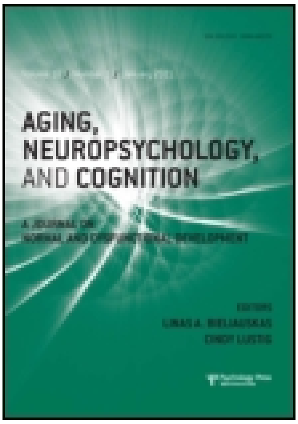

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Does a simultaneous memory load affect older and younger adults' implicit associative learning?

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ABSTRACT

This study investigated the effects of a simultaneous memory load on implicit associative sequence learning using the Triplets Learning Task (TLT). Participants in the Simultaneous condition held a secondary task memory load during the TLT, while those in the Sequential condition also performed both tasks, but successively, rather than simultaneously. Thus, the Simultaneous condition had a memory load during the TLT, while the Sequential condition did not. Probe blocks without the secondary task allowed separation of effects on learning from effects on its expression. Results revealed that the simultaneous memory load affected older, but not younger adults, by suppressing the expression of learning, not learning itself. Thus, older and younger adults can learn probabilistic associations while holding a simultaneous memory load, but the load can limit the extent to which older adults adapt their performance to environmental structure. Results are consistent with theories which propose that implicit associative learning does not call on limited capacity resources, and highlight the importance of distinguishing effects of dual tasks on the expression of learning from those on learning itself.

Keywords: Implicit learning; Aging; Dual task; Implicit associative learning.

Implicit associative learning involves gaining sensitivity to regularities in the environment, without awareness or intention to learn (Reber, 1989). Such

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learning is typically revealed when, for example, people who have been exposed to repeating sequences of events come to respond more quickly to events that follow the sequence than to those that violate it. Implicit forms of learning are essential because they enable us to be sensitive to regularities in our environment and to adapt to physical and social cues in a constantly changing world. Such learning helps us become skilled at navigating a new town, using language (Kuhl, 2004), and negotiating social interactions (Lieberman, 2000), just by engaging in these activities. Implicit learning often needs to take place as we hold other information in mind. For example, while learning to use a new web browser, we must hold our goal website in mind, or when learning a new language, we must keep our ideas in mind while conjugating verbs and matching noun genders. If implicit associative learning draws on limited cognitive resources, then these circumstances may limit the extent to which people learn about regularities in their environment. Any effects of a memory load on learning are likely to be exacerbated by aging, because older adults have deficits in associative learning, in inhibiting distraction, and in doing two things at once (Andrés, Parmentier, & Escera, 2006; Naveh-Benjamin, 2000).

The present study investigates whether a simultaneous memory load affects implicit associative learning in older and younger adults. This question is important not only for the practical reasons above, but also because it is often assumed that, in contrast to explicit learning, implicit forms of learning do not call on limited capacity resources, at least in young adults (Coomans, Deroost, Zeischka, & Soetens, 2011; Frensch & Rünger, 2003; Rieckmann & Backman, 2009). Research testing this assumption in young adults has yielded mixed results, likely because there are multiple forms of implicit learning, and because different secondary tasks have been used to tax capacity limits.

Nonetheless, research with young adults suggests that at least some forms of implicit learning do not call on limited capacity resources. For example, implicit information-integration category learning (Zeithamova & Maddox, 2007), and implicit learning of spatial contexts in a visual search task are both unaffected by a working memory load (Vickery, Sussman, & Jiang, 2010). In contrast, research on perceptual/motor sequence learning using the Serial Reaction Time (SRT) task, has often seemed to contradict the assumption that implicit learning does not call on limited capacity resources (Schumacher & Schwarb, 2009). In the SRT, participants respond as quickly as possible to events following a repeating sequence of spatial locations. In many studies using the SRT, the secondary task has involved counting high versus low pitched tones that occur during the SRT task itself. Thus, participants must perceive tones while they are perceiving and responding to visual events in the SRT. There is some evidence that it is these simultaneous perceptual/motor demands, rather than any central capacity demands, that interfere with SRT learning (Schwarb & Schumacher, 2012). Therefore, as described below, in the present experiment, we used a secondary task that did not require people to perceive or respond to stimuli during the learning task itself.

Further, even when it appears that a secondary task is interfering with learning in the SRT, the interference is often only with the *expression* of learning, not the learning itself. For example, Frensch and colleagues found that young adults' learning of the sequence in an SRT task appeared to be impaired by a simultaneous tone-counting task, but once the tone-counting task was removed, evidence of sequence learning appeared immediately (Frensch, Lin, & Buchner, 1998; Frensch, Wenke, & Rünger, 1999). These results suggest that learning had been occurring all along, but the tone-counting task had concealed its expression.

Overall, research suggests that in *young* adults, at least some forms of implicit learning are unaffected by a simultaneous memory load and do not draw upon limited capacity resources. However, almost nothing is known about whether this is true for older adults. We are aware of only two published studies examining secondary task effects on implicit learning in older adults (Frensch & Miner, 1994; Nejati, Garusi Farshi, Ashayeri, & Aghdasi, 2008). Both of these studies found that a secondary task, tone-counting, impaired performance on variations of the SRT task. However, as discussed above, it is possible that the simultaneous perceptual demands of the dual task, rather than central capacity demands, affected performance (Schwarb & Schumacher, 2012). In addition, the impaired learning performance may have been the result of interference with the expression of learning, and not learning itself.

We used the Triplets Learning Task (TLT), which assesses the implicit learning of probabilistic non-motor sequences (Howard, Jr., Howard, Dennis, & Kelly, 2008). In the TLT, on each trial people observe two cue events, and respond to a following target event. In the version used here, unbeknownst to participants, the position of the first cue on each trial predicts the position of the target on 90% of the trials. Thus, the TLT contains a second-order probabilistic structure; i.e., the cue two events back probabilistically predicts the target. Learning of this association can be assessed continuously throughout training by comparing response times and/or accuracy to high-probability targets to those of low-probability targets, a difference that increases with practice for both young and old adults in the absence of a dual task (Howard, Jr., et al., 2008; Simon, Howard, Jr., & Howard, 2011). Sensitive recognition measures suggest that learning in the TLT is truly implicit, in that participants typically gain no explicit knowledge of the regularity, presumably because it is hard to become aware of such subtle, probabilistic regularities. This is an advantage, in that participants often become aware of the simpler deterministic repeating sequence in the SRT, so that any effects of a dual task on SRT learning might be reflecting explicit, rather than implicit learning.

The secondary task used in the present study consisted of a working memory load matrices task based on Mitchell, Johnson, Raye, and D'Esposito (2000). Participants in our *Simultaneous* condition were shown a series of 3 × 3 matrices, with each matrix containing a letter in one of its cells. They were to hold the letter and its location in mind for each of the matrices throughout the subsequent TLT block, and then their memory for the matrices was tested after the block was over. This matrices task requires binding and retaining verbal and spatial information, thereby taxing limited central capacity, but (unlike tone-counting) it does not require that subjects perceive additional external stimuli during the learning task itself. We contrasted this Simultaneous condition with a *Sequential* one, in which people saw, and were tested on each set of matrices between blocks of the TLT, and so they did not have to retain the matrices during the TLT task. Thus, any impact of the Simultaneous vs. Sequential condition on learning in the current study can be attributed to the concurrent memory load in the Simultaneous condition, rather than to additional perceptual processing demands of a secondary task.

So as to distinguish effects on the expression of learning from effects on learning itself, we included *probe blocks* toward the end of training in which no group was administered the matrices task. Thus, if any secondary-task effects we observe on the learning measure disappear during these probe blocks, this would suggest that the memory load had affected the expression of learning, but not learning itself.

In summary, the present study had two aims. The first was to determine whether young and older adults can learn an implicit second-order probabilistic regularity while holding a simultaneous memory load. Second, for any memory load effects observed, we aimed to distinguish effects on learning from those on only the expression of learning. We predicted that young adults would be able to learn, and that the memory load would not impair implicit learning itself, though it might affect the expression of learning. Given the paucity of related studies in older adults, and the subtle probabilistic regularity used in the present study, we viewed it as an open question whether they would be able to learn at all with the simultaneous load.

METHOD

Participants

Participants were 24 college-aged students (*M* age = 20.96, *SD* = 2.10; 13 females) and 23 older adults (*M* age = 70.39, *SD* = 6.55; 8 females), all well-educated (young adults: *M* years of education = 14.67, *SD* = 1.27, older adults: *M* = 17.48, *SD* = 2.73). Young participants were from Georgetown University and received class credit or monetary compensation, while older adults were recruited via an advertisement in the *Washington Post* and were paid for their participation. The participants' neuropsychological data are shown in Table 1. These data reveal typical age-related patterns, with young adults showing significantly higher scores than older adults on processing speed, cued recall, free recall, and short-term and working memory measures. All of the older adults had a score of 26 or higher on the Mini Mental State Examination.

Half of the participants in each age group were assigned randomly to a Simultaneous condition and the other to a Sequential condition. All participants in both conditions completed two interleaved tasks, the Triplets Learning Task (TLT) and a Matrices task, but the conditions differed in whether or not people had to hold the matrices in memory while they completed the TLT (see Figure 1).

Tasks

Triplets learning task

For the primary task, participants saw four evenly spaced open circles in the middle of a computer screen. As in Howard, Jr., et al. (2008), each trial consisted of three successively presented events, two cues and a target, which together made a triplet. The first cue consisted of one of the four circles filling in red, followed by a second cue (the same or a different circle), also filling in red. The target, to which participants were to respond, occurred when a third circle filled in green. Each of the two cues remained on for 120 ms followed by a 50-ms interstimulus interval. The third stimulus, the green target, remained lit until the participant responded correctly. Participants responded to targets by using their right and left middle and index fingers on a standard keyboard to press keys, "z", "x", ".", and "/", in response to the first, second, third, or fourth circle, respectively. There were 50 trials per block, 15 blocks per session, and three sessions for each participant, all completed in a single visit to the laboratory.

The triplet sequence contained a second-order regularity, in that the location of the first red cue predicted the location of the target (i.e., the green event), with the location of the second red cue being random (Howard, Jr., et al., 2008). Referring to the circles as 1, 2, 3, and 4 from left to right, one possible pattern is 1r2r3r4r, where r is one of the four circles chosen randomly. Participants receiving this pattern would see the high frequency triplets 1r2, 2r3, 3r4, and 4r1 on 90% of the trials, and the low frequency triplets (e.g., 1r3, 2r4) on the remaining trials. There were six unique triplet patterns counterbalanced across age and condition (1r2r3r4r, 1r2r4r3r, 1r3r2r4r, 1r3r4r2r, 1r4r2r3r, and 1r4r3r2r). With four possible positions and three circles being lit per trial, there are 64 possible triplets. For each pattern, there would be 16 possible high frequency triplets, and 48 possible

Table 1. Neuropsychological test results for younger and older adults

		Younger adults		Older adults				
Cognitive test	Cognitive processing	Simultaneous	Sequential	Simultaneous	Sequential	Age M.E.	Condition M.E.	Age × Condition
Digit symbol coding	Processing speed	85.92 (18.50)	82.42 (15.81)	56.25 (14.40)	60.55 (17.18)	$p < .001$	$p = .93$	$p = .42$
Digit symbol pairing	Cued recall	14.33 (2.93)	15.67 (2.81)	10.92 (5.00)	7.64 (2.94)	$p < .001$	$p = .35$	$p = .03$
Digit symbol recall	Free recall	7.08 (2.54)	8.42 (0.79)	7.17 (1.47)	6.36 (1.21)	$p = .05$	$p = 58$	$p = .03$
Digit span forward	Short-term memory	12.50 (2.78)	11.75 (2.22)	11.00 (2.70)	10.27 (2.61)	$p = .06$	$p = .33$	$p = .99$
Digit span backward	Working memory	8.75 (3.08)	8.42 (2.19)	7.42 (2.71)	7.00 (1.27)	$p = .06$	$p = .60$	$p = .95$
Vocabulary	Vocabulary			57.08 (8.97)	55.91 (9.78)	n/a	$p = .77$	n/a
MMSE	Screen for dementia			29.33 (0.89)	28.82 (1.54)	n/a	$p = .33$	n/a

Note: All cognitive tests except the MMSE are WAIS-III.

low frequency triplets. Repetitions (e.g.: 111, 222) and trills (e.g.: 121, 131, 141) were not presented in this study because they would be confounded with triplet frequency, occurring with low frequency for all possible patterns. In addition, they have been found to have pre-existing response tendencies (Howard, Jr., et al., 2008). Therefore, there were 16 high frequency and 32 low frequency triplets for each participant, and because of the counter-balancing of patterns across participants, a given triplet (e.g., 1r4) was high frequency for some participants, but low for others.

Matrices task

The secondary Matrices task was adapted from Mitchell et al. (2000). Each trial consisted of a study phase and a test phase. The *matrix study* phase began with a 3 × 3 matrix, which contained one of eight consonants (B, C, F, N, P, S, T, and X) in one of the eight possible positions, with a letter never appearing in the center position of the matrix. Older adults saw three consecutive matrices in each study phase, while younger adults saw four, as pilot testing suggested this would equate accuracy for the two age groups. Each matrix contained a different letter in a different location, and matrices were presented consecutively, appearing for 1500 ms, with 500 ms between each matrix. For the *matrix test* phase, participants were shown a matrix containing one of the letters they had just seen in one of the locations they had just seen. Participants pressed 1 to indicate if the exact stimulus matrix (i.e., the same letter in the same location) had occurred during the study phase, and 2 if it had not. Thus, to be correct, they would need to remember each letter and its location. Cumulative feedback was given at the end of each block within a session, where a percentage correct was continuously updated following each block over the course of that session.

As shown in Figure 1, in the Simultaneous condition, the study phase for a given set of 3 or 4 matrices (for old and young adults, respectively) occurred before a block of the TLT and the test on those matrices occurred after that block, so that the two phases of the Matrices task were separated by a block of the TLT. In contrast, in the Sequential condition, the study and test phases for a given set of matrices occurred together between TLT blocks. Thus, both groups experienced a matrix study phase and test between the TLT blocks. However, participants in the Simultaneous condition were holding the matrices in mind during the TLT task with the matrix test at the end of that TLT block, whereas those in the Sequential condition were not, completing both phases of the Matrices task for a given set of matrices before the next TLT block began.

Probe blocks

The TLT and Matrices tasks were interwoven, as described earlier, for all groups for all blocks except for blocks 6–10 in session 3. For these

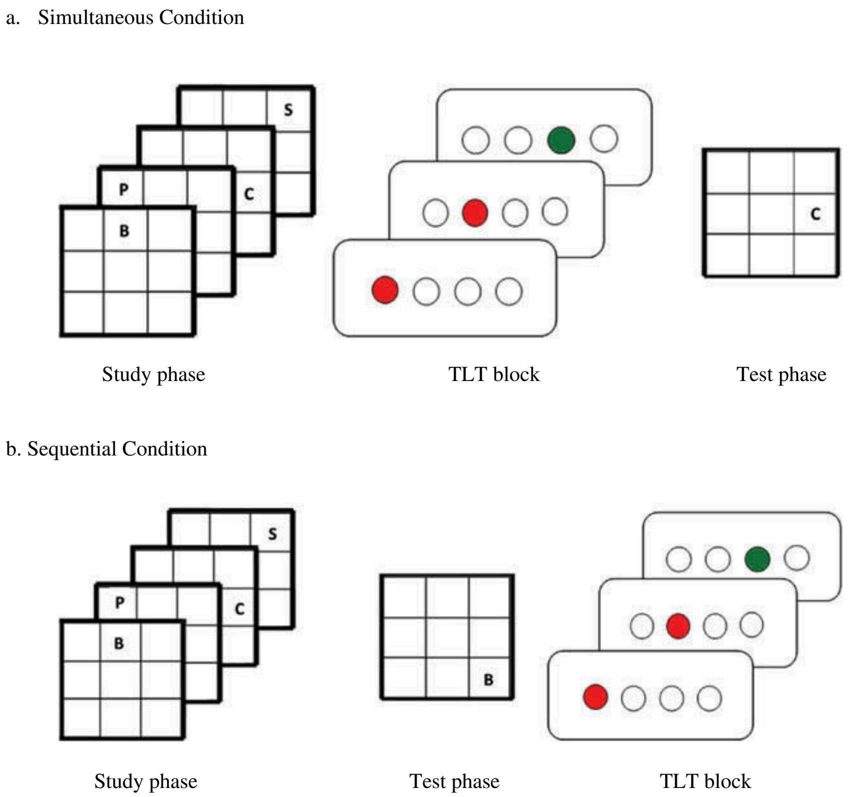


FIGURE 1. Sequence of events in each block: (a) Participants in the Simultaneous condition were required to remember items from the Study phase in the Matrix task throughout a block of the TLT, which was followed by the Test phase. (b) Participants in the Sequential condition received both the Study phase and the Test phase before beginning a block of the TLT, and so had no memory load during the TLT.

five blocks, no group performed the Matrices task. The purpose of these probe blocks was to determine whether any disruption in learning measures observed in the Simultaneous condition was due to an effect on *learning* itself or only on its *expression.*

Procedure

Participants provided informed consent, were administered biographical and health questionnaires, and were then read instructions explaining the two tasks. All procedures were approved by the Georgetown University Institutional Review Board.

For the TLT, participants were told that they would see two red lights followed by a green light, the target to which they were to respond with the appropriate key press. They were encouraged to be both quick and accurate, and told that they would receive feedback regarding their reaction time and accuracy at the end of each block, and that this would prompt them to be quicker or more accurate. They were not told of the pattern embedded within the task, or of the triplet regularity. For the Matrices task, participants were told to pay attention to both the letter and the location in each matrix in the study phase, and to recall both types of information when making their choice in the test phase. Before the third session, participants were informed that some of the blocks during that session would not contain either part of the Matrices task, but that they were to complete the "button pressing task" as in other blocks.

At the end of the TLT, participants' explicit knowledge was tested in two ways. First, they completed a *Recognition task* on the computer during which they were presented with a random selection of the 64 possible high and low frequency triplets. Each triplet was presented with the same inter-event timing as during the TLT, and participants were asked to press one key if they had seen the triplet "more often" and another key if they had seen it "less often" during learning. Next, they completed an oral *questionnaire*, probing strategy use and ability to describe any regularity in the events.

Following the questionnaire, in order to characterize the samples, the Digit Span and Digit Symbol tasks were administered, and older adults were also given the Mini-Mental State Examination and the WAIS Vocabulary test. The visit ended with a debriefing.

RESULTS

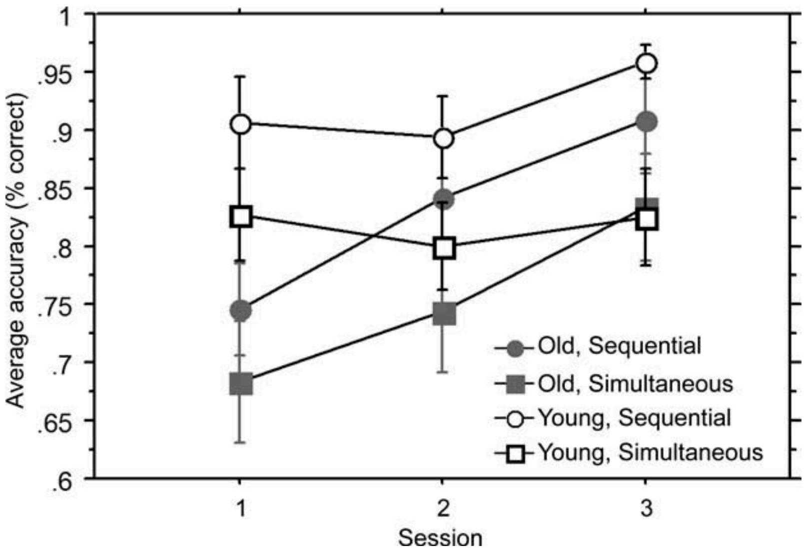
Test of explicit knowledge

Because our goal is to study the effects of a memory load on *implicit* learning, we first determined whether any individual showed explicit knowledge of triplet frequency on the Recognition task, by conducting a 2 (Frequency Rating: High vs. Low) × 2 (Actual frequency: High vs. Low) Chi-square analysis on each individual's frequency rating data. Four young participants in the Sequential condition yielded significant Chi-square values ($p < .05$), suggesting that they had some explicit knowledge of triplet frequency. Therefore, even though their verbal reports indicated no awareness, these participants were replaced with four new participants. Thus, the data presented here contain 47 participants who showed no evidence of explicit knowledge (Chi-square, $p > .05$), so we can be sure that any effects observed are on implicit learning.

Matrices task

To establish that the participants were in fact holding the memory load, we next examined accuracy on the Matrices task. As Figure 2 reveals, accuracy was above chance (50%) and below ceiling (100%) in all four groups for all three sessions. A 2 (Age) × 2 (Condition: Sequential vs.

FIGURE 2. Mean accuracy and standard error in the Matrices task test. The Sequential condition is portrayed by the circles and the Sequential condition by the squares, with Older adults shown with filled symbols and Young adults with open symbols.



Simultaneous) × 3 (Session) mixed design ANOVA, with Age and Condition as between-subjects variables, revealed significant main effects of Condition, $F(1, 43) = 6.92$, $p = .01$, $\eta_p^2 = .139$, Age, $F(1, 43) = 4.84$, $p = .03$, $\eta_p^2 = .101$, and Session, $F(2, 86) = 9.83$, $p < .01$, $\eta_p^2 = .186$, as well as a significant interaction of Age × Session, $F(2, 86) = 5.37$, $p < .01$, $\eta_p^2 = .111$. No other effects were significant, with all p's being $\geq .69$ and η_p^2's being $\leq .009$. Overall, accuracy was poorer in the Simultaneous ($M = 0.78$, $SD = 0.13$) condition than in the Sequential ($M = 0.87$, $SD = 0.12$) condition, establishing that the matrices memory load in the Simultaneous condition was taxing. Follow-up analyses of the Age × Session interaction revealed that, although younger adults were more accurate than older adults in Session 1 ($t(45) = 3.53$, $p < .01$, $d = -1.03$), the age groups did not differ in Sessions 2 ($t(45) = 1.25$, $p > .05$, $d = -.036$) or 3 ($t(45) = 0.53$, $p > .05$, $d = -0.15$). This suggests that, at least for the last two sessions, the memory load challenged young and older adults to a similar degree.

Triplets learning task

Overall performance

Before examining associative learning, we first compared the groups in overall accuracy and response time. A 2 (Age: Old vs. Young) × 2 (Condition:

Simultaneous vs. Sequential) × 3 (Session) ANOVA for accuracy showed only significant main effects of Age, $F(1, 43) = 21.88$, $p < .001$, $\eta_p^2 = .337$, and Session, $F(2, 86) = 43.81$, $p < .001$, $\eta_p^2 = .505$. No other effects were significant, with all p's being $\geq .38$ and η_p^2's being $\leq .022$. Although accuracy was high overall, older adults ($M = 0.963$, $SD = 0.022$) were more accurate than young ($M = 0.925$, $SD = 0.029$), and it decreased slightly over sessions (older adults: Session 1 = 0.963, Session 2 = 0.961, Session 3 =0.966; young adults: Session 1 = 0.938, Session 2 = 0.926, Session 3 =0.922).

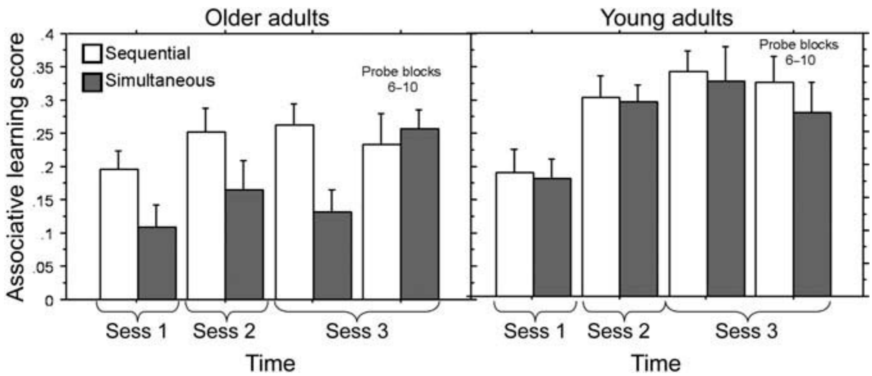
A 2 × 2 × 3 ANOVA for reaction time showed a similar pattern, in that there were significant effects of Age, $F(1, 43) = 28.76$, $p < .001$, $\eta_p^2 = .401$, and Session, $F(2, 86) = 4.50$, $p = .01$, but there was also a significant interaction of Age × Session, $F(2, 86) = 5.23$, $p = .007$, $\eta_p^2 = .109$. Older adults ($M = 557.90$, $SD = 146.76$) were slower than young ($M = 373.20$, $SD = 69.79$), where older adults did not show as much change over time as young adults (old adults: Session 1 = 595.54 ms, Session 2 = 548.66 ms, Session 3 = 538.56 ms; young adults: Session 1 = 406.81 ms, Session 2 = 364.82 ms, Session 3 = 363.82 ms). No other effects were significant, with all p's being $\geq .44$ and η_p^2's being $\leq .019$.

Associative learning: Non-probe blocks

Given these age differences in overall performance, we assessed TLT learning via an Associative Learning (AL) measure, as developed in our earlier work (see Howard, Jr., et al., 2008; Simon et al., 2011). This measure takes into account individual differences in overall response time and variability by capturing the extent to which each subject's RT to a given triplet is related to that triplet's frequency of occurrence. To calculate this measure, for each subject for each session, for each triplet (e.g.: 123), we determined the actual number of times that triplet occurred, and the median response time on correct trials for that particular triplet. We then correlated triplet frequency with triplet median RT across all triplets within that session for that subject. A high degree of learning would yield a negative correlation, in that triplets that occur often would have faster reaction times. For ease of interpretation, we multiply these scores by –1, so that a higher AL score denotes more learning.

Associative Learning scores are shown in Figure 3a for older and 3b for younger adults. The figures present the data from the probe blocks (blocks 6–10 in session 3) separately from the remaining non-probe blocks, and the following analyses are based only on these non-probe blocks; the probe blocks are examined separately below. A mixed design 2 (Age) × 2 (Condition) × 3 (Session) ANOVA on the scores for the non-probe blocks, with Age and Condition varying between-subjects, revealed a significant main effect of Session, $F(2, 86) = 11.50$, $p < .01$, $\eta_p^2 = .209$; AL scores increased with training, demonstrating associative learning. There were also significant

FIGURE 3. Associative Learning scores and standard error for older and younger adults in the Sequential and Simultaneous conditions. Scores show sessions 1–3, with session 3 composed of blocks 1–5 and 11–15, with the probe blocks 6–10, shown adjacent.



main effects of Age, $F(1, 43) = 12.02$, $p < .01$ $\eta_p^2 = .238$, showing overall higher AL scores for young than old adults, and Condition, $F(1, 43) = 6.14$, $p = .02$ $\eta_p^2 = .116$, showing higher AL scores for the Sequential than the Simultaneous condition. Importantly, these effects were qualified by an Age × Condition interaction, $F(2, 86) = 3.95$, $p = .053$ $\eta_p^2 = .082$. Follow-up ANOVAs conducted separately for younger and older adults showed a significant main effect of Condition for older, $F(1, 21) = 11.64$, $p < .01$ $\eta_p^2 = .350$, but not for younger adults, $F(1, 22) = 0.11$, $p = .97$ $\eta_p^2 = .003$. Thus, having to keep in mind a simultaneous memory load decreased associative learning scores in older, but not younger adults. Interactions of Condition × Session ($p = .81$, $\eta_p^2 = .005$) and Age × Condition × Session ($p = .94$ $\eta_p^2 = .003$) were not significant.[1]

Associative learning: No-matrices probe

To determine whether the simultaneous memory load interfered with learning *itself* in the older group, we examined Associative Learning scores for the no-matrices probe blocks (6–10 in Session 3), as shown in Figure 3. As the figure suggests, although AL scores were lower for the older adults in the Simultaneous than the Sequential condition for the surrounding dual task blocks in Session 3 ($t(21) = 2.17$, $p = .04$, $d = 1.18$), the scores for these groups did not differ on the probe blocks ($t(21) = –0.32$, $p = .75$, $d = –0.14$).

[1] We conducted this same analysis (Age × Condition × Session) while eliminating participants who scored below 75% (4 young and 5 old) and 85% (4 young and 9 old) on the Matrices task, and found that the pattern of results remained the same in both cases. Thus, these results hold even when we include only people who did very well on the Matrices task, and hence must have been devoting capacity to it.

These findings suggest that, at least by this point in training, the Simultaneous memory load did not impair learning in older adults, but rather its expression.[2]

DISCUSSION

The present study found that implicit associative learning occurs in both young and older adults even while holding a memory load in mind. Older, but not younger adults, had lower learning scores in the Simultaneous than the Sequential condition, making it appear that the simultaneous memory load had impaired their learning. However, probe blocks toward the end of training, in which the secondary task was removed entirely, indicated that the simultaneous memory load had only hurt the *expression* of learning, not learning itself. Thus, these findings suggest that this form of implicit associative learning does not call on limited capacity resources, even in older adults. This ability to learn under a memory load is particularly impressive given that the regularity to be learned in this task is subtle and probabilistic; the regularity is second-order, in that the predictive cue is not immediately adjacent to the target, and the cue is not perfectly predictive.

These findings build on those of Frensch and Miner (1994) and Najati et al. (2008), who reported that SRT learning was impaired by a secondary tone-counting task in older adults. We too found that older adults appeared to have impaired learning in the Simultaneous condition. However, the probe blocks included near the end of training in the present study showed that, once the secondary task was removed, the measure of associative learning in older adults in the Simultaneous condition increased immediately to the level of that in the Sequential group. This suggests that older adults in the Simultaneous group had been learning all along, but that the presence of the secondary task had hidden the expression of that learning. Thus, our results show that the simultaneous memory load interfered with the *expression* of learning in the older adults, not with the learning itself. In fact, Frensch and colleagues have conducted subsequent studies with young adults in which they included a single-task probe similar to the one used here, and they concluded that in young adults, the secondary task hurt only the expression of learning (Frensch et al., 1998, 1999). They did not test older adults in these studies, but our results from the single-task probe blocks suggest that the secondary task impairment in older adults in Frensch and Miner (1994), as well as in Najati et al. (2008), may have reflected effects on only the expression of learning.

[2] As with the ANOVA on AL scores, we repeated the *t*-tests on the probe blocks for Session 3 after eliminating participants who scored below 75% and 85% on the Matrices task, and again, found the same pattern of results as with the full sample.

The current study enables us to rule out several alternative interpretations of these effects on the expression of learning in older adults. First, we can be sure that the dual task effects were on the expression of *implicit* learning, as sensitive recognition measures indicated that no participants who were included in the analyses showed any evidence of explicit knowledge of the regularity. Second, because the memory load was encoded before a triplets block and the test was responded to before or after a block, we know that neither encoding nor responding to the secondary task affected the expression of learning in the TLT (no parallel processing). Third, effects on the expression of learning could not be due to task-switching. Participants in both the Sequential and Simultaneous conditions completed the TLT and the Matrices task, such that participants in both conditions had to switch between tasks. Thus, any effects of task-switching on learning would occur in both groups, and not have an exclusive effect on the Simultaneous group.

The finding that in the current study, both groups learned in the presence of a memory load is encouraging, showing that older adults are able to pick up patterns and regularities within their environment even when their working memory is occupied with a memory load. Although these results are consistent with theories which posit that implicit learning does not call on limited capacity resources (e.g., Frensch & Rünger, 2003), they are surprising in light of recent functional neuroimaging findings showing that older and younger adults rely on different neural systems for implicit associative learning. Using the TLT, Simon, Vaidya, Howard, Jr., and Howard (2012) found that late in training, learning was positively correlated with caudate activation in young adults, but with hippocampal activation in older adults. These results are further supported by two studies using the SRT, which showed that activation in the hippocampus (Dennis & Cabeza, 2011) and caudate was related to learning in young adults, while learning was only related to hippocampal activation in older adults (Dennis & Cabeza, 2011; Rieckmann, Fischer, & Backman, 2010). Thus, these three studies suggest that older adults rely more than young on the hippocampus for implicit associative learning. The Matrices task used here has been shown to activate regions involved in working memory and stimulus binding, including the hippocampus (Mitchell et al., 2000), and thus it is surprising that older adults in the present study showed only a suppressed expression of learning in the TLT, and no interference with learning itself. Perhaps older adults are able to adapt in light of striatal declines (Raz et al., 2005) when completing two tasks that call on the same brain region and, whether through compensation or strategy change, learn even while holding a simultaneous memory load.

Although we found that both older and younger adults show implicit associative learning while holding a simultaneous memory load, there are limitations to this study. It is possible that the Matrices task was not taxing enough to affect the expression of learning in young adults, and learning itself older adults. This is unlikely, however, as neither age group ever reached perfect accuracy on the Matrices task in the Simultaneous condition, the two age groups showed similar accuracy on the Matrices task by Session 3, and the Matrices task was taxing enough to affect the expression of learning in older adults. Future studies may investigate the effects of a more demanding or different type of memory load. The present study also cannot determine whether or not learning itself was hurt early in training in the older adults, because the probe blocks did not occur until the end of training. Future studies should present single-task probes throughout training. Finally, it is possible that our results are specific to the type of implicit associative learning investigated in the present study. We think these results are more broadly applicable, however, as they are similar to those found by Vickery et al. (2010) and Zeithamova and Maddox (2007) as described above, though these studies were only done with young adults.

In summary, we found that implicit associative learning can occur in both young and older adults while they hold a simultaneous memory load. These results suggest that this form of learning does not make strong demands on limited capacity resources, and indicate that older adults are able to pick up subtle regularities in their environments even while their minds are otherwise occupied by a capacity-demanding activity. Results from the probe blocks, however, also highlight the importance of distinguishing learning from its expression. The fact that older adults' *expression* of learning was affected by the simultaneous memory load suggests that making simultaneous demands on cognitive resources decreases older adults' ability to adapt their behavior to environmental regularities.

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