effect on increasing retrieval strategy use, as would be predicted if incentives lead to increased memorization through deliberate encoding. To the contrary, when a surprise cued recall test of problem solutions was given after training, there were no reliable condition differences in recall, and the trend in younger adults was actually for lower cued recall in the incentives condition.

In fact, both young and older adults in the incentives condition were less accurate in both standard trials and in the memory tests. After Block 5, both older and younger participants in the incentives condition had faster RTs and higher error rates, suggesting a strategy-driven speed–accuracy trade-off. Given incentives, individuals risked and experienced more errors by substituting faster but more errant memory retrieval for slow computation. However, it is critical to recognize that accuracy did not suffer substantially from this trade-off; accuracy in memory probe trials was consistent with the probability of retrieval use in the incentives condition for both age groups, at least with moderate practice.

A fascinating feature of older adults' performance in the incentives condition was a paradoxical increase in RT in the first five blocks of practice that accompanied higher error rates. Although the source of this unexpected effect is unknown, it could be an outcome of incentives encouraging older adults to attempt retrieval use before they had sufficiently learned the solutions. As seen in the upper panel of Figure 4, computation RTs were exceptionally long for older adults in the incentives condition. Longer (and more variable) RTs could result if individuals first search memory for the solution, but then revert to standard computation when retrieval fails to produce a solution. Follow-up research with think-aloud protocols could be used to test this conjecture.

As shown previously (Touron & Hertzog, 2004a; Touron et al., 2007), memory test confidence did not vary by age group, despite obtained performance differences. Furthermore, indices of high levels of item learning, such as fluent retrieval speed and high response confidence for forced recognition memory trials, do not seem to account for the age difference in retrieval use. The conditional probability of retrieval was higher when retrieval RTs were fast and confident, but this effect did vary between older and younger adults. Furthermore, the faster computations were still markedly slower than even the slowest responses in a retrieve-only phase, countering Cerella et al.'s (2006) hypothesis that older adults' deficient associative learning generates slow retrievals that are overtaken by fast computations. We argue, therefore, that the incentives manipulation indicates that individuals in the standard control condition who can rely on memory still choose to compute the solution, and that this effect is a major influence on older adults' slower rates of RT improvement.

Accordingly, a purely mechanistic account of age differences rates of associative learning is not a sufficient explanation of age related slowing in skill acquisition (c.f., Onyper et al., 2008). The metacognitive influences we have identified in the NP task environment appear to also be operating in an artificial arithmetic task. Metacognitive contributions to age differences in strategy-based skill acquisition tasks cannot be ignored.

Although RTs were faster overall for participants in the incentives condition, separate examination by strategy revealed possible age differences in the strategic adjustment to incentives. Whereas young adults with incentives retrieved more quickly than young adults in the control and instruction conditions, older adults with incentives computed more slowly than those in other conditions. As noted earlier, this effect could reflect disruptive effects of attempting to retrieve prior to sufficient solution learning. An alternative possibility is that individuals in the incentives condition computed only when confronted by a subset of difficult items. In analyses not reported in detail here, we searched for and did not detect reliable item differences in RTs.

Another alternative explanation for this effect is that older adults in the incentives condition attempted more purposeful learning behavior by taking additional time to encode solutions for items they had just computed. To evaluate this possibility, we examined the RT data for evidence of intentional encoding behavior. Intentional encoding when computing the problem could require additional time for rehearsal, which in turn would result in greater learning and retrieval of stimuli but at a cost of slower RTs. We compared the percentage use of retrieval following computation for trials where computation was fast (the 5th percentile of computation RTs), normal (the 25th to 75th percentiles of computation RTs), and slow (the 95th percentile of computation RTs). No evidence of additional rehearsal was obtained, as participants were actually more likely to retrieve following fast computation RTs ($M$ = 56.9 %) compared to normal ($M$ = 52.6 %) or slow RTs ($M$ = 44.6 %), $F(2, 232) = 9.88$, $MSE = 463$, $p < .01$. [3] In effect, fluent computation could be a harbinger of successful solution learning that later affords solution retrieval. Given that this pattern did not vary by condition or age, $p$s > .50, it does not appear that differences in additional time taken for rehearsal of the solution can account for the obtained results. Admittedly, intentional encoding might not be accompanied by additional rehearsal time, so we cannot rule out the intentional learning hypothesis on the basis of available data.

Although the current study has the advantage of extending demonstrations of retrieval reluctance to a novel arithmetic task, we should note that the current memory test probes could be a less valid measure of retrieval ability. In the NP task we have generally used, removal of the lookup table allows for memory probes where the algorithm-based scanning strategy is unavailable. In the present study, it is possible that participants defied explicit instructions and used computation to produce responses. Given that both accuracy and RT data are more consistent with retrieval-based responding than computation, however, and participants rarely exceeded the retrieval RT deadline, this argument is not supported by the current data.

Despite improvements in retrieval use and speed, older adults in the incentives condition did not demonstrate superior accuracy when using memory retrieval late in practice, or in memory probe conditions. These older adults also did not demonstrate higher response confidence, and did not vary in task approach or subjective reactions compared to the other conditions, as indicated by responses to the posttask survey. The general message, then, is that the incentives motivate older adults to use retrieval against their initial preferences and sentiments. It appears that older adults are generally reluctant to rely on the memory retrieval strategy and would prefer to be more conservative in their responding, even following retrieval incentives and success with retrieval strategy use.

Such outcomes may relate to age differences in spontaneous speed–accuracy response criteria (e.g., Hertzog et al., 1993); with older adults prefer slow and more cautious responding, whereas young adults prefer faster responding with greater potential for errors. It is worth noting that increased retrieval use in the incentives condition reversed older adults' cautiousness, as participants given incentives were faster and less accurate because they used the retrieval strategy to a greater extent. It also appears that incentives serve to alter the spontaneous mental task model as well as response criteria for older adults. Older adults' posttask ratings after incentives indicated greater perceived performance improvement from retrieval strategy use. This measure correlated with retrieval use for older adults in other conditions but not in the incentives condition, consistent with the hypothesis that incentives overrode a mental model that retrieval could not enhance RT without harming response accuracy. Future studies should directly measure participants' mental models in novel arithmetic tasks.

In summary, our data indicate that older adults' skill acquisition can be affected by metacognitive factors, even in a computation-based task. Furthermore, it does not appear that retrieval strategy use is driven solely by fast and fluent retrieval mechanisms, as gauged by recognition memory RT and confidence outside the skill acquisition context. As such, a purely mechanistic perspective which ignores strategic choice and metacognitive factors cannot fully account for age and individual differences in skill learning. In general, failures to account for various forms of response conservatism in older adults may lead one to overestimate age-related declines in cognitive processes and mechanisms that are the target of an experimental investigation.

**Footnotes**

[1] In some cases, findings taken as supporting a mechanistic perspective may have been influenced by excluding participants behaving in ways that were inconsistent with a simple associative deficit hypothesis. Cerella et al. (2006) dropped two older adult participants in the skill training (SK) condition from analysis due to extremely low levels of retrieval strategy use, which might have masked age differences in the condition effect. Furthermore, participants in the SK group who did not reach a criterion level of retrieval performance appear to have been modeled as reaching criterion at the final block, a questionable procedure that would obscure retrieval reluctance. Therefore, the similarity of the paired-associates training and SK groups might have partly resulted from ignoring or substituting data from 5 of the 23 older adults in their SK group.

[2] Despite slower associative learning by older adults, it appears that learning was equated across age groups by this point in the task. It is possible that older adults had more difficulty transitioning to the new trial type and deadlines, leading to age differences in Block 1.

[3] This outcome was not biased by data aggregation, as the same outcome emerged when confining to the first five blocks of training.

**References**

Ackerman, P. L., & Woltz, D. J. (1994). Determinants of learning and performance in an associative memory/substitution task: Task constraints, individual differences, volition, and motivation. *Journal of Educational Psychology*, *86*, 487–515.

Botwinick, J. (1984). *Aging and behavior* (3rd ed.). New York: Springer.

Brébion, G. (2001). Language processing, slowing, and speed/accuracy trade-off in the elderly. *Experimental Aging Research*, *27*, 137–150.

Cerella, J., Onyper, S., & Hoyer, W. J. (2006). The associative-memory basis of cognitive skill learning: Adult age differences. *Psychology and Aging*, *21*, 483–499.

Dunlosky, J., & Hertzog, C. (2001). Measuring strategy production during associative learning: The relative utility of concurrent versus retrospective reports. *Memory & Cognition*, *29*, 247–253.

Dunlosky, J., Kubat-Silman, A. K., & Hertzog, C. (2003). Training monitoring skills improves older adults' self-paced associative learning. *Psychology and Aging*, *18*, 340–345.

Hertzog, C. (2008). Theoretical approaches to the study of cognitive aging: An individual differences perspective. In S. M.Hofer & D. F.Alwin (Eds.), *Handbook of cognitive aging* (pp. 34–49). Thousand Oaks, CA: Sage.

Hertzog, C., Cooper, B. P., & Fisk, A. D. (1996). Aging and individual differences in the development of skilled memory search performance. *Psychology and Aging*, *11*, 497–520.

Hertzog, C., & Dunlosky, J. (2004). Aging, metacognition, and cognitive control. In B. H.Ross (Ed.), *Psychology of learning and motivation* (pp. 215–251). San Diego, CA: Academic Press.

Hertzog, C., Dunlosky, J., & Robinson, A. E. (2008). *Intellectual abilities and metacognitive beliefs influence spontaneous use of effective encoding strategies*. Unpublished manuscript.

Hertzog, C., McGuire, C. L., & Lineweaver, T. T. (1998). Aging, attributions, perceived control, and strategy use in a free recall task. *Aging, Neuropsychology, and Cognition*, *5*, 85–106.

Hertzog, C., & Touron, D. R. (2006, April). *Aging and individual differences in algorithm to retrieval shift with practice*. Poster presented at the 2006 Cognitive Aging Conference, Atlanta, GA.

Hertzog, C., Touron, D. R., & Hines, J. (2007). Does a time monitoring deficit influence older adults' delayed retrieval shift during skill acquisition?*Psychology and Aging*, *22*, 607–624.

Hertzog, C., Vernon, M. C., & Rypma, B. (1993). Age differences in mental rotation task performance: The influence of speed/accuracy tradeoffs. *Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, *48*, P150–P156.

Hoyer, W. J., Cerella, J., & Onyper, S. (2003). Item learning in cognitive skill training: Effects of item difficulty. *Memory & Cognition*, *31*, 1260–1270.

Kausler, D. H. (1994). *Learning and memory in normal aging*. San Diego, CA: Academic Press.

Lachman, M. E., & Andreoletti, C. (2006). Strategy use mediates the relationship between control beliefs and memory performance for middle-aged and older adults. *Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, *61*, 88–94.

Lachman, M. E., Andreoletti, C., & Pearman, A. (2006). Memory control beliefs: How are they related to age, strategy use, and memory improvement?*Social Cognition*, *24*, 359–385.

Lachman, M. E., Bandura, M., Weaver, S. L., & Elliot, E. (1995). Assessing memory control beliefs: The memory controllability inventory. *Aging & Cognition*, *2*, 67–84.

Lemaire, P., Arnaud, L., & Lecacheur, M. (2004). Adults' age-related differences in adaptivity of strategy choices: Evidence from computational estimation. *Psychology and Aging*, *19*, 467–481.

Lineweaver, T. T., & Hertzog, C. (1998). Adults' efficacy and control beliefs regarding memory and aging: Separating general from personal beliefs. *Aging, Neuropsychology, & Cognition*, *5*, 264–296.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review*, *95*, 492–527.

Nosfsky, R. M., & Palmeri, T. J. (1997). An exemplar-based random walk model of speeded classification. *Psychological Review*, *104*, 266–300.

Onyper, S. V., Hoyer, W. J., & Cerella, J. (2006). Determinants of retrieval solutions during cognitive skill training: Source confusions. *Memory & Cognition*, *34*, 538–549.

Onyper, S., Hoyer, W. J., & Cerella, J. (2008). Effects of item difficulty on the retrieval of solutions during cognitive skill acquisition: Age differences. *Aging, Neuropsychology, & Cognition*, *15*, 358–383.

Palmeri, T. J. (1999). Theories of automaticity and the power law of practice. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 1–9.

Reder, M., & Ritter, F. E. (1992). What determines initial feeling of knowing? Familiarity with question terms, not with the answer. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*, 435–451.

Rickard, T. C. (1997). Bending the power law: A CMPL theory of strategy shifts and the automatization of cognitive skills. *Journal of Experimental Psychology: General*, *126*, 288–310.

Rickard, T. C. (2004). Strategy execution in cognitive skill learning: An item-level test of candidate models. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*, 65–82.

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

Rogers, W. A., Hertzog, C., & Fisk, A. D. (2000). An individual differences analysis of ability and strategy influences: Age-related differences in associative learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 359–394.

Saczynski, J. S., Willis, S. L., & Schaie, K. W. (2002). Strategy use in reasoning training with older adults. *Aging, Neuropsychology, and Cognition*, *9*, 48–60.

Thapar, A., Ratcliff, R., & McKoon, G. (2003). A diffusion model analysis of the effects of aging on letter discrimination. *Psychology and Aging*, *18*, 415–429.

Touron, D. R. (2006). Are item-level strategy shifts abrupt and collective? Age differences in cognitive skill acquisition. *Psychonomic Bulletin & Review*, *13*, 781–786.

Touron, D. R., & Hertzog, C. (2004a). Distinguishing age differences in knowledge, strategy use, and confidence during strategic skill acquisition. *Psychology and Aging*, *19*, 452–466.

Touron, D. R., & Hertzog, C. (2004b). Strategy shift affordance and strategy choice in young and older adults. *Memory & Cognition*, *32*, 298–310.

Touron, D. R., Hoyer, W. J., & Cerella, J. (2001). Cognitive skill acquisition and transfer in younger and older adults. *Psychology and Aging*, *16*, 555–563.

Touron, D. R., Hoyer, W. J., & Cerella, J. (2004). Cognitive skill learning: Age-related differences in strategy shifts and speed of component operations. *Psychology and Aging*, *19*, 565–580.

Touron, D. R., Swaim, E., & Hertzog, C. (2007). Moderation of older adults' retrieval reluctance through task instructions and monetary incentives. *Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, *62*, 149–155.

Verhaeghen, P., & Marcoen, A. (1996). On the mechanisms of plasticity in young and older adults after instruction in the method of loci: Evidence for an amplification model. *Psychology and Aging*, *11*, 164–178.

Wechsler, D. (1981). *Wechsler Adult Intelligence Scale–Revised*. New York: Psychological Corp.

White, A. S., Cerella, J., & Hoyer, W. J. (2007). Strategy transitions during cognitive skill learning in younger and older adults: Effects of inter-item confusability. *Memory & Cognition*, *35*, 2106–2117.

Wilding, E. L., & Sharpe, H. (2004). The influence of response-time demands on electrophysiological correlates of successful episodic retrieval. *Cognitive Brain Research*, *18*, 185–195.

Zachary, R. (1986). *Shipley Institute of Living Scale revised manual*. Los Angeles: Western Psychological Services.