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RESEARCH ARTICLE

A comparison of motor skill learning and retention in younger and older adults

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Abstract The goal of the current study was to explore learning and short-term retention using a modified serial reaction time task. The multi-finger sequence task was designed to present repeated and random sequences in a completely interleaved fashion, giving participants within block, variable practice, on the two types of sequences. Eighteen younger adults ($M_{age} = 24$ years) and 15 older adults ($M_{age} = 65$ years) participated in the experiment. Participants were asked to respond on a piano keyboard to a visual stimulus that appeared in one of four squares on the computer screen. They were not informed that one of the sequences presented would repeat. Sequence-specific learning, within-day and across-days, was inferred from differences in accuracy and reaction time between repeated and random sequences. Age equivalence was observed in sequence-specific learning and retention across days, and suggests that older adults may benefit from variable practice.

Keywords Motor skill learning · Aging · Serial reaction time · Retention · Variable practice

Introduction

Generally when compared to younger adults, older adults are not fast or accurate on fine motor tasks (Krampe 2002; Spirduso et al. 2005). Despite these declines, research supports older adults' ability to learn fine motor skills (Seidler 2006; Ketcham and Stelmach 2001), and highlights factors such as practice, expertise, and type of presentation (implicit) that can positively influence an older adults' ability to acquire a fine motor task (Krampe 2002; Spirduso et al. 2005). In addition, research on skill learning (e.g., Strickgold and Walker 2005; Walker et al. 2002; Walker and Strickgold 2004) has clearly demonstrated that young adults are capable of retaining and even improving their performance after a delay and with no additional practice. However, research on retention of a motor skill in older adults is mixed (Smith et al. 2005; cf. Spencer et al. 2007). While gross motor research (Dick et al. 2000) has demonstrated that healthy older adults show benefits at retention when asked to practice two motor tasks in a variable fashion, this finding has not been replicated in the fine motor domain. Given the potential benefits of variable practice, the current study has the goal of examining the benefits of variable practice with a variant of the well-known motor learning task: the serial reaction time task (Nissen and Bullemer 1987).

Background

The serial reaction time (SRT) task (Nissen and Bullemer 1987) is a tool frequently used to investigate motor sequence learning in younger and older adults (Cherry and Stadler 1995; Cohen et al. 1990; Curran 1997; Daselaar et al. 2003; Frensch and Miner 1994; Howard and Howard 1989, 1992; Howard and Wiggs 1993; Willingham and Goedert-Eschmann 1999). In the SRT, participants make sequential key-press responses to cues presented in four spatial locations. Unbeknownst to the participant, a repeating sequence of locations is presented and the

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response time to the associated stimuli decreases compared with that seen for random stimuli. These experiments typically use a blocked design in which a series of blocks of the repeating (REP) sequence are followed by a block of the random (RAND) sequence (i.e., REP–REP–REP–RAND–REP) to test sequence-specific learning (in which performance on REP is faster than RAND).

Sequence acquisition

In the aging literature, many researchers have demonstrated age equivalence in the within-day learning of the SRT (Daselaar et al. 2003; Howard and Howard 1989, 1992). In the (Howard and Howard 1989, 1992) blocked design SRT research, younger and older adults demonstrated similar patterns of sequence specific learning on the SRT. With a slightly different design, in which the REP and RAND blocks were intermixed during the test phase, Daselaar et al. (2003) replicated the behavioral age equivalence in within-day learning and showed that younger and older adults activated a similar network of brain areas during the acquisition of the sequence. Other SRT paradigms testing learning of "higher-order" sequences have shown age decrements (Bennett et al. 2007; Howard and Howard 1997; Howard et al. 2007).

Retention

In classic SRT studies (Howard and Howard 1989, 1992), the primary goal is to examine learning within a single day, not testing retention across days. Of the few studies that have examined both within-day learning and retention in young adults (Strickgold and Walker 2005; Walker et al. 2002, 2005; Walker and Strickgold 2004), most report that young adults are able to retain a motor sequence after a delay and that performance may even improve. This improvement in performance is termed consolidation and many researchers argue that it is sleep-dependent. In contrast, there is more debate as to whether older adults can benefit to the same degree as younger adults and show retention or consolidation on Day 2 (Smith et al. 2005; Spencer et al. 2007).

In the single study of sleep-dependent consolidation using the classic-blocked SRT, Spencer et al. (2007) reported age equivalence in learning on Day 1, but only younger adults demonstrated improvement after a night of sleep. In contrast, older adults' ability to retain a motor skill has been demonstrated in other motor tasks (Dick et al. 2000; Smith et al. 2005). Smith et al. (2005) had participants (aged 18–95 years) who learnt a complex fine motor task and found that all age groups had preserved motor memories and were able to retain the task even after 2 years. Dick et al. (2000) examined retention of a gross motor skill, bean bag tossing, and found that older adults' retention over 2 days was robust. Taken together, SRT research suggests declines in consolidation abilities in older adults, but research using other motor tasks has found preserved retention abilities.

A possible moderator of age differences in retention abilities is the type of practice that participants received. In the Spencer et al. (2007) study, participants learned the sequence in the typical blocked design and age differences in consolidation were found. In the Dick et al. (2000) study, the type of practice during learning varied. In their study, comparisons were made between constant and variable practice conditions. In the constant condition, participants practiced underhand or overhand tossing in a blocked manner, one task at a time. In the variable condition, underhand and overhand trials were intermixed within the test session. In healthy older adults, retention was better after variable practice than constant practice. These results are consistent with the contextual interference literature, which posits that variable practice may slow acquisition in the learning process but that, ultimately, this type of training will produce better learning and retention when compared to blocked practice (Lee and Magill 1983, 1985; Schmidt 1998; Shea and Morgan 1979).

A few within-day studies from the SRT aging literature have intermixed sequence types within blocks (i.e., 10 trials of REP, 10 trials of RAND, 10 trials of REP, etc; Stradler 1993; Curran 1997). This is in contrast to the typical SRT paradigm in which several blocks of the repeating sequence are presented prior to a block of random sequences (i.e., Howard and Howard 1992). The intermixed design has the advantages of minimizing explicit awareness of the repeating sequence, eliminating the potential confound of fatigue and boredom that may occur towards the end of a testing session, and allowing for the evaluation of sequence-specific learning throughout the training process because each block contains data on both the repeating and random sequences. To our knowledge, no aging study has examined retention, using SRT, when the trial types (repeating and random) are intermixed within a block. One developmental study (Meulemans et al. 1998) which used the intermixed trial types within a block did not find any age differences between younger adults and children in the implicit sequence learning or in retention of the SRT task after a 1-week delay.

Given the preceding literature review, we aimed to examine within-day learning and retention using a modified SRT task, the multi-finger sequence task (MFST). In contrast to the classic SRT blocked design, we modeled our design after Meulemans et al. (1998), and presented the repeating and random sequences in an intermixed fashion within each block. This type of variable practice produced the best retention in healthy older adults performing a gross motor task (Dick et al. 2000) and therefore should facilitate retention in older adults in a fine-motor SRT task. Further, younger adults and children show no age differences in retention with an intermixed SRT design (Meulemans et al. 1998), but the question remains if this finding would extend to older adults.

In line with the classic SRT literature (e.g., Cherry and Stadler 1995; Howard and Howard 1989, 1992) we expected that with the MFST, there would be sequence-specific learning by the end of Day 1 in both age groups. For retention, we predicted that the variable practice presentation of REP and RAND would facilitate retention in both age groups and therefore there would be age equivalence in sequence-specific learning across days. Finally, on Day 2 with additional practice, we expected sequence-specific learning to be maintained and improve across the final test blocks for both age groups. As in the classic SRT literature, we predicted that performance on REP sequences would continue to improve with added practice but would remain unchanged on the RAND sequences.

Method

Participants

Eighteen younger (18–35 years, $M = 24$) and fifteen older (60–78 years, $M = 65$) adults participated in this study. The younger adults were recruited through advertisements posted at local universities and older adults were recruited from a pre-existing participant database. All participants were right-handed, had normal or corrected vision, never suffered a stroke, and were screened for medical conditions (i.e., Parkinson's disease, severe arthritis) and medications that would affect their movement. Further, all participants had less than 3 years of musical experience and were not currently practicing a musical instrument. All participants completed the Vocabulary and Forward Digit Span subtests of the Wechsler Adult Intelligence Scale III (WAIS; 1981) to obtain a global measure of cognitive function and to assess short-term memory. For both these measures, participants were within a normal range for their age [Scaled scores: Vocabulary ($M_{\text{Older}} = 12.93$, $SD_{\text{Older}} = 1.3$; $M_{\text{Younger}} = 12.61$, $SD_{\text{Younger}} = 2.0$), Forward Digit Span ($M_{\text{Older}} = 11.47$, $SD_{\text{Older}} = 3.5$; $M_{\text{Younger}} = 10.06$, $SD_{\text{Younger}} = 2.6$)]. In addition, given that there are often age differences in sleep patterns and that we were examining short-term retention after a night of sleep, we also asked participants about the number of hours they slept and the quality of their sleep prior to each day of testing. For all sleep measures, we used a modified Stanford Sleepiness Scale (Hoddes et al. 1973) in which participants recorded the time they went to bed and the time they woke up and rated their quality sleep as either: very good, average, or bad. There were no age differences in either sleep measure ($ps > 0.10$); most participants reported very good or average sleep quality and an average of 7.5 h of sleep. All procedures met Concordia University ethical guidelines. Both younger and older adults were paid a small honorarium for their participation.

Materials and apparatus

Multi-finger sequence task and stimuli

The MFST is a variant of the SRT task used by Meulemans et al. (1998). In the present study, participants learned to reproduce 10-element sequences of key presses on an M-Audio O_2 midi-compatible electronic keyboard (44 × 21 cm), using four fingers of their right hand (i.e., index, middle, ring, and pinkie). All participants were seated approximately 46 cm from the computer screen. The visual stimuli consisted of a 4.5-cm^2 cartoon animal (i.e., "Rolly the hamster") appearing in one of four horizontally presented colored 5 cm^2 frames, which remained in the center of the Dell 19-in. LCD screen for the entire duration of each trial. For each stimulus presentation, participants responded by pressing on the corresponding key (1-2-3 or 4) with the appropriate finger. The stimulus duration was 600 ms and the inter-stimulus interval was 1,000 ms. Responses were recorded after stimulus onset.

The REP sequence always had the same pattern (4-1-3-4-2-3-1-2-4-3) and the RAND sequences contained the same elements but were randomly ordered each time. The REP and RAND sequences were designed to be of equal difficulty. For instance, the same key was never pressed twice in succession, the same transition between two fingers (e.g., index to pinkie) never occurred twice consecutively, at least one transition between the fingers occurred within each block, and the frequency of specific finger transitions was counterbalanced across blocks.

One block of the MFST included 14 trials, of which 10 trials were REP sequence and 4 trials were RAND sequences. The REP and RAND blocks were quasi-randomly ordered, such that the REP and RAND sequences alternated unpredictably within each block (e.g., One block = REP–REP–RAND–REP–REP–REP–RAND–REP–REP–RAND–REP–REP–RAND–REP). The blocks followed similar rules of presentation, such that they never started or ended with a RAND sequence and two RAND sequences never appeared consecutively. There was a 1,300 ms delay between trials. In total, participants completed five blocks of trials: 50 trials of the REP sequence and 20 trials of the RAND sequence.

Procedure

Testing took place over two consecutive days. Each day began with the familiarization phase in which participants imitated simple forward (1-2-3-4-1-2-3-4-1-2-3-4) or backward (4-3-2-1-4-3-2-1-4-3-2-1) 12-element sequences to familiarize them with the keyboard and visual stimuli. Following familiarization, the MFST practice blocks were presented as a game in which participants were instructed to catch "Rolly the hamster" by pressing the key that corresponded to its location. In order to minimize anticipatory responses and maximize response synchronization, participants were instructed to wait until the animal appeared in the frame before responding. During the MFST practice blocks, breaks were encouraged to prevent fatigue and optimize performance. On Day 1, participants completed the Vocabulary and Digit Span subtests of the WAIS and three blocks of MFST. On Day 2, participants completed two more blocks of MFST, the remaining paper and pencil tests, and recall and recognition tests. In the Recognition test, participants were shown three separate sequences (two RAND foils and the REP sequence) and were asked to identify the sequence they saw most frequently. In the Recall test, participants were asked to reproduce the REP sequence on the keyboard, with no visual stimulus to guide them.

Statistical analyses

Motor learning was assessed using two dependent measures of motor performance: accuracy (percent correct) and reaction time for correct responses (ms). The window for a correct response ranged from 100 ms before stimulus onset to 300 ms after the stimulus offset. Only the first key pressed within each window was scored. Additional key presses made within each window were counted as extra key presses, but were not scored. To analyze an equivalent number of REP and RAND trials within each block of practice, all four RAND trials were averaged and compared with the average of the first, fourth, seventh, and last REP trials in each block. We chose these four REP trials because they appeared at the beginning, middle, and end of the block, and therefore would be more representative of learning across the block. To analyze the separate effects within each day of practice and across the 2 days, the data were analyzed with several repeated measures analyses of variance (ANOVAs; Greenhouse-Geiser correction), with group as a between-subject factor and sequence type and block as within-subject factors. Separate analyses were conducted to assess sequence-specific learning within Day 1, short-term retention from Day 1 to Day 2, and sequence-specific learning within Day 2. First, we assessed age-differences and sequence-specific learning across the first three blocks of practice on Day 1 (Blocks 1, 2, and 3). Second, we assessed retention in the same way as Meulemans et al. (1998) by comparing the last block of practice (Block 3) on Day 1 and the first block of practice (Block 4) on Day 2. Finally, we re-assessed sequence-specific learning on Day 2 by comparing the last two blocks of practice (Blocks 4 and 5). Significant main effects and interactions were further analyzed using pairwise comparisons, with Bonferroni adjustment for multiple comparisons. Additionally, in order to compare the number of participants who correctly identified the REP sequence on the Recognition test, a Chi-square analysis was employed. For the Recall test only the first ten responses were analyzed and a one-way ANOVA was used to compare the mean percentage of correct key presses on the Recall test between the groups. The alpha level was set at 0.05 for all statistical tests.

Results

The main goal of this study was to evaluate age-differences within- and across-days, in sequence-specific motor learning. For both age groups, it was expected that there would be sequence-specific learning for the REP sequences. However, we predicted that the pattern of learning would be different in younger and older adults, such that older adults might take longer to learn the REP sequences than the younger adults. Analysis of the accuracy data revealed a slight age difference in learning pattern, such that older adults needed 1 day of learning to reach the same accuracy level as younger adults. Analysis of the reaction time data revealed that older adults had similar learning patterns to that of younger adults across- and within-days. Interestingly, both younger and older adults maintained improvements in performance on the REP sequence across days and demonstrated a distinct decline in performance on RAND sequences on Day 2.

Day 1 (Blocks 1–3)

Accuracy

Figure 1 depicts the accuracy data across sequence types, blocks, and age groups. The analysis of accuracy scores revealed a main effect of group, F (1, 31) = 5.69, $P = 0.023$, $\eta_p^2 = 0.16$, such that younger adults ($M = 96\%$, SE = 1) were more accurate than older adults ($M = 93\%$, SE = 1) on Day 1 overall. There was also a main effect of block, F (1, 31) = 6.35, $P = 0.004$, $\eta_p^2 = .17$. Pairwise comparisons confirmed that there was a significant difference in accuracy ($P = 0.004$) between Blocks 1 ($M = 93\%$, SE = 1) and 2 ($M = 96\%$, SE = 0.7) only. Further, there was a marginal effect of sequence type, F (1, 31) = 3.76, $P = 0.062$, $\eta_p^2 = 0.11$, such that performance on the REP sequence (M = 95%, SE = 0.7) was slightly more accurate than on the RAND sequences (M = 94%, SE = 0.9). None of the interactions reached significance ($ps > 0.10$).

Reaction time

Figure 2 illustrates mean reaction times per sequence type, block, and age group. For the measure of reaction time, there was a sequence type by group interaction, F (1, 31) = 5.24, $P = 0.029$, $\eta_p^2 = 0.15$. Paired t tests split by age group revealed that across all blocks, performance on the REP sequence was significantly faster (M = 438 ms, SE = 12) than on RAND sequences (M = 456 ms, SE = 12) for younger adults. In contrast, for older adults, there was only a marginally significantly difference ($P = 0.08$) between REP (M = 521 ms, SE = 11) and RAND (M = 537 ms, SE = 13) responses on Block 1 but REP sequences were faster than RAND by Blocks 2 ($M_{REP} = 496$, SE = 14 vs. $M_{RAND} = 537$, SE = 15) and 3 ($M_{REP} = 491$, SE = 14 vs. $M_{RAND} = 533$, SE = 12). In addition, there was a significant main effect of sequence type, F (1, 31) = 62.66, $P < 0.001$, $\eta_p^2 = 0.67$, where responses to the REP sequence (M = 470 ms, SE = 9) were significantly faster than to the RAND sequences (M = 496 ms, SE = 9). This main effect was further qualified by a sequence type by block interaction, F (1, 31) = 4.11, $P = 0.021$, $\eta_p^2 = 0.12$, such that for the REP sequence type only, responses on Blocks 2 (M = 465 ms, SE = 9) and 3 (M = 459 ms, SE = 10) were significantly faster than on Block 1 (M = 487 ms, SE = 10). There were no significant differences across the blocks for the RAND sequence type ($ps > 0.61$). As expected, there was a main effect of group, F (1, 31) = 17.32, $P < 0.001$, $\eta_p^2 = 0.36$, where younger adults (M = 447 ms, SE = 12) were significantly faster to respond than older adults (M = 519 ms, SE = 13), overall.

Retention (Blocks 3–4)

Accuracy

Analysis of changes in accuracy from Day 1 to Day 2 revealed a marginally significant block by group interaction, F (1, 31) = 4.38, $P = 0.045$, $\eta_p^2 = 0.12$, such that older adults demonstrated significant ($P = 0.002$) gains in accuracy from Block 3 (M = 93%, SE = 1.2) to Block 4 (M = 96%, SE = 0.9) and younger adults did not show significant gains ($P = 0.61$, Block 3 M = 96%, SE = 1.1, and Block 4 M = 97%, SE = 0.8). Further, there was a significant main effect of block, F (1, 31) = 7.81, $P = 0.009$, $\eta_p^2 = 0.20$, in which performance on Block 4 was more accurate (M = 96%, SE = 0.6) than on Block 3 (M = 95%, SE = 0.8).

Reaction time

There was a main effect of block, F (1, 31) = 13.75, $P = 0.001$, $\eta_p^2 = 0.31$, such that overall, responses on Block 4 were significantly faster (M = 456 ms, SE = 9) than on Block 3 (M = 476 ms, SE = 9). There was a main effect of sequence type, F (1, 31) = 55.80, $P < 0.001$, $\eta = 0.64$, in that all participants responded more quickly on the REP sequence (M = 450 ms, SE = 9) than on RAND sequences (M = 483 ms, SE = 8). In addition, there was a main effect of group, F (1, 31) = 22.18, $P < 0.001$, $\eta_p^2 = 0.42$, where younger adults (M = 426 ms, SE = 12) were significantly faster than older adults (M = 506 ms, SE = 13). None of the interactions were significant. With the goal of minimizing re-learning effects that may occur after the completion of an entire block, the test of retention was also conducted at the trial level. In line with the block analysis, the first trial of Block 4 (for both REP and RAND trials) was faster than the last trial on Block 3 ($ps < 0.02$).

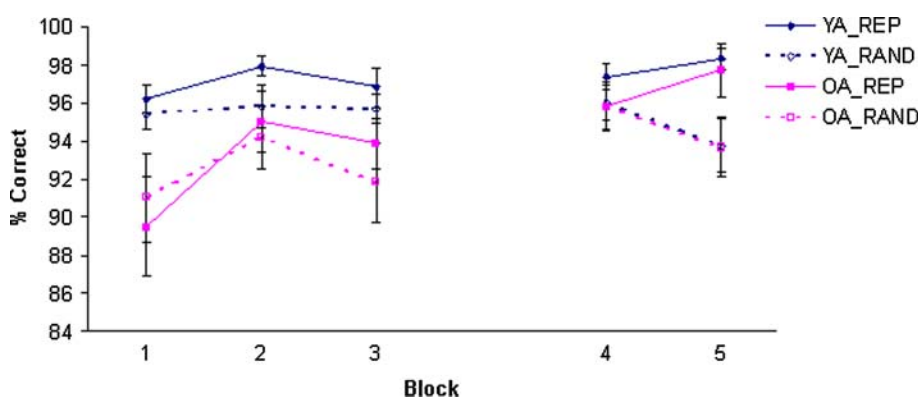
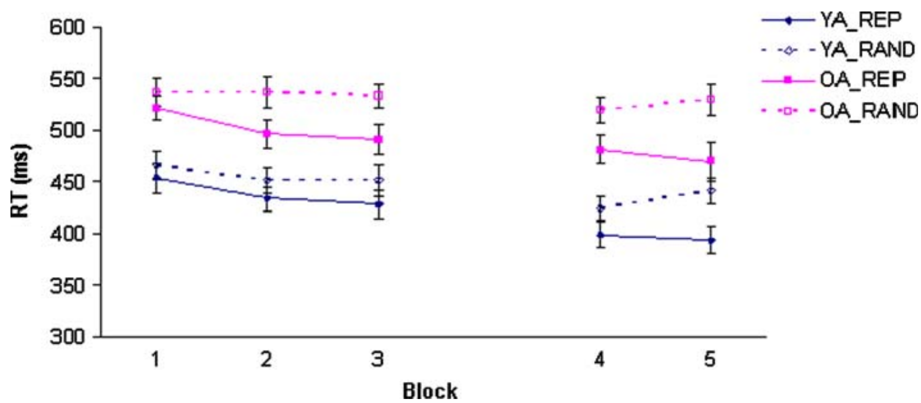


Fig. 1 Accuracy (percent correct) data for both age groups across all five blocks. *YA* younger adult, *OA* older adult, *REP* repeating sequence, *RAND* random sequence. *Error bars* are ±1 standard error of the mean

Fig. 2 Reaction time data for both age groups across all five blocks. *YA* younger adult, *OA* older adult, *REP* repeating sequence, *RAND* random sequence. *Error bars* are ±1 standard error of the mean



Day 2 (Blocks 4–5)

Accuracy

On Day 2 there was a significant sequence type by block interaction, F (1, 31) = 8.39, $P = 0.007$, $\eta_p^2 = 0.21$, such that accuracy decreased significantly ($P < 0.001$) from Block 4 (M = 96%, SE = 0.8) to 5 (M = 94%, SE = 1.1) for the RAND sequences only. There were no significant differences ($P = 0.45$) for REP Blocks 4 (M = 97%, SE = 0.7) and 5 (M = 98%, SE = 0.7). In addition, there was also a main effect of sequence type, F (1, 31) = 10.78, $P = 0.003$, $\eta_p^2 = 0.26$, such that overall responses to the REP sequence were more accurate (M = 97%, SE = 0.6) than to the RAND sequences (M = 95%, SE = 0.8).

Reaction time

There was a sequence type by block interaction, F (1, 31) = 12.87, $P = 0.001$, $\eta_p^2 = 0.29$, such that for the RAND sequence type only, Block 5 responses (M = 485 ms, SE = 8) were significantly slower than Block 4 responses (M = 472 ms, SE = 10) and the REP sequences did not differ significantly ($P = 0.27$) from Block 4 (M = 440 ms, SE = 9) to Block 5 (M = 432 ms, SE = 11). There was also a main effect of sequence type, F (1, 31) = 93.54, $P < 0.001$, $\eta_p^2 = 0.75$, in that responses to the REP sequence (M = 436 ms, SE = 10) were faster than to the RAND sequences (M = 479 ms, SE = 9). In line with the Day 1 findings, there was a main effect of group, F (1, 31) = 22.46, $P < 0.001$, $\eta_p^2 = 0.42$, where younger adults (M = 415 ms, SE = 12) were significantly faster than older adults (M = 500 ms, SE = 13), overall.

Recognition and recall

When asked to choose out of three possible sequences, 72% of the younger and 53% of the older sample chose the correct sequence. The younger group was marginally better at identifying the correct sequence, $\chi^2(2, N = 18) = 3.56$, $P < 0.059$. To rule-out recognition as a factor influencing our results, ANOVAs with recognition (recognized sequence, did not recognize sequence), age (younger and older), and sequence type (REP and RAND) were conducted on the accuracy and reaction time (RT) measures. The main effect of recognition was non-significant for both accuracy ($P = 0.25$) and RT ($P = 0.26$). In addition, the interaction between recognition, age, and sequence type was non-significant for both accuracy ($P = 0.09$) and RT ($P = 0.22$). The lack of interaction between recognition group and age suggests that the degree of explicit awareness was not a factor influencing the reported results.

When asked to reproduce the REP sequence on the keyboard without visual stimuli, analysis of the first ten taps revealed that none of the participants were able to recall all ten taps of the sequence. Younger adults tapped 35% of the sequence correctly and older adults tapped 39% of the sequence correctly on an average. A *t* test comparing younger and older adults on percentage of taps correctly identified was non-significant ($P = 0.66$). Closer analysis of the ten elements revealed that only the first three taps of the sequence were identified at an above chance level (above 50% correct).

Discussion

The goal of the current research was to examine within-day and across-day sequence-specific learning in younger and older adults. We predicted that within Day 1 and Day 2 both age groups would show sequence-specific learning improvements with extended practice. For retention (from Day 1 to Day 2), due to the variable practice presentation, we expected age equivalence in sequence-specific improvements. For within-day learning (Days 1 and 2) and retention, younger and older adults demonstrated a similar pattern of results. By the end of Day 1 there was sequence-specific learning in both age groups. However, in terms of reaction time measures, older adults needed an additional block of practice to demonstrate the same sequence specific improvements as younger adults. For retention, the REP sequences remained faster than the RAND from Block 3 to 4, but the lack of a significant block by sequence type interaction suggests that sequence-specific learning was maintained but did not improve across days. On Day 2, performance on the REP sequence was stable and performance on the RAND sequences significantly declined in both age groups. In general, the age equivalence in acquisition, on Day 1, is consistent with the existing SRT literature (Howard and Howard 1992; Cherry and Stadler 1995; Curran 1997). However, the findings of age equivalence in retention across days and after extended practice (within Day 2) differ from other aging SRT findings (Spencer et al. 2007; Howard et al. 2004). The pattern of age equivalence in performance within- and across-days broadens gross motor research findings (Dick et al. 2000) by demonstrating that healthy older adults can benefit from variable practice, and also extends existing SRT aging literature by demonstrating that older adults can show sequence-specific learning in a variable practice design.

Age equivalence in sequence acquisition

Our Day 1 results of age equivalence are typical of classic SRT studies (Howard and Howard 1992; Cherry and Stadler 1995) and other fine motor sequence learning research (Seidler 2006). Accuracy was very high on both sequences (greater than 90%) and both groups were equally accurate by the end of Day 1. That both age groups demonstrated marginally higher accuracy scores for REP versus RAND sequences supports our expectation of similar amounts of sequence-specific learning on Day 1. In terms of reaction time, older adults needed more repetitions than younger adults to show sequence-specific learning. From Block 1 to Block 2, older adults made significant gains in speed on the REP sequences in comparison to the RAND, whereas younger adults demonstrated these sequence-specific differences across all blocks of Day 1.

The age-differences reaction time for the first block of practice differ from the findings reported by Howard et al. (1992), in which young and older adults learned similarly across blocks (see also Seidler 2006). It could be the case that our findings differ from those of Seidler (2006) and Howard et al. (1992) simply because the older participants found this variant of the SRT task globally more difficult than the younger participants. However, the high levels of accuracy that we observed argue against this. Rather, the slowed acquisition in older adults in comparison to young during the first block implies that initially variable practice had a negative impact on older adults. Adapting to learning with the switching between REP and RAND sequences may have taken slightly longer for the older adults, but by the second block they have adapted and are showing equivalent gains to the younger adults.

The negative impact, specific to older adults, of the interference generated by switching between trial types in the variable practice regime, may help to explain why deficits in within-day learning have been observed in alternating SRT (ASRT) tasks that require learning of higher-order sequences (i.e., Howard et al. 2004). In these tasks, a repeated higher-order sequence is embedded in a series of random key-presses (e.g., 14332314312, where 1-3-2 is the repeated sequence). Considered in light of variable practice between two sequences, these sequences represent a very high level of interference between the two sequences types, which may impair within-day learning in older adults to a greater degree than the variable practice design, or more standard blocked SRT designs.

One benefit of the variable practice design is that it allows for the early detection (within the first block) of age-differences in sequence-specific learning. Indeed, one of the goals of the Howard et al. (1992) experiments was to examine if fewer repetitions would produce age-differences in sequence-specific learning. In experiment 2 (Howard et al. 1992), they compared participants that learned the repeating pattern to those who learned random sequences and they noted that there was an indication of an age-difference in the first block (where younger adults were faster than older) but it did not reach statistical significance.

Age equivalence in retention

The finding of age equivalence in motor skill retention across days appears to conflict with previous studies showing age-related declines in SRT consolidation (Spencer et al. 2007). In the current study, both age groups maintained their accuracy and reaction time across sequence types and days. The lack of interaction between sequence type and block suggests that general aspects of task performance (i.e., one-to-one stimulus-response mappings) improved for both age groups and sequence types. The overnight delay may have a role in general motor skill improvements across days but it did not seem to facilitate sequence-specific learning. This finding parallels recent ASRT research with younger adults by Song et al. (2007), in which they found no improvement in sequence-specific learning after a night of sleep, but they did find that participants maintained performance or retained the sequence from one day to the next. This finding is also consistent with Meulemans et al.'s (1998) study in which children showed improved performance after a 1-week delay, and these improvements were not sequence-specific.

In contrast to our results, Spencer et al. (2007) reported distinct sequence-specific learning improvements, or consolidation, after a night of sleep in their younger sample and no such gains in their older sample. While older adults showed no gains in performance, consistent with our results, they showed no significant losses, and thus were able to retain the sequences. While this study also used a SRT, there were important procedural differences that could account for the divergent findings, particularly the type of practice and the differences in the ratio of RAND to REP sequences. Our RAND to REP ratio for Day 1 was 40% while Spencer et al.'s was 22%. This means that we had a more even distribution of sequence types during practice. Indeed, secondary analyses of the reaction time data revealed that each REP sequence that occurred after a RAND sequence was slower than the REP sequence that occurred before the RAND sequence ($P < 0.001$) across all the blocks. This analysis suggests an even distribution of the amount of interference that occurs when a RAND sequence is introduced. In contrast, Spencer et al. (2007) presented a series of REP blocks and then ended their first day of practice with three test blocks, REP–RAND–REP. In this design, all blocks of RAND occur at the end of training, likely generating maximum interference for consolidation of REP. Thus, in the Spencer study interference at the end of Day 1 may have blocked improvements in older adults. In contrast, in our study, the interference between trial types may have slowed acquisition in the first block, but may have facilitated retention and contributed to the age-equivalence in our sample. Interestingly, we did not observe sequence-specific improvement in performance on the first block of practice on Day 2 for either the younger or older groups. This suggests that the consolidation defined as across-day improvements in performance may be a phenomenon related only to certain practice regimes.

Age equivalence in sequence representation after extended practice

Divergence between REP and RAND sequence types was clearly established on Day 2. Performance was maintained in the REP sequences from Block 4 to 5, but RAND performance dropped significantly across blocks in both age groups, such that in Block 5 REP sequences were faster and more accurate than RAND because RAND performance had deteriorated. A similar pattern was reported with the ASRT task (Howard et al. 2004). Participants made errors consistent with the patterned sequence when performing the random sequence suggesting that strengthening the representation of the REP sequence leads to interference during performance of RAND sequences. Although the number of trials presented per block and the particular design of our sequence types do not allow for the fine structure analysis conducted by Howard et al. (2004), a future study with strategically designed sequence types and additional trials may allow us to explore the interference of the REP sequence on the RAND.

The variable practice design

In terms of the implicit learning literature using the SRT paradigm, the participants in the current study were never told that there was a repeating sequence and yet they were able to use the regularities in the task presented to them to improve their performance on the repeating sequence. The Forgetting and Reconstructing Hypothesis (FRH; Lee and Magill 1983, 1985) from the contextual interference literature (Dick et al. 2000) offers a possible framework of mechanisms that underlie the implicit learning that occurred in this variable practice context. In the FRH, superior performance is hypothesized due to "forgetting" and "reconstructing" processes. Each time there is an alternation between the tasks one needs to forget one and reconstruct the other. In the current study, participants had to forget and reconstruct the REP sequence each time a random sequence was presented. Initially, the forgetting and reconstructing of the REP sequence slowed acquisition in older adults but after one block of practice this inequity disappeared as both groups improved their sequence-specific learning with additional practice.

In addition, the concept of alternation echoes works on aging and task switching in which it has been shown that practice on task-switching (Kramer et al. 1999) reduces performance costs in older adults to the point that there is age-equivalence in task-switching abilities. Further, practice on task-switching abilities promotes skill retention in younger and older adults (Kramer et al. 1999). It is possible that the early age-differences in sequence-specific learning are a result of the older adults needing more repetitions than the younger adults to truly benefit from the variable practice regime. However, consistent with the task-switching literature, after one block of practice alternating between the two sequence types, young and older adults show similar patterns of learning within- and across-days.

Taken together, the contextual interference literature and the task-switching literature seem to suggest that the current variant of the SRT task (the MFST) with a variable practice design seems to foster flexibility. One sequence does keep reoccurring but in the context of sequences that are completely random. It may be the case that this also fosters more explicit awareness of the patterned sequence, but the lack of interactions with recognition and age in the current study suggests that alternating regularly between sequence types may be equally beneficial to younger and older adults.

If it is the case that variable practice can lead to improved retention and age-equivalence in sequence-specific learning across days in an aging population, then perhaps the slowed acquisition early on in practice is a small price to pay for eventual age-equivalence in sequence-specific learning and retention. The current findings of age-equivalence using a variable practice design replicate existing developmental research (Meulemans et al. 1998) and extend existing findings into the aging domain. In addition, the variable practice design has the advantage of enabling the assessment of sequence-specific learning much earlier than is possible with a blocked design. As such, this type of design may prove to be an alternate way to examine sequence-specific learning in an aging population. Future studies could directly test if the variable practice design is a more beneficial practice regime for older adults in comparison to other design types.

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