Implicit Sequence Learning in Aging: The Effect of Accuracy, Timing, and Test Structure

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ABSTRACT

Chris Michael Foster: Implicit Sequence Learning in Aging: The Effect of Accuracy, Timing, and Test Structure
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Implicit sequence learning is thought to be preserved in aging when the to-be learned associations are first-order; however, when associations are second-order, older adults (OAs) have been shown to experience deficits as compared to young adults (YAs). Two experiments were conducted using a first (Experiment 1) and second-order (Experiment 2) serial-reaction time task. A between subject's manipulation was utilized in both experiments. Stimuli were presented at a constant rate of either 800 milliseconds (fast) or 1200 milliseconds (slow). Results indicate that both age groups learned first-order dependencies equally in both conditions. OAs and YAs also learned second-order dependencies, but learning only occurred for OAs in the slow condition, and for YAs in the fast condition. The sensitivity of implicit sequence learning to the flow of information, and not age, supports the idea that implicit learning is preserved across the lifespan.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ASRT	Alternating serial reaction time
FOC	First order sequence
ICC	Intra-class correlation
ISI	Inter-stimulus interval
MMSE	Mini Mental State Exam
OA	Older adult
RSI	Response-stimulus interval
RT	Reaction time
SOC	Second order sequence
SRT	Serial reaction time
TLT	Triplet learning task
TOC	Third order conditional
YA	Younger adult

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The study of memory within the field of cognitive psychology has led to two major subdivisions, implicit and explicit memory. Explicit memory involves the conscious recollection of a specific past learning episode, while implicit memory produces a change in future performance based on information that is learned during a previous episode (Schacter, 1987). Typical explicit memory tests include free recall, cued recall, and recognition. In this way, explicit memory involves a learning episode that is consciously reflected upon at a later time to produce a response. Implicit memory is measured through changes in performance between study and test, and is associated with little or no conscious awareness that there has been a change in behavior. These two forms of memory are utilized across the lifespan and believed to be differentially impacted by the aging process.

Explicit memory is generally found to be lower in older adults (OAs) as compared to young adults (YAs) while most forms of implicit memory are generally found to be intact in OAs as compared to YAs (Fleischman, Wilson, Gabrieli, Bienias & Bennett, 2004; Rybash, 1996). Further, there is evidence to suggest that these two forms of memory not only differ in the way they are assessed, but may also rely on different systems within the brain. Several studies have investigated patients who have an impaired ability to retrieve new explicit memories; however, their performance on implicit memory tasks remains intact (Squire & Knowlton, 1995; Hamann & Squire, 1997). While the notion that these two forms of memory are wholly separable is not a settled debate, there is sufficient evidence to suggest that at least some forms of implicit memory should remain intact across the life span and maintain comparable performance whether a person is cognitively normal or cognitively impaired.

Both explicit and implicit memory can also be non-associative or associative in nature. Non-associative memory is utilized for an individual item, such as a single word on a word list or a change in behavior due to an encounter with one item; whereas, associative memory relies on the formation of links between two distinct pieces of information within the environment. Word fragment completion is a type of implicit non-associative memory task in which participants are shown a list of words prior to being shown a list of word fragments. Participants are then asked to fill in each word fragment, but no reference is made to the prior word list. Participants are more likely to fill in a word fragment if they encountered that word on an earlier list than if they had not (Roediger, Weldon, Stadler & Riegler, 1992), the change in performance occurs because a single item was encountered and influenced later performance. Implicit associative learning can be defined as the "acquisition of, or memory for, co-occurrence and dependencies between stimuli or trials that are expressed through performance only" (Rieckmann & Backman, 2009, p. 490). Essentially, implicit associative learning occurs when a person builds novel associations within their environment without utilization of a conscious strategy to learn or awareness that there is an association present. This type of learning is thought to underlie our ability to acquire complex associations (e.g., grammar, procedural and skill learning) without the ability to express the exact sequence or rules that we are engaged in (for review see; Rieckmann & Backman, 2009).

One task used to measure implicit associative learning is the serial-reaction time task (SRT) and its variants. This type of task has been used to show intact learning between OA and YA groups; however, equivalent performance depends on the level of complexity built into the task. For example, when the associations are relatively simple, tasks of implicit associative learning have yielded equivalent learning between YAs and OAs, while higher order tasks with more complex associations are typically learned by both age groups, but not as quickly or to the same degree in OAs (Howard & Howard, 2004). However, impairments on tasks requiring higher-order learning in OAs needs further investigation because this finding depends on the type of sequence that is utilized, the instructions given, and the way learning is measured.

Implicit associative learning, as measured through varying types of SRT tasks, can be expressed through changes in efficiency (Seger, 1994). Improvements in efficiency due to implicit learning involve a change in speed or accuracy when participants respond to a particular stimuli or set of stimuli. Therefore, while people become better with practice during the serial reaction time task overall, implicit learning is demonstrated by significant and greater improvements in structured sequences compared to random sequences or sequences that are structured using different rules.

Automaticity, Attention and Implicit Associative Learning

While implicit learning typically occurs outside of conscious awareness, there does seem to be different levels of attention needed depending upon the complexity and nature of the implicit task. Hasher and Zacks (1979) propose that frequency, spatial locations, and time of events can be encoded automatically. Specifically, Hasher and Zacks (1979) have stated that, “These processes, which we believe are at one anchor point in the attentional demand continuum, allow us to cognitively orient to the routine flow of events in our environment” and that “these processes should be widely shared and minimally influenced by differences in age” (p. 360). All of these processes occur within a SRT suggesting that at some level, improvements in efficiency may be due to automatic processes and should largely be preserved across aging.

Nissen and Bullemer (1987) offer contrary evidence to the automaticity of learning within an SRT task. In their experiments, one group of participants performed the SRT under full attention conditions and another group performed the task under divided attention conditions, simultaneously engaging in a tone counting task. The divided attention manipulation interfered significantly with learning, suggesting that implicit learning requires attention and effort. While this result argues against the automatic nature of sequence learning, there are alternative interpretations. For example, Stadler (1995) performed two experiments that provide evidence for the automaticity of implicit learning. In his experiments, three critical manipulations were employed. One group of participants saw a string of letters prior to each block of sequence learning. They were told to remember the letters (i.e., memory load) and tested for their memory at the end of each block. Another group performed a tone counting task that occurred throughout the SRT task. A third group received intermittent 2000ms pauses at approximately the same rate as the tone counting group received target tones. Compared to control conditions, the pause group and tone counting group showed the greatest interference with learning, while the memory load group showed the least amount of interference. Based on these results Stadler (1995) concluded that implicit sequence learning can be thought of as automatic and that the dual task of tone counting and pauses interfere with the stream of organization of the stimuli, not implicit sequence learning per se. That is, when a person is able to orient to the routine flow and this information is not temporally disturbed, implicit sequence learning is driven by automatic processes.

Further evidence for the automaticity of implicit sequence learning comes from Jimenez and Mendez (1999). In their study, a typical SRT task was performed; however, each location maintained a unique shape and the predictability of the sequence was based on prior grammar learning studies. Grammar learning sequences were interspersed, with approximately 20% of the trials not following the structured sequence. The same experimental stimuli were used in both single and dual task conditions. In the dual task, participants counted the number of times a particular shape appeared within the sequence. Importantly the shapes and the locations allowed for the same predictive relationships to be learned. They found that both single and dual task conditions showed equivalent learning and, interestingly, only the dual task group showed learning based on the shapes; “The results of these studies consistently indicate that what participants learn under these circumstances is intimately bound to the tasks that they are told to perform” (Jimenez & Mendez, 1999 p. 254; also see Perruchet & Pacton, 2006 for a similar interpretation). This offers support for the notion of automaticity, with the caveat that the to-be learned aspects of the stimuli are being attended. The automatic processing utilized during implicit sequence learning should allow it to be preserved across healthy aging; so long as studies carefully control aspects of the task that may impact performance.

Implicit Associative Learning Tasks

There are a few commonly utilized paradigms that investigate implicit learning: Contextual cueing, SRT, and the triplet learning task (TLT). Each paradigm controls and tests for different aspects of implicit learning. In all of these, the rate of learning and degree of learning are measured through improvements in reaction time (RT) or changes in accuracy to repeated, compared to random trials.

Contextual cuing is proposed to be a spatial implicit learning task. Participants encounter screens filled with distractors (L’s varied in their orientation) and a target, typically a T. The T is tipped horizontally and placed randomly on the screen. Participants indicate which direction it is facing with a button press. Certain screen configurations are repeated across blocks, but intermixed with random screen configurations within a block. When a screen is repeated over many blocks participants respond more quickly to the repeated screen configurations when compared to random screen configurations.

The most typical implicit sequence learning paradigm is a SRT. In the SRT, a participant sees a horizontal row of four empty circles on a screen. These circles are filled in, one following another, and a corresponding key is pressed for each location as it is filled. Unbeknownst to the participant the sequences follow a fixed pattern such as, 32413214. After several blocks of the pattern sequence a random sequence or a transfer block is introduced. The difference in mean RT between the last block of pattern trials as compared to the block of random trials is used as the indirect measure of implicit learning. This type of SRT is not usually used to investigate accuracy changes in a meaningful way since participants engage in the same sequence for the first set of blocks and in a completely new sequence in only the last block. The same SRT task can also be given with a mix of pattern and random sequences within each block (e.g., P-R-P-P-R-R-P-P-R-P). Since each block contains pattern and random sequences, skill learning can be compared to implicit learning throughout the entire task with both RT and accuracy.

A modified version of the SRT task is called the alternating serial reaction time (ASRT) task. It is very similar to the standard version, but, the pattern trials are intermixed with random trials (1r2r3r4r) which allows for every block to contain high frequency triplets and low frequency triplets. High frequency triplets (i.e., 1r2, 2r3, 3r4, 4r1) should lead to greater improvements in RT and higher accuracy as compared to low frequency triplets (i.e. r1r, r2r, r3r, r4r). Comparisons are made between RT and accuracy as participants move through blocks. Significant reductions in RT and improvements in accuracy in the high frequency triplets as compared to the low frequency triplets indicate that learning has occurred. Importantly, this particular task is thought to tap probabilistic learning since the associations, while probabilities are essentially fixed overall, are not fixed on a trial by trial basis.

Another modification of the SRT task is the TLT. Participants are shown a similar display as in the other sequence learning paradigms, but respond to every third stimulus in the sequence. The first two stimuli in the sequence are a different color than the stimuli that requires a motoric response, allowing participants to engage in implicit sequence learning while removing some of the motor learning aspects of the procedure. As with other sequence learning paradigms, learning is measured through improvements in RT to the target stimuli for high frequency triplets, as compared to low frequency triplets. Also, accuracy tends to improve on high frequency triplets, while accuracy decreases for low frequency triplets. The TLT also enables the manipulation of joint and conditional probabilities. Joint probabilities are a measure of the occurrence of a particular sequence in relation to other sequences of the same length (i.e. how often does AB occur compared to CB), while conditional probabilities are a measure of the probability of one event given another event (i.e. the probability of B given A).

Sequence Complexity

All implicit sequence learning tasks can be manipulated to vary the complexity of the pattern sequences. A sequence where the next stimulus can be predicted based on the location of the previous stimulus is a first order conditional (FOC) sequence. A FOC can be utilized in a SRT and a TLT, but cannot be used in an ASRT due to the intervening random trials. This type of sequence is thought of as simple implicit learning because it can be learned through associations based on the prior trial. Higher order sequences, such as second order conditional (SOC) or third order conditional (TOC), use predictive associations that are based on stimuli that occurred two or three trials before and are considered to be more complex. A further distinction can be made between a SOC and TOC and lag-2 and lag-3 associations (Remillard & Clark, 2001). SOC sequences may have target predictability in the entire triplet (1 – 3 – 2) as compared to another triplet (1 – 4 – 2) in which the target 2, is better predicted by 1 – 3 than 1 – 4. A lag-2 sequence however, maintains target predictability based solely on the event that occurred two prior (i.e., 1 – x – 2) where the middle item has no predictability within the sequence. All of the sequence learning paradigms described above can use a SOC, TOC, lag-2 or lag-3 sequences depending upon the way the sequence is designed. In a SRT, the sequence can be built such that all possible associations occur equally on the first order (i.e., 121423413243), meaning learned associations must come from stimuli occurring two or more before the current stimuli. In a TLT, triplets can be built that have every possible location between the first and third allowing for the second location to lack predictive information for the third, while creating a predictive association between the first and third location.

Sequence Constraints

There are primarily five constraints that can vary between sequences: location frequency, transition frequency, reversal frequency, rate of full coverage and rate of complete transition (Reed & Johnson, 1994). These constraints must be controlled to ensure that the only difference between training sequences and transfer sequences are the first or second-order portions of the sequences. As an example, the five constraints will be discussed as they relate to the SOC sequence, 121342314324, where each number represents a target location presented on the screen. Location frequency refers to, and can be calculated as, the frequency with which each target is represented within the repeating sequence. In the example sequence this would be .25 for each location since each target occurs 25% of the time. Transition frequency refers to the frequency with which each possible location transitions to each other location. In this example, each transition occurs one per 12 locations or .083% of the time since all 12 transitions are equally represented (e.g., 12, 13, 14, 21, 23, 24, 31, 32, 34, 41, 42, 43). Reversal frequency (e.g., 121) is a type of SOC which may be particularly salient. Each target location remains primed temporarily. When the first part of the sequence (e.g., 12) remains primed, the last element of the run (e.g., 1) leads to a particularly fast RT (Remillard & Clark, 2001). In this sequence there is a reversal frequency of .083% because only one reversal occurs out of the twelve possible locations where a reversal could occur. Rate of full coverage is measured by averaging, from each location, the number of locations that need to be encountered before each possible location is occupied. For example, starting at the first location, 1, the participant must encounter 5 locations before each possible location is used (12134). For this sequence, the rate of full coverage is 4.6. Rate of full transition usage can only be calculated for sequences that contain all possible transitions. In the example sequence each transition occurs once every 13 locations; therefore, the rate of full transition usage is 13. A final constraint is used to reduce explicit awareness. Sequences containing complete runs, such as (1234 or 4321) might be salient for reasons that have nothing to do with the implicit learning and are typically avoided. Based on these constraints two SOC and two FOC structured sequences have been made that are matched across simple frequency information (Cherry & Stadler, 1995; Stadler 1992).

Response-Stimulus Interval

For all sequence learning paradigms the duration between stimuli can be manipulated by altering the response stimulus interval (RSI). After a circle is filled and a participant responds, a constant interval is used before the next stimulus appears. This allows for a small break between successive trials and typically ranges from 0ms – 600ms. Using a constant RSI controls for the processing time that can occur after a response is made. When comparing age groups with different overall reaction times this type of manipulation causes the two groups to systematically encounter successive stimuli at different temporal distances. Frensch and Miner (1994) extended the RSI from 500ms to 1500ms. This eliminated implicit sequence learning in YA’s on a FOC structure, when they were unaware that they were engaging in a sequence learning task. This brings into question the use of this type of manipulation when comparing age groups, since the OA group has significantly slower RT's which, by definition, would increase the temporal distance between stimuli. Further, Willingham, Greenberg and Thomas (1997) showed that varying the RSI had little impact on implicit sequence learning; however, they noted that a long RSI impaired the expression of learning. In their studies, participants who engaged in a short RSI (500 ms) as compared to a long RSI (1500 ms), showed significantly faster rates of learning in some, but not all, experiments. Importantly, there was no difference in the amount of learning when compared to a random sequence transfer block in 3 out of 4 experiments that used this manipulation. Interestingly, when the short RSI group transferred back to the learned sequence but switched to a long RSI, they failed to show the RT benefit of the learned sequence. While it is unclear exactly what caused changes in the display of post transfer learning, we can assume that different intervals between trials did have measurable impacts on performance during the SRT task. The appearance of impairments on implicit sequence learning tasks may reflect the fact that OAs are simply encountering successive stimuli at a greater temporal distance, leading to what appears to be less learning. This effect would be especially problematic when comparing learning during a task with a random sequence, instead of a transfer block, when one group is overall slower.

Some research has suggested that a longer RSI may lead to more explicit knowledge of a SOC sequence (Destrebecqz & Cleeremans, 2001, 2003). In these studies, participants in a 250 ms RSI condition were found to be more accurate for explicit recognition tests of the sequences, as compared to a 0 ms RSI condition, and participants in a 1500 ms RSI condition showed a similar pattern when compared to the 250 ms RSI condition. Recently, Runger (2012) performed an experiment to better understand the role of RSI in explicit knowledge. In this study, four groups of incidental learners performed an SOC training sequence. An old or new recognition test was given with a six level confidence rating. The four groups showed no differences in recognition performance based on their training RSI, indicating explicit recognition was not impacted by length of RSI at training. The difference between these studies lies in the fact that Destrebecqz & Cleeremans (2001, 2003) had participants engage in the recognition portion of the task with the same RSI they used at training. It is likely that the participants in the slower RSI's were simply less able to express any explicit sequence knowledge they may have accrued, not that they had less explicit sequence knowledge.

Measuring Implicit Learning

Learning rates have typically been analyzed with ANOVA's using group X block conditions, where the RT's throughout the learning blocks are compared without transfer block data. If an interaction is found then there is evidence that one group may be learning at a quicker rate than the other group. For example, if a transfer block is used as an indirect measure of implicit sequence learning in block 8, then the first seven blocks of learning could be compared with an ANOVA to see if different conditions or groups showed differential rates of improvement throughout the learning trials. Transfer blocks allow for the use of difference scores to show the amount of learning in an SRT. The mean of participants' median RT during the transfer block containing a random sequence is subtracted from the mean of participants' median RT during the last block containing a pattern sequence. These difference scores can be subjected to a t-test to assess significant effects of sequence learning. To determine whether multiple groups or conditions show equivalent implicit learning an ANOVA can be used.

Additionally, ANOVA's examining RT and accuracy can be used to compare degree of learning and learning rates within groups and between older and younger adults during SRT tasks that do not use a transfer block. In this case, a random sequence is intermittently displayed between pattern sequences giving a continuous measure of learning the pattern sequence as compared to the random sequence. When investigating RT data, a main effect of block (performance improvements occurring as the amount of trials increase) is used to measure skill learning. Main effects of type (sequence trials and random trials) show that learning of the sequence has occurred beyond that of skill learning. Interactions between block and type show that RT's improved at a greater rate for sequence trials as compared to random trials. Main effects of group (old and young) simply show that YAs have faster overall RT's than OAs. Importantly, when comparing groups, three way interactions (Block x Type x Group) confirm whether or not one group has learned significantly more than the other group.

As discussed above, learning can be measured through comparisons of a trained sequence to a different sequence or a random sequence, but we can also find out more precisely what was learned by making comparisons within the trained sequence itself. Remillard & Clark (2001) point out that many implicit learning sequences contain repetitive information that may allow for first order learning to be captured by second order learning or higher and vice versa. SOC sequences maintaining the constraints outlined previously (i.e., 121342314324) have equivalent simple frequency information. Each couplet, triplet and quadruplet occurs only once, meaning the only information that can be learned in the sequence occurs from the predictability gained from $P(2|4 - x)$, $P(4|3 - x)$ and the $P(1|2 - x)$. The predictability of the target from the lag-2 position is 66% (i.e., 4 predicts a 2, two positions in the future only 66% of the time). A comparison can be made on the reaction time to the target when the predictability is valid and on the target when the predictability is invalid. A comparison of RT can also be made between the target and all other non-predictable trials. If learning has taken place, then the valid sequence should lead to a faster reaction time to the target than the invalid or non-predictable portions of the sequence. Learning can be investigated through RT on the target across blocks using ANOVA block x (type: predictable or non-predictable) interaction, and further between groups with a block x type x group interaction. FOC sequences cannot be broken into different parts based on predictability due to the fact that this information is also conflated with simple frequency information.

Measuring Explicit Knowledge

While SRT tasks are thought to measure implicit learning, this must be confirmed with explicit test after the learning period has ended. There are many ways to assess explicit knowledge of the sequence. Almost all studies start with a brief questionnaire to determine if a participant became aware of the repeating sequence. These questionnaires begin with relatively basic questions that attempt to get at explicit knowledge while not directly alluding to the fact that the sequences maintained a pattern. Willingham, Greeley, and Bardone (1993) used an interview containing 5 questions: 1) Did you adopt any special strategy in performing the task?; 2) Did the stimuli appear randomly or predictably? After the first two questions participants were told that the sequence was repeating and then asked: 3) Can you tell me something about the way they appeared?; 4) Were stimuli in a single repeating sequence or were some positions more probable?; 5) Did the sequence appear continuously, or did it come and go? Willingham et al.'s (1993) study contained two groups, one group participated in an SRT task without a repeating sequence and the other group participated in an SRT task that did contain a repeating sequence. Interestingly, both groups responded similarly to question 1, with 25% of respondents in the random sequence group mentioning a pattern and 35% in the sequence group mentioning a pattern. Only responses to questions 2 and 4 differentiated the two groups, suggesting that the more detailed questions are needed to get a measure of explicit awareness. Question 5 did not differentiate the groups because both tended to think that the sequence came and went throughout the task. After the questionnaire or interview, participants were then probed with explicit tests, to further determine their awareness.

Some form of recognition tests is almost always used when trying to assess explicit knowledge of the sequence learning; however, this can come in many forms. Willingham et al. (1993) sought to better understand the nature of three types of recognition tests and understand the role of perceptual or motor fluency in making explicit judgments about sequence knowledge. Three recognition tests were used: a digit group, a watch group and a watch-push group. After engaging in the SRT task the digit group saw a string of numbers representing a sequence and were asked to make a judgment on a scale of 0 (certain it was not seen) to 100 (certain it was seen) about whether the sequence was learned or not. The watch group observed a sequence just as they would have during the learning trials, except they did not respond during the recognition test. The watch-push group observed and responded to a sequence during the recognition test, exactly as they did during the learning stage. Again, both the watch and watch-push group rated the likelihood that each sequence was the one learned in the SRT task on a scale of 0 – 100. It was found that the style of the recognition test had no bearing on recognition performance, suggesting that explicit recognition was not impacted by perceptual or motor fluency and that these three recognition tests were essentially equivalent in their ability to show explicit sequence knowledge.

Implicit learning in Aging

Aging studies, testing older adults between 60 – 80 years of age, have typically found that first order sequences are learned at equivalent rates and to the same degree between YAs and OAs under full attention conditions (e.g., Dennis, Howard & Howard, 2006; Frensch & Miner, 1994; Howard & Howard, 1989). Interestingly, Howard, Howard, Dennis and Kelly (2008; Experiment 2), found impairments in FOC sequence learning when using a TLT task. More specifically, they reported a significant Group x Triplet interaction for both RT and accuracy suggesting OAs were not able to learn a FOC structured sequence as well as YAs. The TLT task does allow for a constant inter-stimulus interval which controls for the temporal distance of the to-be learned associations; however, OAs were significantly more accurate throughout the experiment and the stimuli were presented at a rapid pace of 270 ms. This leaves open the possibility that OAs are engaging in the task with a different bias or focus on accuracy, which might impair implicit learning abilities or alter the expression of their abilities. It also assumes one rate of presentation is ideal for both groups.

Higher order sequences are thought to elicit impaired learning in OAs (e.g., Howard & Howard, 2008; Howard, Howard, Dennis & Vaidya, 2004). Howard, Howard and Dennis (2007) used a unique manipulation to match YA's to the ISI experienced by OAs. They used a Gaussian random variable with a mean and standard deviation for the RSI to give both groups the same ISI. Utilizing this manipulation, Howard et al. (2007) found that "aged" YAs showed greater learning as measured by RT, when compared to OAs and a control group of YAs (not engaged in the longer ISI). When comparing accuracy, the "aged" YAs showed less learning than a control YA group but more than the OA group. Importantly, the "aged" YA group showed higher accuracy overall, meaning that longer ISI's do improve accuracy for YAs. While this is an important first step in understanding temporal flow and its effects on learning, the OA comparison group was tested under conditions that altered instructions throughout the task. The switching of focus between speed and accuracy may have its own impacts which will be discussed more fully in the next section.

Despite the prevailing idea that OAs show impaired learning during higher order tasks, many studies have not replicated this result (e.g., Curran, 1997; Daselaar, 2003; Dennis et al., 2006). Aizenstein et al. (2006) performed a sequence learning fMRI study using Markov chain predictability (each of three stimuli are 70% predictive of the next stimuli) and equivalent learning between OAs and YAs was shown through accuracy and RT data. In another neuroimaging study, conducted by Dennis and Cabeza (2011), equivalent learning rates occurred between OAs and YAs. Importantly, Aizenstein et al. (2006) implemented a constant interval between stimuli of 2000 ms and Dennis and Cabeza (2011) used a variable inter-trial fixation period ranging from 500 ms to 1250 ms. These two neuroimaging studies highlight the importance of the temporal flow of information in implicit sequence learning, and this may be especially critical when trying to understand the effects of age on learning.

Confounding Factors

Importantly, there are a several critical factors that may confound and hinder interpretation when comparing across age groups. OAs tend to perform the task much more accurately than younger adults. This suggests that the two age groups are approaching the task with different goals. OAs emphasis on accuracy could result in a slow-down of reaction time and a more item by item focus during task performance. To control for this difference in accuracy many studies alter the instructions between blocks of trials (e.g., Howard et al., 2004; Howard et al., 2007; Howard et al., 2008, Dennis et al., 2006; Simon, Howard & Howard, 2010). When OA's performance in a block is too accurate, they are told to speed up and decrease their accuracy. When OAs perform too poorly, they are told to slow down and increase their accuracy. The same manipulation is implemented with YAs, with a goal of around 92% accuracy for both groups. The resulting "matched" accuracy is proposed to allow for easier interpretation of reaction time data. While this does match performance in terms of accuracy it comes at a greater cost of interpretability. Explicitly encouraging participants to constantly alter their task performance will impact their reaction time and learning, as is evidenced by the greater variability in RT data and loss of learning (e.g., Howard et al. (2008); Experiment 1b). It is also apparent that OAs are more susceptible to explicit strategy or awareness, which further confounds interpretation of data when using an explicit accuracy matching paradigm. Howard et al. (2004) provide evidence that OAs who become aware of the repetition to contextual cueing, potentially altering their approach to the task, show no implicit learning in their RT data. Since this is the primary measure of learning in a SRT, manipulating instructions throughout the experiment makes it difficult to interpret results when this type of paradigm is utilized. This finding could also be used to explain the diverging results of RT data when comparing YAs and OAs in an explicit accuracy manipulation. By constantly changing the strategy used to accomplish the task, OAs are forced to monitor performance in relation to a learning irrelevant goal. This inadvertently puts OAs in a dual-task condition which may impair their implicit learning performance.

Another major confound in interpreting potential impairments is YA's overall faster reaction time. While this is expected due to their faster processing speed, it also allows them to encounter stimuli at closer time intervals than older adults due to the fact that most studies employ a constant time delay post button press. As mentioned earlier, Frensch and Miner (1994) have shown that manipulating the response-stimulus interval (RSI) can have a dramatic impact on learning. When RSI's are pushed as high as 1500ms younger adults fail to show implicit learning of even first order sequences. Howard et al. (2007) manipulated the RSI in a group of young adults ("aged" young adults) to match the inter-stimulus interval (ISI) of older adults. Mean ISI was successfully matched in this experiment. It was shown that the "aged" young adults overall accuracy increased to be more like older adults providing support for the idea that the different ISI's between the OA and YA groups have an impact on performance.

A final confound is the role of the indirect measure of implicit learning. All studies that have investigated aging's impact on implicit learning using an SRT have used a random sequence, either throughout learning or during a transfer block, to indirectly determine the amount of implicit sequence learning that has taken place. Further, a random sequence is used to show that complex, second order conditional learning, has or has not occurred (Curran 1997, Howard et al. 2004, Howard et al. 2004, Howard et al. 2007). Using a random sequence as an indirect measure of learning fails to show that complex information has been truly acquired. As noted previously, sequences contain many constraints and performance differences on a structured sequence versus a random sequence could be due to any of these simple frequency constraints, such as: location frequency, transition frequency, reversal frequency, rate of full coverage and rate of complete transition usage (Reed & Johnson, 1994). All of these constraints could be learned without necessarily learning higher order or more complex information.

Sequence learning depends upon the association of events that are separated by time and space. Theories on the automaticity of implicit sequence learning rely on the fact that the learner needs very low levels of attention, so long as they can orient to the routine flow of information. The divided attention literature has given the best support for the importance of the flow of information. Implicit sequence learning occurs readily when the information flow is not disrupted, but learning is greatly impaired when the alternate task directly interrupts the acquisition of associations across time. Importantly, dividing attention may not be the only way to disrupt the routine flow of information. Altering task instructions, allowing for different age groups to have different accuracy goals, and giving each participant control over the temporal spacing of events through the use of RSIs, may cause disruptions in the flow of information for the learner. There has also been a great deal of investigation on shorter and longer RSIs, but never a direct manipulation of speed between age groups that controls the temporal flow of information. Past research has been conducted under the assumption that a quicker flow of information is ideal for implicit sequence learning, yet, to my knowledge, this has never been directly tested in OAs. It is probable that there needs not only to be a constant flow of information for adequate learning, but it must be possible for the learner to orient to this flow.

The present experiments use constant ISIs and constant instructions to ensure that every subject encounters either a fast or slow temporal flow of information regardless of their individual preferences for accurate performance. If YAs show greater learning in both fast and slow conditions, then the flow of information may be important for implicit learning, but not an important predictor in changes in learning across the lifespan. If OAs show equivalent learning to YA's in the fast condition, then quicker temporal spacing can be said to be critical for efficient sequence learning. If the two age groups show an interaction with learning and the speed conditions, then both the temporal flow of information and being able to adequately orient to the flow will be important factors for efficient implicit sequence learning.

Experiment 1

Experiment 1 was conducted to investigate the impact of a constant ISI during a sequence learning paradigm that has been shown to elicit equivalent learning in both OAs and YAs. It was hypothesized that the experimental manipulation should have little effect on learning for simple first-order sequences, since a wealth of evidence under many different conditions suggests that this learning is robust regardless of age.

Method

Participants

Subjects participated individually. Thirty community-dwelling OAs were recruited from emails or flyers that were posted around Chapel-Hill. OAs were reimbursed $10 an hour for their time. Thirty YAs in an introductory psychology course participated as part of the course credit. Participants were excluded from this study if they had any neurological or psychological disorders. They were also screened the day of testing for cognitive status with the Mini Mental State Exam (MMSE, Folstein, et al. 1975) and excluded from participation if they scored below a 27. One OA and 1 YA were excluded from this analysis due to at chance performance throughout the task. OAs were significantly older, $t(35.27) = -47.28$, $p < .05$, and had significantly higher education $t(56) = -7.71$, $p < .05$; however, MMSE scores were not significantly different, $t(56) = -1.10$, $p = .28$ (see Table 1).

Table 1
Participant Data

	Experiment1		Experiment 2	
Variable	Young	Old	Young	Old
Gender	12m/17f	16m/13f	7m/23f	9m/19f
Age	20.28(2.09)	73.90(5.74)*	18.70(.88)	66.0(4.83)*
Education	13.76(1.46)	17.34(2.04)*	12.60(1.04)	16.96(3.33)*
MMSE	29.17(.80)	29.41(.87)	29.20(.76)	29.43(.84)

Note. Numbers represent Mean and (Standard Deviation). MMSE = Mini Mental State Exam
**p* < .05.

Analysis

Hierarchical linear modeling was used for all data analysis except where noted. This type of analysis was utilized to account for the dependence that exists within a repeated measures design. An intra-class correlation (ICC) was calculated for each analysis. A range of .42 - .86 was found for each set of data analyzed with this type of model, further supporting the use of a hierarchical linear model. The strong ICCs found within the data indicate that much of the error variance comes from between individuals and not solely within individuals as is assumed by a repeated measures ANOVA. After finding an ICC for each data set, a progressive analysis was conducted to determine the appropriate final model for the data. First, a random intercepts linear growth model was run to check linearity across all the data. A random intercepts and slopes model was run to assess whether there was significant variation in starting points, slopes, and to see if there was any significant covariance between the two. Each model was tested to ensure a linear model was the most appropriate, and to accommodate heteroscedasticity and non-equivalent variance between groups when needed. The final model reported for each analysis was confirmed as the best fit with a likelihood ratio test. The design was a mixed-model block X age X speed, where age and speed were manipulated between subjects, and block was manipulated within subjects. A separate analysis was conducted for learning and transfer blocks. All models used the YA and slow speed condition as the reference group.

Stimuli

A Lenovo ThinkPad T420 computer with a 13-in. monitor was used to display the stimuli and the keyboard was used to collect data. Stimuli were presented electronically using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). Four evenly spaced open circles were displayed horizontally on the computer screen and sequentially filled with an asterisk that fit completely inside of the circle. The asterisk moved between circles with no RSI and filled the circle for the entire duration of the trial. There were two speeds of ISI. Stimuli occurred at constant rates of either 1200ms (i.e., “slow”) or 800ms (i.e., “fast”) and this was manipulated between subjects. A 1200ms ISI was chosen because it has been shown that both age groups are highly accurate and show evidence of learning at this speed (Daselaar, 2003) while a 800ms ISI was chosen because it is an achievable rate of presentation while still being relatively fast for both groups and potentially dropping accuracy. Participants responded to stimuli by pressing the (“z”, “c”, “,”, and “/”) keys.

Procedure

A single experimenter introduced the study and each participant was tested individually. Participants were consented according the UNC-Chapel Hill IRB protocol. The repeating nature of the stimuli was never mentioned to participants and they were informed that the research was aimed at understanding the role of extended practice on a SRT task. Two random 20 trial SRT tasks were given with a brief break between, to acclimatize the participant to the task. The duration of the asterisk (i.e., fast or slow) was the same for the practice as for the actual experiment. The practice was repeated as necessary to ensure that the participants fully understood the directions and task objectives. Participants were told to respond as quickly and accurately as possible and to do their best to respond while the asterisk was still in the circle. After the practice session participants were able to ask any questions.

Experiment 1 employed a first order SRT task. All 8 blocks began with 8 random trials, followed by 10 runs through the sequence. A 10-element FOC sequence occurred 10 times during each of the first six blocks. This was followed by a transfer block with an alternate 10 item sequence given 10 times on the seventh block. A self-paced eighth block was given where participants switched back to the original sequence; however, this block was not analyzed in the present set of results. 600 trials were given during the learning phase and 100 trials were given during the transfer phase. A brief 2-minute break was given between blocks. Participants could use as much or as little of the time as they wanted, but they could not take more than 2 minutes between blocks. To prevent sequence specific effects, the two speed conditions (fast and slow) and two sequences (FOC sequence A and B), were counterbalanced across subjects.

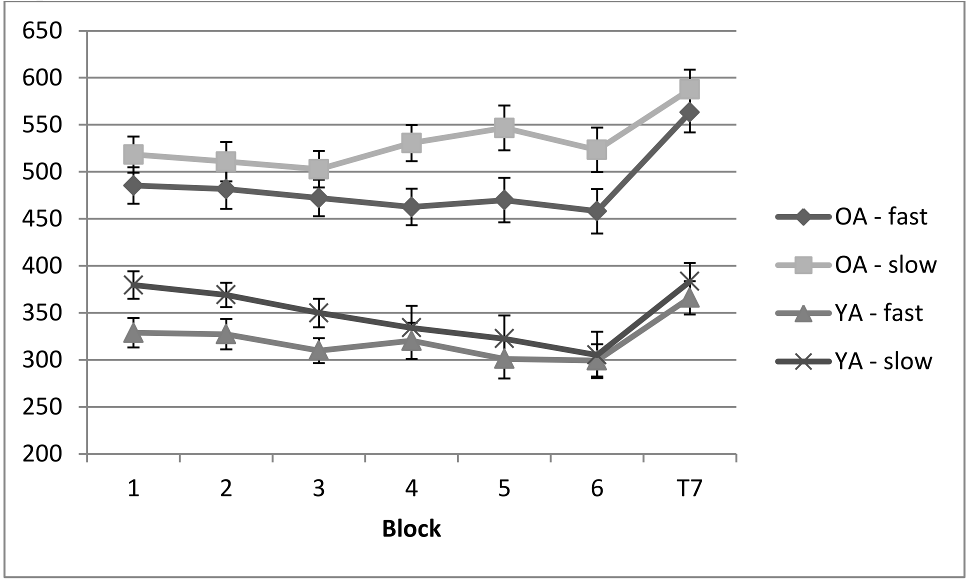
After completion of the SRT task, participants were asked a series of increasingly specific questions about their awareness during the task. These questions were the same as those specified earlier (Willingham, Greeley & Bardone, 1993). Following this task, a recognition test was given. The recognition test was administered at the same rate as the learning trials and participants were told to respond to the stimuli just as they had done during the task. A unique sequence was created that did not share characteristics with either of the learning or the transfer sequences and participants were told to rate whether they thought the sequence just presented was “old” or “new”. The sequences were displayed randomly with each sequence being shown starting from each location within the sequence leading to 10 responses for the old and new sequences. Participants responded on a 1 – 5 scale, where “1” represented “sure it was old”, “5” represented “sure it was new”, and “3” represented “unsure”. They were told they could respond with any level of confidence between 1 - 5 and this scale was displayed on the screen when they made the choice.

Results

Learning Blocks

A hierarchical linear growth model that allowed for heteroscedasticity across blocks was used to analyze RT changes across learning blocks. There was a significant intercept where YAs in the slow and non-predictable condition had a reaction time of 382.38ms, $t(54) = 21.96$, $p<.05$ and a significant slope across blocks for YAs in the slow condition $t(285) = -4.06$, $p<.05$. With every unit increase in blocks there was an expected -15.44 ms drop in RT for younger adults in the slow condition. YAs showed a significant effect of speed on intercepts t (54) = -2.04, p = .046. At block 1 they responded 51.2 ms faster in the fast condition as compared to the slow condition. There was also an effect of age on the intercept, $t(54) = 5.22$, $p<.05$, where OAs in the slow condition responded 128.64 ms slower at block 1 than did younger adults. Age interacted with block, $t(54) = 3.45$, $p<.05$, indicating that OAs experienced less of a slope in the slow condition as compared to YAs in the slow condition. A significant interaction existed between block, age and speed $t(285) = -2.28$, $p=.02$. Within a group, the speed manipulation did not result in significantly different slopes; however, the 3-way interaction reflected the fact that OA's changed from a positive slope to a negative slope across slow and fast conditions, where YA's decreased their slope when moving from the slow to fast conditions (see Fig. 1).

Figure 1
Experiment 1 – Mean Median RT (ms)

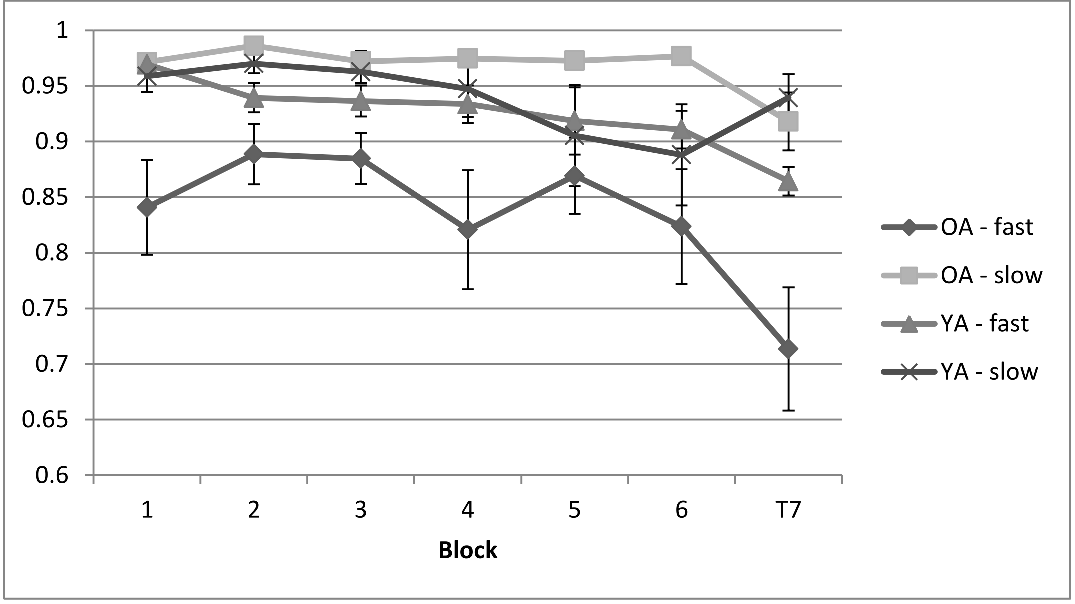


Note: OA = Older Adult, YA = Younger Adult, Error bars represent standard error

For accuracy changes across learning blocks, the model allowed for heteroscedasticity across blocks and non-equivalent variance between groups. There was a significant intercept, where YA's accuracy in the slow condition was .98, *t*(54) = 98.95, *p*<.05, a marginally significant effect of block -.01, *t*(285) = -1.96, *p* = .05 and speed -.03, *t*(54) = -1.99, *p* = .05. The effect of block shows a trend toward reduction in accuracy across learning trials and the effect of speed indicates YAs have reduced accuracy in the fast as compared to the slow condition. There was also a significant interaction with age and speed *t*(54) = -2.11, *p* = .04, where OAs showed a significantly greater reduction in accuracy between the speed conditions than YAs. No other effects were significant. Across learning blocks accuracy is consistently high, but both groups tend to reduce their accuracy overall as a results of the quicker speed (see Fig. 2).

Figure 2

Experiment 1 – Mean Accuracy



Note: OA = Older Adult, YA = Younger Adult, Error bars represent standard error

Transfer Blocks

A random intercepts only, multiple group hierarchical linear growth model was used to analyze RT changes from block 6 to block 7. There was a significant intercept where YAs in the slow condition had a reaction time of 305.08ms, $t(54) = 15.35$, $p<.05$ and a significant slope $t(54) = 5.71$, $p<.05$. After transfer, there was a significant 78.37ms increase in RT for YAs in the slow condition. There was also an effect of age $t(54) = 7.4$, $p<.05$ where OAs in the slow condition responded 218.27ms slower at block 6 than younger adults. No other effects were significant. Overall older adults are slower at block 6, but speed did not significantly impact intercepts and the slopes were similar across conditions and age groups (See Fig 1).

The same model used in the previous analysis was used for analyzing changes in accuracy at transfer. There was a significant intercept where accuracy for the YAs in the slow condition was .89, $t(54) = 32.41$, $p<.05$ and a significant slope for YAs in the slow condition .05, *t*(54) = 2.17, *p* = .03. YA's intercepts in the fast condition were not significantly different .02, *t*(54) = .58, *p* = .57 between the slow and fast conditions; however, their slopes were significantly different and negative in the fast condition as compared to the slow condition -.10, *t*(54) = -2.87, *p* <.05. There was no effect of age on intercepts in the slow condition *t*(54) = 1.88, *p* = .07, but in the fast condition OAs experienced a significant reduction in their initial accuracy -.16, *t*(54) = -2.59, *p* = .01. In the slow condition OAs showed a significantly different and negative slope after transfer -.11, *t*(54) = -2.33, *p* =.02 as compared to YAs in the slow condition but no significant interaction *t*(54) = .68, *p* = .49 between slopes in the slow and fast condition (See Fig. 2).

Explicit Awareness

In response to the questionnaire, 23 OAs and 28 YAs mentioned that some sort of pattern was present during the experiment; however, only 2 OAs and 5 YAs responded that a repeating sequence was present. Of these 7 participants only 1 YA described the actual sequence that occurred throughout the learning trials and this participants RT and accuracy data was not systematically different than the other participants. A 2 (age) x 2 (speed) x 2 (type) repeated measures analysis of variance with the average rating across all 10 encounters with an old and new sequence as the dependent variable was run on the recognition data. Participants were able to recognize an old (*M* = 2.33, *SD* = .57) vs. new (*M* = 3.57, *SD* = .57) sequence, *F*(1,54) = 126.54, *p* < .05 but this did not interact with age or speed. There was an effect of age where overall OAs (*M* = 3.10, *SD* = .88) were more likely to rate a sequence new than YAs (*M* = 2.81, *SD* = .79), *F*(1,54) = 8.95, *p* < .05 and an age by speed interaction, *F*(1,54) = 7.05, *p* = .01. YAs in the fast condition (*M* = 2.87, *SD* = .76) rated all sequences essentially the same as they did in the slow condition (*M* = 2.74, *SD* = .82), but OAs in the fast condition rated all sequences slightly lower (*M* = 2.91, *SD* = .87) than they did in the slow condition (*M* = 3.27, *SD* = .88).

Discussion

The primary finding of RT data across learning trials is YAs respond differently to the slow condition than do OAs. In the fast condition, both groups reduced their RT in block 1, as compared to the slow condition and then maintained a slight negative slope across the rest of the learning trials. In the slow condition, YAs show a negative slope in the slow condition where OAs showed a positive slope in the slow condition. Additionally, both groups initially increased RT when given more time. By the final learning block, YA's RT performance is equivalent regardless of the speed manipulation. YAs exhibit a strong preference to do the task as quickly as possible even when they are given more time to accomplish the task. The opposite effect was seen in OAs. Specifically, whereas OAs responded to the slower speed with increased RT as did YAs, they then increased their RT even further to accommodate the fact that they were given more time. YAs and OAs had matched accuracy in the slow condition, suggesting that even when accuracy is matched in a condition, the two groups have different preferences for how they allocate their time.

At transfer, a similar result was observed, but on different measures. The RT results revealed that all groups and conditions were equally impacted when switching to a novel sequence. The accuracy results at transfer showed that YA and OA groups experienced similar changes in accuracy across transfer in the fast condition. In the slow condition YAs increased their accuracy while OAs decreased their accuracy. Since YAs pushed themselves to similar RT and accuracy rates on the block before transfer, they appear to be able to take advantage of the slower condition and improve their accuracy after the sequence changed. OAs accommodated the slow down by increasing RT, giving them less time to adjust when the sequence changed, which lead to more errors.

While there may have been some explicit knowledge of the sequence, the recognition results show that this knowledge was constant across age and speed. In line with past research, we can conclude that both groups showed equivalent learning during the SRT task since the transfer effect on RT was the same across all conditions. It is important to note that the groups did respond differently when given more time between trials, showing different preferences for performance in a SRT task where ISI is controlled. The different preferences for performance did not impact learning for this experiment, but it does give insight into the way YAs and OAs adapt to different time pressures. YAs maintain quick performance regardless of ISI, while OAs use more time when they are given a longer ISI. These preferences may have impacts on learning when the sequence becomes more complex.

Experiment 2

A second experiment was conducted to test the impact of two constant ISIs on a more complex, second-order sequence. There is less consistency in the extant literature when investigating whether OAs show equivalent implicit sequence learning using higher order sequences. It is hypothesized that the speed manipulation presented in Experiment 1 will have an impact on learning when the associations are separated by intervening events. The temporal flow of information has shown to be critical in YAs using divided attention manipulations (Stadler, 1995). It has yet to be tested whether the speed preferences exhibited in the first experiment interacts with the temporal flow of information. When given the opportunity, OAs take advantage of being given more time by slowing down during the task, yet YAs show a different preference. The desire to go slower supports the idea that OAs may be experiencing very different task demands during a self-paced sequence learning task. If they are experiencing increased cognitive demands during task performance, these demands could disrupt the temporal flow of the to-be-learned information. By allowing OAs to slow down, but still maintain a constant flow of information, it is probable that they will show equivalent learning to YAs.

Method

Participants

A new set of 30 community-dwelling OAs and 30 undergraduate YAs were recruited as they were in experiment 1. One OA was excluded due to data collection error, and 1 OA was excluded for at-chance performance throughout the task. All participants were given the MMSE the day of testing to screen for cognitive impairment. OAs were significantly older than YAs $t(28.67) = -51.04$, $p < .05$, and had significantly higher levels of education, $t(31.88) = -6.65$, $p < .05$. MMSE scores were similar between the two age groups $t(56) = -1.09$, $p = .28$ (see Table 1).

Analysis

Hierarchical linear modeling was used for all analyses except where noted. Final models are reported in the results section; however, a similar data analysis stream was utilized to ensure the model assumptions (i.e., Linearity, Homoscedasticity, Equivalent variance between groups) were appropriate for each data analysis. Random intercepts and slopes were included to account for the dependence that exists within repeated measures data. ICCs were calculated for each analysis and ranged from .52 - .78. The second-order sequences maintained equivalent relative frequency information. This enabled the extraction of behavioral data depending upon which type of trial was being responded to. Since second order information is the only predictable information, median RT was taken from the predictable and non-predictable trials within each sequence and averaged across each block. One triplet occurred during each sequence and this RT data was excluded from the analysis. A transfer block was also present and that data was analyzed in the same manner. All models used the YA, slow speed, and non-predictable information as the reference group.

Procedure

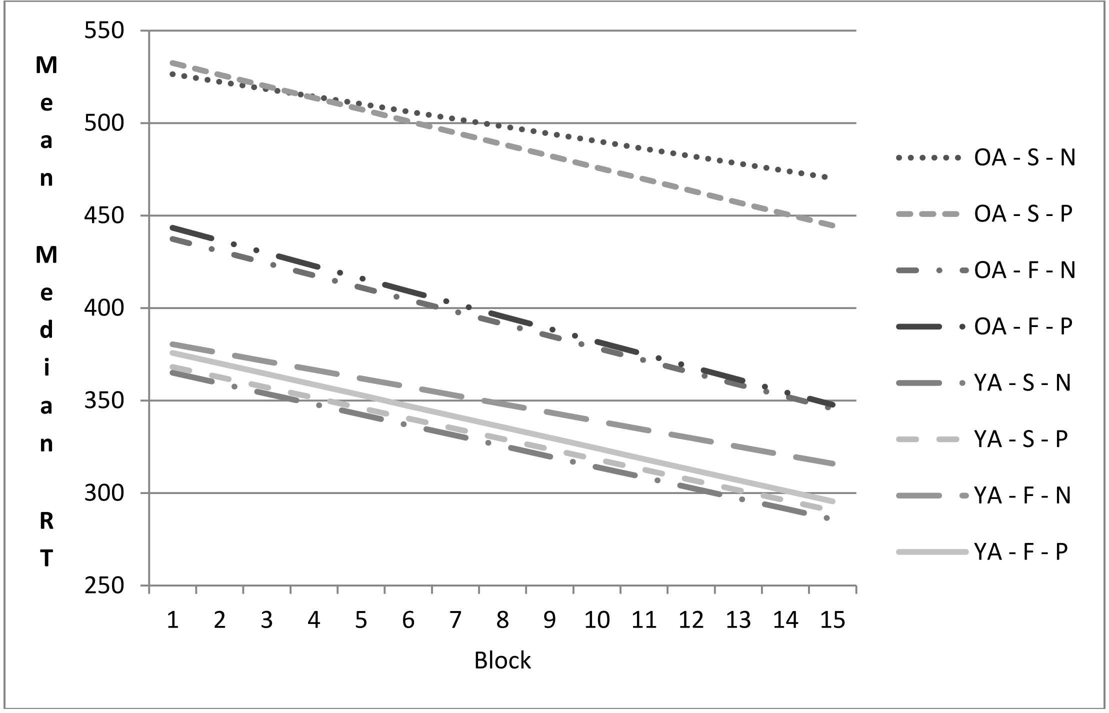
The stimuli were identical to those used in Experiment 1, except the sequences were second-order and 12-items long. Participants were consented according to UNC-Chapel Hill IRB protocol, administered the MMSE, and then given instructions for the task followed by at least one administration of 40 random practice trials. These practice trials were broken into two sets of 20 and a brief break was given between the trials, which replicates the breaks given between blocks during the actual experiment. After participants were comfortable with the task and the instructions, they were tested with 17 blocks of a second-order sequence. Two sequences were created and counterbalanced across participants and the speed manipulation. Each block began with 8 random trials followed by 10 runs through the 12-item sequences. The first 15 blocks maintained the same sequence. In the 16th block the sequence changed to an alternate second-order sequence that maintained the same constraints on relative frequency information. The 17th block was self-paced and used the same sequence that occurred during the learning trials. This block was not analyzed in the present analysis. Between each block participants were given the option for a brief 2-minute break. After the 8th block participants were given the option to take a longer 10 minute break if desired. Any of these breaks could be ended before the time limit was reached, but no one was allowed to go over the allotted time. After the sequences, a questionnaire was given. Two questions were added to the questionnaire for Experiment 2: “Did you try to take advantage of this repeating regularity to anticipate what event was coming next? Did this help?”. These questions were asked after they were told the stimuli did not appear completely randomly. Following the questionnaire, a recognition test was given. The responses and scale were the same as Experiment 1; however, the sequence was broken down into all twelve, 3-item elements. These elements were displayed randomly with twelve, 3-item elements that were not presented during the SRT task.

Results

Learning Blocks

The model for RT data across learning blocks was a multiple group hierarchical linear growth model. There was a significant intercept where YAs in the slow and non-predictable condition had a reaction time of 364.89 ms, $t(54) = 28.22$, $p < .05$. A significant slope across blocks, $t(1671) = -4.41$, $p < .05$, with every unit increase in blocks there was an expected -5.66 ms drop in RT for YAs in the slow and non-predictable condition. There was also an effect of age on the intercept, $t(54) = 6.87$, $p < .05$ where older adults in the slow and non-predictable condition responded 161.3 ms slower at block 1 than younger adults. Age interacted with speed, $t(54) = -2.71$, $p = .01$. OAs experienced a significant 89 ms reduction in reaction time at block 1 in the fast compared to slow condition where YAs did not show a significant change in reaction time in the two speed conditions at block 1, $t(54) = .84$, $p =.40$. There was a significant interaction between block, age and predictability, $t(1671) = -2.44$, $p =.02$. OAs in the slow condition showed a greater difference in RT across blocks between predictable and non-predictable trials than YAs. Finally, there was a significant four-way interaction with block, age, speed and predictability, $t(1671) = 3.5$, $p < .05$. To understand this interaction it was decomposed into four, 2-way interactions (See Fig. 3).

Figure 3
Experiment2 – Model Implied Trajectories for Learning Blocks



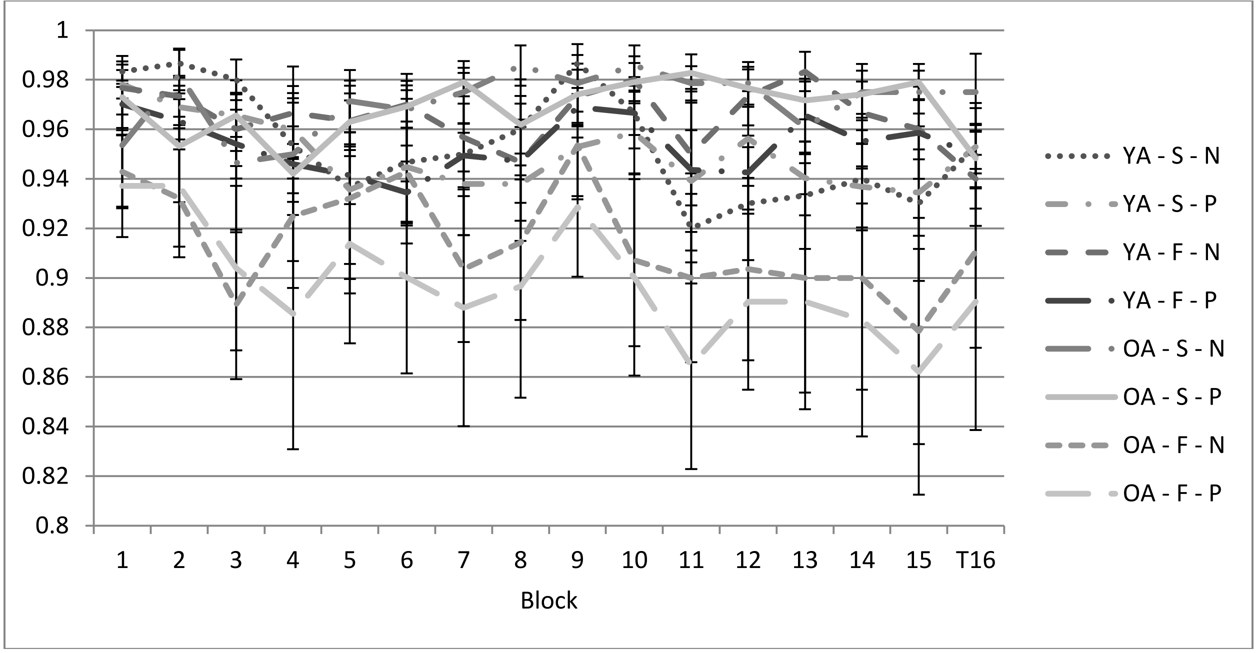
Note: S = Slow, F = Fast, N = Non-predictable trials, P = Predictable trials

YA's in the slow condition did not show significantly different slopes between predictable and non-predictable information, *t*(1671) = .17, *p* = .87; however, they showed a trend toward a significant difference in slopes between predictable and non-predictable information in the fast condition, *t*(1671) = -1.78, *p* = .07. The exact opposite effect was observed for OAs. In the slow condition OAs showed a significant difference in slopes between predictable and non-predictable information, *t*(1671) = -2.62, *p* < .05, but did not show this effect in the fast condition, *t*(1671) = -.45, *p* = .65. The four-way interaction shows that the speed of the stimuli, or the temporal flow of information, is a critical factor in how information is learned implicitly.

A multiple group hierarchical linear growth model allowing for heteroscedasticity was used to analyze accuracy data across the learning trials. There was a significant intercept where YAs in the slow and non-predictable conditions accuracy was .98, *t*(54) = 106.82, *p* < .05. A significant slope across blocks, *t*(1671) = -3.63, *p* < .05, with every unit increase in blocks there was an expected .004 drop in accuracy for younger adults in the slow and non-predictable condition and a significant effect of predictability on intercepts for YAs in the slow condition, *t*(1671) = -2.01, *p* = .045. YAs showed an interaction with block and speed .004, *t*(1671) = 2.47, *p* = .014. The slow condition had a slightly steeper slope than the fast condition. There was no effect of age on the intercept -.017, *t*(54) = -.73, *p* = .47; however, there was a significant three way interaction between block, age and speed, *t* (1671) = -2.05, *p* = .04, where YAs had significantly different slopes between the speed conditions and the OAs did not. No other effects were significant. Overall this analysis shows that across learning blocks accuracy is consistently high and varies little across groups and conditions (See Fig. 4)

Figure 4

Experiment 2 – Mean Accuracy



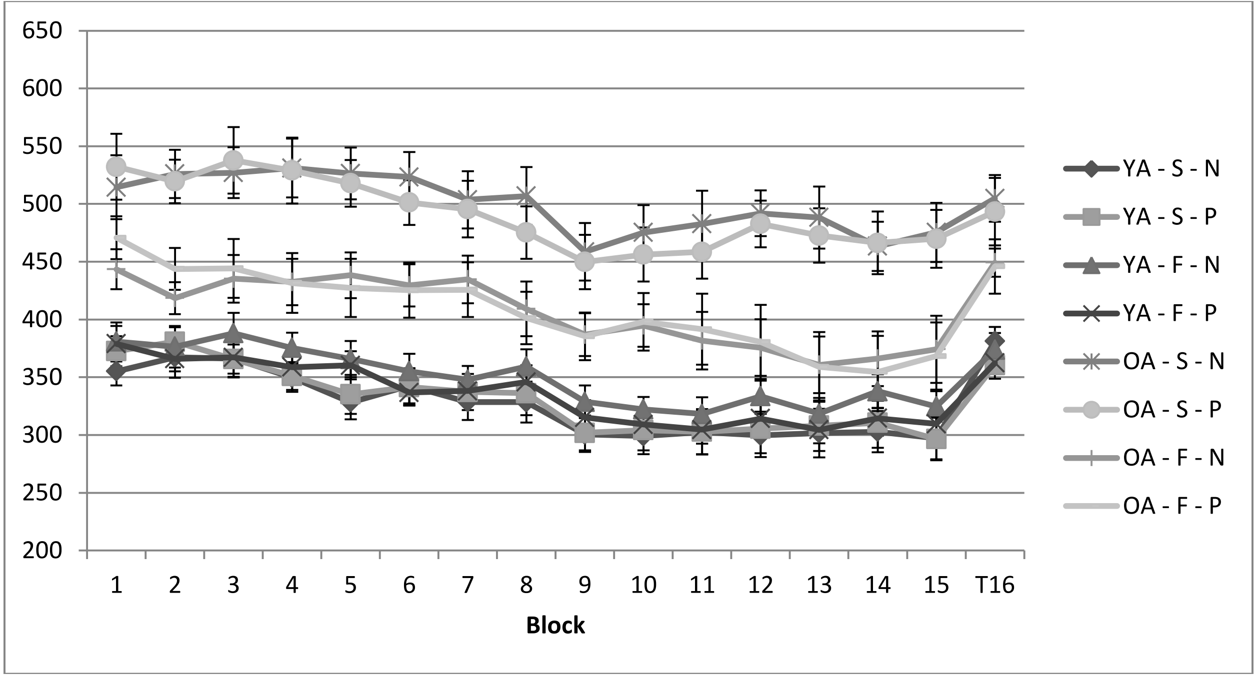
Note: S = Slow, F = Fast, N = Non-predictable, P = Predictable, Error bars represent standard error

Transfer Blocks

The final model for RT data across transfer was a multiple group hierarchical linear growth model. There was a significant intercept where YAs in the slow and non-predictable condition had a reaction time of 298.42 ms, *t*(54) = 18.99, *p*<.05 and a significant increase in RT after transfer, *t*(163) = 4.87, *p*<.05. There was also an effect of age, *t*(54) = 5.60, *p*<.05 where OAs were slower than YAs. Age interacted with speed, *t*(54) = -2.81, *p*=<.05, indicating that OAs experienced a significant reduction in RT in the fast condition as compared to the slow condition while YA's did not show a significant difference in reaction time in the two speed conditions, *t*(54)=1.14, *p* = .26. In this model there was a significant interaction between block and age, *t*(163) = -2.05, *p*=.04. OAs in the slow condition showed less of a transfer effect than YAs in the slow condition. There was also an interaction between block, age and speed, *t*(163) = 2.14, *p* =.034, reflecting OAs different slopes across transfer (i.e., less of a transfer effect on the slow condition but a greater transfer effect in the fast condition) and YAs similar slope across transfer. Predictability of trials showed no effects or interactions suggesting that this pattern of results holds for both predictable and non-predictable trials (See Fig. 5).

Figure 5

Experiment 2 – Mean Median RT (ms)



Note: S = Slow, F = Fast, N = Non-predictable trials, P = Predictable trials, Error bars represent standard error

To explore the effect of transfer on accuracy, a multiple group hierarchical linear growth model was conducted. There was a significant intercept where YAs in the slow and non-predictable conditions accuracy was .93, *t*(54) = 46.10, *p*<.05. The only other significant effect was an interaction between age and speed, *t*(54) = -2.45, *p* =.018, where OAs in the fast condition were significantly lower in accuracy than they were in the slow condition, but this difference did not exist between YA's. These results are in line with the changes in accuracy across learning trials, because in all conditions accuracy was high and relatively constant; however, OAs are the least accurate in the fast condition (See Fig. 5).

Explicit Awareness

When looking at participants responses to the questionnaire, it again seems that most people noticed some regularity across the experiment. Twenty-two OAs and 25 YAs indicated that there were predictable portions of the experiment. The added question of whether people tried to use this information to aid in performance resulted in 17 OAs and 23 YAs stating they did attempt to use the information. Importantly, only 1 OA and 3 YAs described a continuously repeating sequence and correctly reported portions of the sequence. The recognition data showed an effect of old vs. new sequences, $F(54) = 38.33$, $p < .05$, but this average response for old sequences was ($M = 2.11$, $SD = .73$) while the average response for new sequence was ($M = 2.86$, $SD = .68$). The type of sequence (old vs. new) did not interact with age or speed. An interaction between age and speed, $F(54) = 4.35$, $p = .04$, reflected that OAs in the fast condition were more likely to say a sequence was new ($M = 2.36$, $SD = .81$) as compared to the slow condition ($M = 2.65$, $SD = .92$), where YA's in the fast condition were more likely to say a sequence was old ($M = 2.61$, $SD = .59$) as compared to the slow condition ($M = 2.32$, $SD = .84$). While there was a significant difference in recognition, it is clear that on a scale of 1 – 5 with three being unsure, the responses were very low in confidence. This, coupled with the inability to describe the actual regularity, suggests that this was an implicit task.

Discussion

This experiment gives strong support for the idea that the speed of a SRT task has an important and profound impact on implicit learning. YAs have a strong preference to do the task as quickly as possible. Regardless of the speed condition, YAs RTs across blocks differed very little. OAs are slower overall, but, when given the chance, do the task much more slowly. The larger difference in RTs between OAs across the speed conditions as compared to YAs across the speed conditions represents a fundamental difference in the way the two age groups do the task. OAs are not just slower, but when given more time they are also more likely to adjust to task demands by slowing down further. They are more accurate in the slow condition as compared to the fast condition, but importantly, only show significant learning in the slow condition. When task demands are increased by decreasing the time they have to respond, their accuracy drops despite still being quite high, but their ability to implicitly learn becomes compromised. The increased task demands disrupt the temporal flow of information preventing adequate processing of the stimuli and formation of an association across time, space, and intervening trials. Almost all past research using different variations of the sequence learning task have implemented a self-paced timing structure, in which the next stimulus appears after a response, not on a regular interval. Many of these studies also implement a strategy of changing the instructions across blocks to attempt to match performance between age groups. This approach seems to have inadvertently placed OAs in a task with different demands on performance and these different demands were sufficient to disrupt only the OA's ability to acquire complex associations.

YAs show a similar disruption on implicit sequence learning; however, the effect runs in reverse. Accuracy is dropped slightly in the faster condition showing some increased demands on performance. Importantly these demands are not sufficient to disrupt implicit learning and may in fact be desirable for the YA group. It is clear that their RT is similar regardless of the speed manipulation, but the extra time given for the slow condition lowers task demands to the point that they are not able to make the complex associations needed to show learning in this task. Again, the flow of information is disrupted, but this time due to the larger amount of time given between trials. Other research has shown similar patterns of results when YA's are given long RSI's between stimuli (Frensch & Miner, 1994).

The transfer effect on RT reveals a pattern of results that seem somewhat contradictory to the learning effect across trials. All conditions lead to a significant transfer effect except OA's in the slow condition. This is also the condition that led to the greatest difference between predictable and non-predictable trials across learning blocks. The transfer effect in a SRT task has traditionally been the primary measure of learning, yet in this study the effect may be masked by two mechanisms. First, the extra time given during the slow condition may generally allow a participant more time to adjust when changes occur. Second, YAs did not utilize this extra time while OAs did so, potentially reducing the impact of a new sequence on RT. The accuracy data for OAs in this condition support this idea as well. They showed no significant change in accuracy across the transfer blocks in the slow condition. Due to this possibility, the transfer effect is difficult to interpret as a clean measure of learning. The transfer effect also did not differ between predictable and non-predictable trials, further suggesting that it may not capture the unique properties of implicit sequence learning under controlled ISI conditions.

Aging does lead to differences in ability to rapidly perform, but this slowing in performance and in many facets of cognitive processing, does not mean that there are impairments in implicit learning. Previously the primary factor purported to drive differences in implicit sequence learning has been age. With age our ability to retain implicit information degrades. The factor of age in this study is secondary to the factor of speed. Both age groups experience deficits in learning when they are forced to do a task outside of a preferred speed. For older adults, the faster condition increases task load to a point where the acquisition of associations becomes disrupted. For younger adults, the slower condition decreases task load to a point where the flow of information became disrupted. The spreading of associations in time does impair learning for YAs and it is easy to assume that this would be true for all persons. When taking into account a learner who has a preference for slower performance or an inability to perform at quicker rates, spreading out events has a beneficial impact on learning.

General Discussion

The present set of experiments offer strong support for the idea that implicit sequence learning is preserved in healthy aging. In Experiment 1, equivalent learning was observed across both age groups and speed conditions. Importantly, the YAs and OAs did show different patterns of responses in the slow condition. YAs initially showed slower RTs in response to a longer ISI, but by block 6, had equivalent RTs in both speed conditions. OAs also showed an initial increase in RT in the slow condition, yet maintained this slower speed across all blocks. While both groups learned equivalently, this was evidence that the two groups have different preferences for the rate at which they respond. The fast condition also forced OAs to respond in a way that was similar to YAs. This led to increased task demands for OA's as shown by the increased error rates across the SRT. First-order learning relies on associations that occur with no intervening trials and this simple information appears to enable robust learning even when preferences for performance and task demands are different across conditions.

In Experiment 2, learning was significantly impacted by the different demands placed on performance in the speed conditions. As discussed previously, OAs and YAs show learning in the exact opposite conditions. When the task places too little demand on performance for YAs or too much demand on performance for OAs, learning does not occur. Maintaining an uninterrupted flow of information requires a match between an appropriately demanding temporal flow of information and the learner's ability to orient to the flow of information. When a mismatch between these two factors occurs, critical items are not associated. The present experiments did not divide attention and controlled for overt disruptions to implicit learning; however, it is possible that preventing the learner from adequately orienting to the flow of information leads to an enhanced focus on individual trials and prevents implicit associative links from being forged.

Implicit sequence learning can be thought of as an automatic process. This learning does not require the intention to learn, awareness of exactly what was learned, and is thought to require very little attention. In a SRT task comparing divided attention conditions, Stadler (1995) concluded that learning is automatic, so long as the stream of organization is not disrupted. The results of the present experiments fall in line with this interpretation, adding a caveat that disruptions can occur if the learner is unable to adequately orient to the flow of information. Prior research using YAs suggested that longer time intervals between trials impaired implicit sequence learning because the associations were too far apart in time (Frensch & Miner, 1994). When the temporal spacing of to-be associated events is too great, there is a natural disruption to the automatic processes used to acquire the associations. This assumption, along with the fact that OAs generally showed impaired learning and took longer to do the task, meant most experiments were created trying to push OAs to behave more like YAs in both speed and accuracy. The present experiments provide support for the idea that a constant flow of information is important and that a longer interval between trials disrupts learning in YAs; however, an ideal flow of information is not universal and depends upon the learner.

Other research appears to have found this result despite it not being the primary goal. Dennis and Cabeza (2011) found equivalent learning between age groups during a functional imaging study that also manipulated speed. This manipulation was solely for imaging purposes, yet these results are highly comparable to the present results. In this study a variable inter-trial fixation period was presented ranging from 500 ms to 1250 ms. The equivalent learning in this experiment may have been driven by the fact that the variable trial lengths fall into both age groups ideal learning conditions. Task demands would have been appropriate for both age groups randomly throughout the experiment leading to equivalent learning.

A key finding throughout the implicit memory literature is its relative sparing across the lifespan (Fleischman et al., 2004; Rybash, 1996). The preservation of complex implicit associative learning has often been found to show deficits in OA's, yet this finding is not always observed. The current experiments suggest that implicit sequence learning is not impaired by age, but from a mismatch between task demands and the learners abilities. Future research should investigate alternative sequence learning tasks and different types of sequence complexity to examine how the flow of information interacts with these parameters. Using a TLT or Markov Chain allows the investigator to control conditional and joint probabilities which were not tested here. While aging alters the ideal temporal flow of information, it may also lead to an expansion or reduction in the range of possible speeds. The present studies only tested two ISI's, and understanding more precisely how speed interacts with age would be critical to taking these results from the laboratory to application. In an increasingly technological world it is important that we ensure people of all ages are able to interact with and adapt to a rapidly changing environment. Building intuitive information flow into computerized interfaces that can adapt to the individuals preferences and abilities would improve usability for all age groups.

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