Fine motor control and aging: A role for executive functions in sequential tapping performance?

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ABSTRACT

Fine motor control and aging: A role for executive functions in sequential tapping performance?

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The primary objective of the current thesis was to examine age differences in sequential finger tapping with concurrent cognitive tasks of varying levels of difficulty. The first study was designed to determine the point at which age equivalence would be reached on the finger tapping task. Results of Study 1 established age equivalence in sequential tapping after one block of practice. The second study was designed to assess age differences in sequential tapping when combined with a low-load semantic judgment task that had also shown age equivalence under single-task conditions. Despite age equivalences in single-task performance, age differences in fine motor performance emerged when the sequential tapping task was paired with semantic judgments. Older adults had greater dual-task costs than younger adults in both motor measures (accuracy and reaction time). Neither age group incurred cognitive costs. Study 3 was designed to examine the boundary conditions of these results using a within-subjects manipulation of cognitive load. The same sequential tapping task was paired with a mental arithmetic task that had two levels of difficulty. Age differences in motor accuracy were evident in low-load conditions and both age groups had motor and cognitive costs in the high load condition. These results suggest that older adult’s resources were already taxed in the low-load condition whereas younger adults’ performance only faltered when load was high. Taken together, these results demonstrate that older adults require greater executive control to tap sequentially than younger adults. These results converge with existing

simple tapping and gross motor aging research in demonstrating cognitive penetration of motor task performance with age.

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To begin, I thank my two supervisors (Karen & Virginia). While some would argue that being co-supervised can be a curse, I can attest that the benefits of co-supervision outweigh the costs. In my case, I have been lucky to work with two very successful, intelligent, and supportive role models. The experience I gained from two people with very different expertise is really only the tip of the iceberg. Their steadfast support and understanding in all my endeavours has truly made this experience worthwhile. Words cannot really capture the depth of gratitude I hold for these incredible women but ultimately I am proud to have called them “Boss”.

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CONTRIBUTIONS OF AUTHORS

This Ph.D. consists of two manuscripts.

Study 1

Fraser, S. A., Li, K. Z.H., & Penhune, V. B. (2009). A comparison of motor skill learning and retention in younger and older adults. *Experimental Brain Research, 195,* 419-427.

Study 2 & 3 (See Chapter 2)

Fraser, S. A., Li, K. Z.H., & Penhune, V. B. (under review). The impact of concurrent cognitive load on sequential tapping in healthy aging. *Journals of Gerontology: Psychological Sciences.*

Relative Contributions

With the help of my two supervisors, I determined the goals and the design of the current set of studies. For each study, I worked closely with computer programmers (Alejandro Endo & Ricco Boma) to design the timing and cues of the tasks included as well as tailoring the output produced by the scoring program. For Study 1, with the help of the research assistant Laura Fontil and Caroline Doramajian all the subjects were recruited and tested on two consecutive days. For Studies 2 & 3, Laura Fontil, Stephanie Torok, Madeleine Ward, Vanessa Raccio and Monique Leblanc helped with the recruitment and testing. For all projects, I prepared and trained students helping with the project on the procedure and verbal protocols. I tested the first 10 participants in each sample to ensure that the protocol and programming was running smoothly. Following completion of the studies, I was responsible for the data entry, statistical analyses, interpretation of the data, and preparation of the manuscripts. For each manuscript, I wrote a draft of each of the sections and Drs. Li and Penhune provided feedback and revisions.

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Chapter 1

General Introduction

It is easy to identify instrumental activities of daily living (e.g., driving and meal preparation) as well as basic activities of daily living (e.g., grooming and bathing) that require adequate fine motor control to complete. Additionally, it is fairly common to complete these and other tasks while attending to other information being presented simultaneously. Consider the example of driving, when driving the driver has to process the motoric demands <u>and</u> the visual and auditory information that is being presented. Age differences in the ability to divide attention between two tasks, has been the focus of many years of research (for review: Kramer & Madden, 2008). Generally, older adults perform more poorly than older adults when two tasks are combined particularly when executive control processes (i.e., shifting, updating, & inhibition) are required (Verhaeghen & Cerella, 2002). The dedifferentiation hypothesis of cognitive aging has suggested that cognitive and sensorimotor functions are more closely related in aging (Lindenberger & Baltes, 1997); and therefore dividing attention may become more difficult when cognitive and motor tasks are combined.

Due to the risk of falls, the majority of dual-task cognitive-motor research has focused on divided attention with gross motor tasks. Gross motor research has demonstrated the importance of executive control and attention in walking and postural control (Woollacott & Shumway-Cook, 2002). Further, divided attention situations that entail a cognitive and a gross motor task have generally demonstrated age differences in the ability to divide attention, with older adults demonstrating greater performance costs than younger adults when these two types of tasks are combined (Li & Lindenberger, 2002; Woollacott & Shumway-Cook, 2002).

Despite the importance of learning and maintaining fine motor skills for the functional status of an older adult (Fogel, Hyman, Rock, & Wolf-Klein, 2000), less research has been devoted to fine motor divided attention situations. Age differences in fine motor control exist, with older adults demonstrating greater variability, increased slowing, and decreased accuracy in comparison to younger adults (Krampe, 2002; Smith, Umberger, & Manning, 1999). Of the existing aging and fine motor research, those that divided attention or adopted a dual-task paradigm (Albinet, Tomporowski, & Beasman, 2006; Crossley & Hiscock, 1992; Kemper, Lian, & Herman, 2003) tend to support age-differences in fine motor performance when attention is divided. Research involving sequential tapping, simple tapping and walking (Kemper et al., 2003) suggests that sequential tapping may be more attentionally demanding for older in comparison to younger adults. Since simple tapping research has supported age differences in fine motor performances that increase with cognitive load (Crossley & Hiscock, 1992), the goal of the current investigation was to assess age differences in sequential tapping performance when performed concurrently with cognitive tasks that vary in load.

The dedifferentiation hypothesis

The general observation of greater cognitive-motor dual-task costs in old age is compatible with the dedifferentiation hypothesis of cognitive and sensorimotor aging (Baltes & Lindenberger, 1997). By this view, cognitive and sensorimotor abilities “differentiate,” or become more distinct, from childhood to adolescence and then “dedifferentiate,” or become more closely related, in old age (Anstey, Hofer, & Luszcz, 2003). Anstey interpreted the hypothesis this way: “Classic dedifferentiation hypotheses would predict that as people age, the boundaries between discrete cognitive abilities blur and the correlations among them increase” (Anstey et al., 2003, p. 482). Initial studies testing the dedifferentiation hypothesis examined correlations between different cognitive functions in old age (Balinsky, 1941), but research has advanced to include cross-domain correlations (i.e., cognitive and sensorimotor; Baltes & Lindenberger, 1997). These correlational findings are largely supportive of the dedifferentiation view, with many studies showing increased covariation between cognitive and sensorimotor performance with age (Anstey, Lord & Williams, 1997; Baltes & Lindenberger, 1997; de Frias, Lövdén, Lindenberger, & Nilsson, 2007; Germain & Collette, 2008; Ghisletta & de Ribaupierre, 2005; Li & Lindenberger, 2002; Lindenberger & Baltes, 1994; cf. Anstey et al., 2003). Experimental studies supporting the dedifferentiation view show that cognitive and motor processes are more interdependent in that paradigms that combine cognitive and sensorimotor tasks tend to be more detrimental to performance of older adults than young (Li & Lindenberger, 2002). The findings support the impact of increased sensory load on the cognitive performance of older adults (e.g., Schneider, Daneman, & Pichora-Fuller, 2002) as well as the impact of increased cognitive load on sensory performance (e.g., Sekuler, Bennett, & Mamelak, 2000).

The dual-task paradigm: Combining cognitive and motor tasks

A large portion of the experimental evidence for dedifferentiation of cognitive and motor abilities utilizes the dual-task paradigm. In dual-task paradigms, participants are asked to perform Tasks A and Task B simultaneously. The cost of dividing attention between two tasks is often measured by comparing individual performance on each task separately (i.e., accuracy and reaction time for Task A alone or Task B alone) versus these same measures under divided attention conditions (i.e., does it take longer to respond and are there more errors when Task A is performed at the same time as Task B?). While it is not always the case (e.g., Brauer, Woollacott, & Shumway-Cook, 2001; Hartley & Maquestiaux, 2007), typically older adults have greater dual-task costs than younger adults (Verhaeghen & Cerella, 2002).

The resource or capacity model (Kahneman, 1973) of attention clarifies why performance costs might be incurred when two tasks are performed concurrently. In this model, when the two tasks combined exceed the individuals' available processing capacity, then dual-task costs will emerge and the performance of one or both tasks will suffer. This model, in combination with dedifferentiation, helps explain why in general there are age differences in the degree of dual-task costs. If cognitive and motor functioning becomes more closely related in old age and one function relies on the other, then this would further constrain older adults' resources in a divided attention situation.

Walking dual-task research

In the motor control and aging literature, dual-task gross motor (balance and walking) research is more prevalent than dual-task fine motor research (e.g., finger tapping and reach and grasp), likely due to the importance of fall-risk associated with walking (see Woollacott & Shumway-Cook, 2002). One of the main goals of this body of research is to understand the role of cognition in posture and balance. The Woollacott and Shumway-Cook (2002) review of postural control and walking pointed to one fundamental conclusion: walking and postural control require attention to coordinate gait and maintain postural stability. Current dual-task research suggests that older adults may need more cognitive control than younger adults for gross motor tasks (e.g., Beauchet, Kressig, Najafi, Aminian, Dubost et al., 2003; Brown, McKenzie, & Doan, 2005; Faulkner, Redfern, Rosano, Landsittle, Studenski et al., 2005).

The difficulty level or the particular demands of the motor and cognitive tasks can modulate the degree of dual-task costs (Alexander, Ashton-Miller, Giordani, Guire, & Schultz, 2005; Li, Lindenberger, Freund, & Baltes, 2001; Lövdén, Schaefer, Pohlmeyer, & Lindenberger, 2008). Li et al. (2001) utilized a “testing-the-limits” approach, when they paired two demanding tasks (i.e., walking over obstacles and memorizing words using the Method of Loci) and they found that healthy older adults prioritized their walking performance at a cost to their memory performance. This exemplifies the “posture-first” principle in aging, in which older adults will tend to preserve their balance and gait above all else (Woollacott & Shumway-Cook, 2002). Research by Faulkner et al. (2005) supports this claim and further argues that physically frail older adults will require greater cognitive control than healthy older adults. Other posture control research has suggested a dual process account for postural control in aging, in which a low level of cognitive load might improve balance by shifting attention externally and high loads of cognitive load may lead to cross-domain resource competition (Huxhold, Li, Schmiedek, & Lindenberger, 2006, Lövdén et al., 2008).

Similar conclusions were drawn in research from our laboratory that paired treadmill walking with different cognitive tasks: (1) semantic judgments (Fraser, Li, DeMont, & Penhune, 2007); (2) two difficulty levels of mental arithmetic (Abbud, Li, & DeMont, 2009; Li, Abbud, Penhune, & DeMont, 2009). Across experiments, we observed age equivalence in cognitive performance and age differences in motor performance. In particular, younger adults were able to adapt their gait in conditions of increasing cognitive load but older adults were not (Li et al., 2009). Older adults lacked the cognitive flexibility observed in the younger adults, again leading to the conclusion that walking requires greater cognitive control in aging. The lack of adaptation on the part of older adults in conditions of greater load, suggests that their resources were already maximally taxed. If cognitive and motor functions are more closely related in old age as is suggested by the dedifferentiation data then managing an increasing load would be more difficult for older adults in comparison to young.

Contemporary aging and gross motor control research has focused on executive functions as the primary factor influencing age differences in dual-task performance. Hausdorff, Schweiger, Herman, Yogev-Seligman, and Giladi (2008) examined the effect of cognitive load on dual-task walking in a large sample of healthy older adults (*n* = 228). All gait parameters demonstrated dual-task decrements, with the tasks with the greatest cognitive load resulting in the greatest decrements. Most interestingly, they tested executive function in their sample, and categorized participants into low and high executive function groups. Older adults with low executive function scores demonstrated greater gait variability than individuals with higher scores. In a second study, comparing the same older adults to younger adults, Srygley, Mirelman, Herman, Giladi, and Hausdorff (2009) found that executive function mediated dual-task decrements in cognitive performance in older adults but not younger adults. The authors conclude that for older adults executive processes play an important role in maintaining gait. In a comprehensive review of executive function in gait (Yogev-Seligman, Hausdorff, & Giladi, 2008) the correlational and dual-task research reviewed supports the role of attention and executive functions in gait and points to a multifactorial model of gait in aging where reciprocal influences between gait variables and executive function variables exist.

The current overview of dual-task walking research highlights the importance of attention and executive functions in gait. Across these studies, with the exception of low-load conditions, older adults seem to be affected by the division of attention to a greater degree than younger adults. Based on this literature, a primary question for this thesis was whether the same age differences in attentional and executive processes would be observed in dual-task fine motor performance?

Fine motor control, dual-task performance, and aging

Similar to walking research, fine motor control research has evidenced a decline in fine motor control with age (Krampe, 2002; Smith et al., 1999; Spirduso, Francis, & MacRae, 2005). In addition, this decline appears to increase in patients with Alzheimer's disease and mild cognitive impairment (Yan, Rountree, Massman, Smith Doody, & Li, 2008). A common paradigm to assess fine motor performance in aging is the serial reaction time task (Nissen & Bullemer, 1987). More specifically, this task has been used to assess age differences in sequence learning in younger and older adults (Cherry & Stadler 1995; Cohen, Ivry, & Keele, 1990; Curran, 1997; Daselaar, Rombouts, Veltman, Raajmakers & Jonkers, 2003; Frensch & Miner 1994; Howard & Howard, 1989, 1992; Howard & Wiggs 1993; Willingham & Goedert-Eschmann, 1999). Typically, implicit versions of the serial reaction time task have yielded age equivalence in the learning phase (e.g., Daselaar et al., 2003; Howard & Howard, 1989; 1992). When the serial reaction time task has been used in a dual-task paradigm, the goal has been to explore if a secondary task will disrupt the acquisition of the motor sequence (French, Wenke, & Rünger, 1999; Jiménez & Vásquez, 2005; Schumacher & Schwarb, 2009; Shanks, Rowland, & Ranger, 2005) rather than to test for age differences in fine motor performance.

In contrast to the acquisition studies noted above, steady-state sequential finger tapping has been used to examine age differences in dual-task performance. Kemper, Herman, and Lian (2003) asked participants to repeatedly tap a four-finger tap sequence (1-3-2-4) while answering questions. This task was compared to simple tapping (involving one finger) and walking. The authors found that the combination of sequential tapping and speech produced the greatest age differences in comparison to simple tapping and walking. Potentially the sequential nature of the fine motor task may have increased the cognitive control needed to perform the two tasks and ultimately resulted in the greatest costs.

Similar age differences in fine motor performance were found in simple one-finger tapping research by Crossley and Hiscock (1992). In their study, simple tapping was paired with three cognitive tasks. The three cognitive tasks each had two difficulty levels (low and high cognitive loads). Across all dual-task conditions the authors found that older adults were more affected by the manipulation of cognitive load than young adults. Age differences in proportional change scores[1] were found only on the motor task, but not the cognitive tasks. The authors also manipulated task emphasis to evaluate age differences in the ability of younger and older adults to allocate their attention to a given task and they did not find any evidence for age differences in attentional allocation. They

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[1] Proportional change scores are the degree to which performance in dual-task trials were altered relative to single task trials.

concluded that neither a general slowing model nor a specific resource model would fit their data and proposed instead that a “general processing resource” declined with aging because differences were evident in dual-task tapping with three different cognitive tasks. If executive control becomes more important in motor control in old age, one possibility is that the “general process” that Crossley and Hiscock (1992) alluded to might be executive control.

In recent fine motor dual-task research by Albinet, Tomporowski, and Beasman (2006) the cognitive task was held constant and the demands of the motor task were varied. For this study, the cognitive task was to generate a series of random numbers at a fixed production rate and the motor task involved tapping alternatively on two targets that varied in size systematically. While both age groups’ motor task performance declined from single to dual-task conditions, only older adults’ cognitive performance declined with the increase in motor task demands (increased control needed for smaller targets). Similar to Crossley and Hiscock (1992), the results suggest that when task demands in either task increase (motor or cognitive) older adults’ performance suffers to a greater degree than younger adults.

Taken together, the limited number of fine-motor dual-task studies reviewed here suggests that similar to dual-task walking, older adults have greater performance decrements when performing a cognitive and a fine-motor task concurrently. Additionally, it seems that increasing the cognitive or motor load of the component tasks is more detrimental to older adults’ dual-task performance than younger adults. However, given the limited findings from previous research, the current studies were designed to more carefully assess possible age differences in dual-task fine-motor performance.

Further, we hoped to assess whether executive functions play a similar role in fine motor control as they do in gross motor tasks. In dual-task gait and posture studies, one of the global interpretations of older adults relatively greater costs in motor performance is that they favour maintaining balance. The ‘posture first’ principle may heighten the importance of executive control in these tasks, and should not be as influential during a simple finger tapping task. In contrast, in the present studies, we hypothesized that using a more complex, sequential fine-motor task might tap into similar executive control mechanisms.

An important limitation of previous studies is that baseline differences in cognitive and motor performance existed between younger and older adults. If the two groups differ in single task performance, then it is difficult to interpret the costs observed under dual-task conditions. In the existing dual-task fine-motor literature, it is rare that studies are designed with age equivalence in single task performance prior to dual-task testing. Combining two tasks that demonstrate no differences at baseline makes for a better assessment of dual-task costs. Therefore, the goal of Study 1 was to examine learning of the fine-motor sequencing task to be used in dual-task experiments (Studies 2 and 3). We used a modified version of the serial reaction-time task because it has been shown that young and older adults can perform similarly with practice. Study 1 examined learning of the task over two days of practice to determine whether or not age equivalence could be achieved and to determine how much practice younger and older adults required to perform at a similar level. The results of this study showed that younger and older adults had equivalent tapping accuracy after one block of practice.

Once age equivalence was established on the motor task, Studies 2 and 3 combined this task with cognitive tasks at varying levels of difficulty that would place increasingly greater demands on executive control. The goal of these experiments was to assess the impact of varying cognitive load on dual-task performance. We chose cognitive tasks that had already demonstrated single-task age equivalence, and had already been used in previous dual-task walking research in our laboratory. These tasks were the semantic judgment task (Fraser et al., 2007) and mental arithmetic task (Abbud et al., 2009; Li et al., 2009). Since studies examining age differences in dual-task costs with fine motor tasks are limited, one of the first goals of Study 2 was to examine age differences in sequential tapping while performing a concurrent low-load semantic task. The goal of Study 3 was to extend the findings of Study 2, using a within-study manipulation of cognitive load, to assess the effect of different levels of load on sequential tapping. To this end, a mental arithmetic task with two levels of difficulty was paired with the sequential tapping task. With such a manipulation of cognitive difficulty, would sequential tapping reproduce dual-task results similar to simple tapping research (Crossley & Hiscock, 1992) in which older adults were affected to a greater degree than younger adults? Alternatively, would the overall load be greater in older adults due to the sequential tapping? The results of Kemper et al. (2003) seem to suggest that sequential tapping is more attentionally demanding than simple tapping and the simple fact that there are four fingers in motion and not just one would suggest that the motoric demands of sequential tapping would be greater. However, it is unknown if this increase in motoric demands would influence younger and older adults differently. Finally, since sequential tapping is paired with cognitive tasks used in previous walking experiments (Fraser et al., 2007; Abbud et al., 2009; and Li et al., 2009) an additional goal of Studies 2 and 3 was to compare the dual-task results of walking and sequential tapping to examine the possibility that similar mechanisms (i.e., declines in executive functions) underlie age differences in both gross motor and fine motor dual-task combinations.

Chapter 2

A Comparison of Motor Skill Learning and Retention in Younger and Older Adults

ABSTRACT

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

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 (Mage = 24 years) and 15 older adults (Mage = 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.

Introduction

Generally when compared to younger adults, older adults are not as fast or as accurate on fine motor tasks (Krampe, 2002; Spirduso, Francis, & MacRae, 2005). Despite these declines, research supports older adults' ability to learn fine motor skills (Seidler, 2006; Ketcham & Stelmach, 2001) and highlights factors such as practice, expertise, 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 & Walker, 2005; Walker, Brakefield, Morgan, Hobson & Strickgold, 2002; Walker & 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, Walton, Loveland, Umberger, Kryscio, & Gash, 2005; cf. Spencer, Gouw, & Ivry, 2007). While gross motor research (Dick, Andel, Hseih, 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 had the goal of examining the benefits of variable practice with a variant of the well-known motor learning task: the serial reaction time task (SRTT; Nissen & Bullemer, 1987).

Background

The serial reaction time (SRT) task (Nissen & Bullemer, 1987) is a tool frequently used to investigate motor sequence learning in younger and older adults (Cherry & Stadler, 1995; Cohen, Ivry, & Keele, 1990; Curran, 1997; Daselaar, Rombouts, Veltman, Raaijmakers, & Jonker, 2003; Frensch & Miner, 1994; Howard & Howard, 1989; 1992;

Howard & Wiggs, 1993; Willingham & 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 response time to the associated stimuli decrease 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 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 & 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, Howard & Howard, 2007; Howard & Howard, 1997; Howard, Howard, Dennis, & Yankovich, 2007).

Retention

In classic SRT studies (Howard & 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 & Walker, 2005; Walker et al., 2002; Walker & Strickgold, 2004; Walker, Strickgold, Alsop, Gaab, & Schlaug, 2005), 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) learn a complex fine motor task and found that all age groups had preserved motor memories and were able to retain the task even after two years. Dick et al. (2000) examined retention of a gross motor skill, bean bag tossing, and found that older adults' retention over two 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 & Magill, 1983, 1985; Schmidt, 1988; Shea & 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…; Stadler, 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 & 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, Van der Linden, & Perruchet, 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 & Stadler, 1995; Howard & 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, had 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 three 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 (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, Zarcone, Smythe, Phillips, & Dement, 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 > .10); most participants reported very good or average sleep quality and an average of 7.5 hours of sleep. All procedures met Concordia University ethical guidelines (sample consent form Appendix A). Both younger and older adults were paid a small honorarium for their participation.

Materials and Apparatus

Multi-Finger Sequence Task (MFST) 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 x 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 coloured 5 cm^2 frames, which remained in the center of the Dell 19-inch 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 1000 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 ten trials were a Repeated (REP) sequence and four trials were Random (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 1300 ms delay between trials. In total, participants completed 5 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 the 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 two 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, & 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 & 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 one 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 both groups 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 = .023, η_p^2 = .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 = .004, η_p^2 = .17. Pairwise comparisons confirmed that there was a significant difference in accuracy (p = .004) between Blocks 1 (M = 93%, SE = 1) and 2 (M = 96%, SE = .7) only. Further, there was a marginal effect of sequence type, F

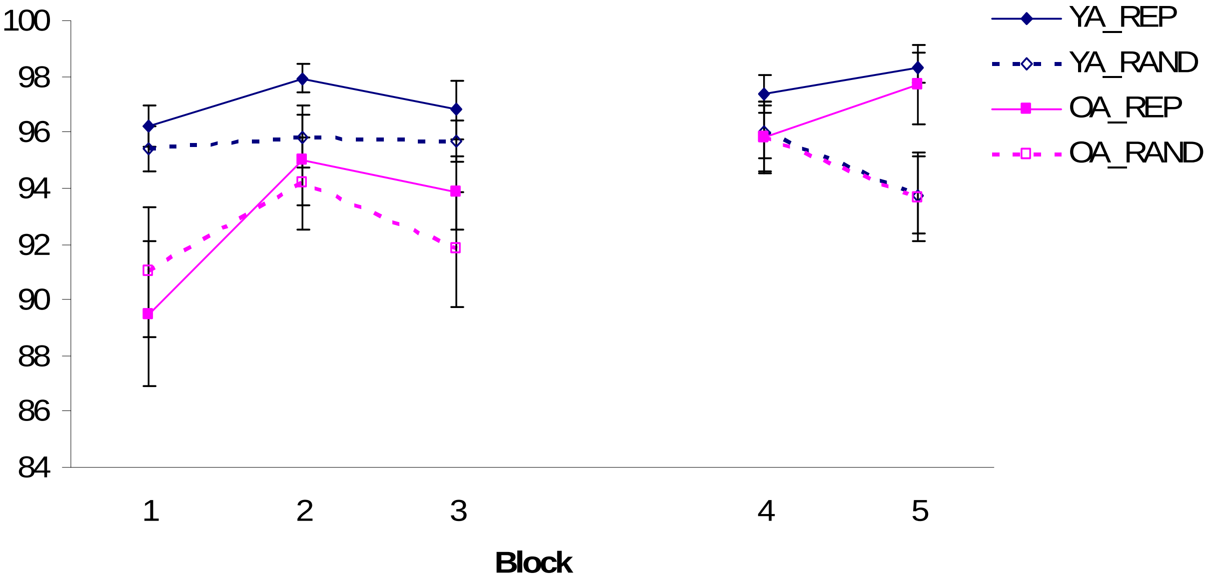

Fig. 1 Accuracy (percent correct) data for both age groups across all five blocks. YA = younger adult, OA = older adult, REP = repeating sequence, RAND = random sequence. Error bars are ±1 standard error of the mean.

(1, 31) = 3.76, p = .062, η_p^2 = .11, such that performance on the REP sequence (M = 95%, SE = .7) was slightly more accurate than on the RAND sequences (M = 94%, SE = .9). None of the interactions reached significance (ps >.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 = .029, η_p^2 = .15. Paired t-tests split by age group revealed that across all blocks, performance on the REP sequence 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 = .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 < .001, η_p^2 = .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 = .021, η_p^2 = .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 > .61). As expected, there was a main effect of group, F (1, 31) = 17.32, p < .001, η_p^2 = .36, where younger adults (M = 447 ms, SE = 12) were significantly faster to respond than older adults (M = 519 ms, SE = 13) overall.

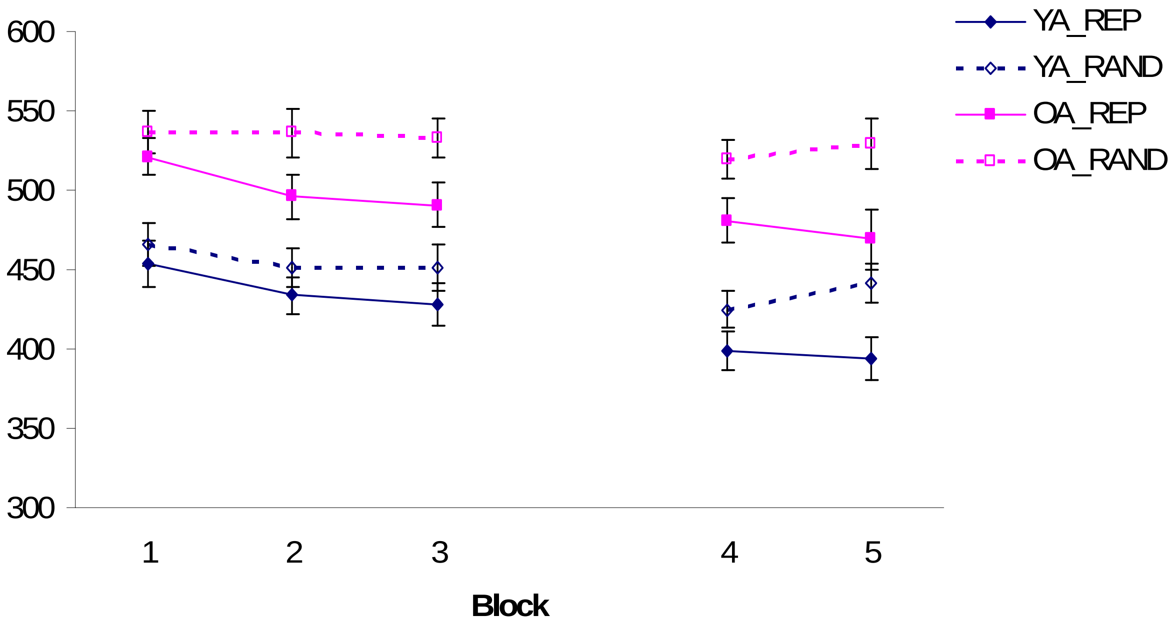

Fig. 2 Reaction time data for both age groups across all five blocks. YA = younger adult, OA = older adult, REP = repeating sequence, RAND = random sequence. Error bars are ±1 standard error of the mean

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, $p = .045$, $\eta_p^2 = .12$, such that older adults demonstrated significant ($p = .002$) gains in accuracy from Block 3 (*M* = 93%, *SE* = 1.2) to Block 4 (*M* = 96%, *SE* = .9) and younger adults did not show significant gains ($p = .61$; Block 3; *M* = 96%, *SE* = 1.1, and Block 4; *M* = 97%, *SE* = .8). Further, there was a significant main effect of block, *F* (1, 31) = 7.81, $p = .009$, $\eta_p^2 = .20$, in which performance on Block 4 was more accurate (*M* = 96%, *SE* = .6) than on Block 3 (*M* = 95%, *SE* = .8).

Reaction time. There was a main effect of block, *F* (1, 31) = 13.75, $p = .001$, $\eta_p^2 = .31$, 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, $p < .001$, $\eta = .64$, 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, $p < .001$, $\eta_p^2 = .42$, 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 (*p*s < .02).

Day 2 (Blocks 4 - 5)

Accuracy. On Day 2 there was a significant sequence type by block interaction, *F* (1, 31) = 8.39, $p = .007$, $\eta_p^2 = .21$, such that accuracy decreased significantly ($p < .001$) from Block 4 (*M*= 96%, *SE* = .8) to 5 (*M* = 94%, *SE* = 1.1) for the RAND sequences only. There were no significant differences ($p = .45$) for REP Block 4 (*M* = 97%, *SE* = .7) and 5 (*M* = 98%, *SE* = .7). In addition, there was also a main effect of sequence type, *F* (1, 31) = 10.78, $p = .003$, $\eta_p^2 = .26$, such that overall, responses to the REP sequence were more accurate (*M* = 97%, *SE* = .6) than to the RAND sequences (*M* = 95%, *SE* = .8).

Reaction time. There was a sequence type by block interaction, *F* (1, 31) = 12.87, $p = .001$, $\eta_p^2 = .29$, 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 ($p = .27$) 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, $p < .001$, $\eta_p^2 = .75$, 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, $p < .001$, $\eta_p^2 = .42$, 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, $X^2(2, N = 18) = 3.56$, $p <.059$. 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* = .25) and RT (*p* = .26). In addition, the interaction between recognition, age, and sequence type was non-significant for both accuracy (*p* = .09) and RT (*p* = .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 average. A *t*-test comparing younger and older adults on percentage of taps correctly identified was non-significant (*p* = .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 (Day 1 & 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 & Howard, 1992; Cherry & 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, Howard, Japiske, Yanni, Thompson 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 (e.g. Howard & 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 across age groups. 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 explain why deficits in within day learning have been observed in alternating SRTT (ASRTT) 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., **1**4**3**3**2**3**1**4**3**1**2**; 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 had a role in general motor skill improvements across days but it did not seem to facilitate sequence-specific learning. This finding parallels recent ASRTT research with younger adults by Song, Howard, and Howard (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. The finding is also consistent with Meulemans et al.’s (1998) study in which children showed improved performance after a one 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 SRTT, 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 ($p < .001$) 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 improvement in performance on the first block of practice on Day 2 for either the younger or older groups. This suggests that 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 ASRTT (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 does 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 & 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 to be due to “forgetting” and “reconstructing” processes. Each time there is alternation between the tasks one needs to forget one task 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 work on aging and task switching in which it has been shown that practice on task-switching (Kramer, Hahn, & Gopher, 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, suggest 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 replicates existing developmental research (Meulemans et al., 1998) and extends 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.

Chapter 3

The Impact of Concurrent Cognitive Load on Sequential Tapping in Healthy Aging

ABSTRACT

The impact of concurrent cognitive load on sequential tapping in healthy aging

The purpose of the current study was to assess the influence of cognitive load on sequential tapping performances in healthy aging. Younger and older adults performed a sequential tapping task separately and concurrently with a semantic judgment task (Experiment 1) and a mental arithmetic task (Experiment 2). Experiment 1 established that under low cognitive load older adults were slower and less accurate in sequential tapping than younger adults. Load was manipulated in Experiment 2, and across mental arithmetic difficulty levels, older adults were less accurate in sequential tapping and mental arithmetic than younger adults. At the highest difficulty level both groups suffered performance costs. Findings suggest that declines in executive function may underlie age differences in sequential tapping with cognitive load.

Introduction

Normal aging produces declines in both motor (Ketcham & Stelmach, 2001; Krampe, 2002) and cognitive functions (Kramer & Madden, 2008, Verhaeghen & Cerella, 2002). In addition, motor and cognitive functions appear to become more strongly coupled, or dedifferentiated, with aging (Baltes & Lindenberger, 1997; Li & Lindenberger, 2002). A common paradigm used to explore motor-cognitive coupling is the dual-task paradigm. This paradigm involves the assessment of motor and cognitive performance separately (single-task) and concurrently (dual-task), with condition differences in performance indicating dual-task cost. While this paradigm has been used extensively to investigate age differences in concurrent cognitive and gross motor (gait, posture) performance (for review: Woollacott & Shumway-Cook, 2002), fewer studies have explored age differences in concurrent cognitive and fine motor (finger tapping, reaching, and grasping) performance (Albinet, Tomporowski, & Beasman, 2006; Crossley & Hiscock, 1992; Kemper, Herman & Lian, 2003). Therefore, the primary goal of the present study was to assess age differences in dual-task performance for a fine motor task.

In both gross and fine motor dual-task research, several factors have been suggested to account for age differences in dual-task performance (Woollacott & Shumway-Cook, 2002; Krampe, 2002). Some of the factors that have been implicated include: a general slowing, declines in executive function, type of tasks combined, and physiological arousal. In the case of executive function, it is well documented that executive control processes may be invoked during motor tasks when adaptive on-line control is needed (Ble, Volpato, Zuliani, Guralnik, Bandinelli, et al., 2005; Krampe, 2002; Woollacott & Shumway-Cook, 2002; Yogev-Seligman, Hausdorff, & Giladi, 2008). Kahneman (1973) maintained that all individuals have a limited capacity to process information and that they should be able to process two tasks at once as long as the two tasks do not exceed the individual’s limited capacity or processing resources. If the tasks demands exceed an individual’s capacity, then performance on one or both tasks can deteriorate (Kahneman, 1973). Given what is known about declines in executive and motor processes, as well as the dedifferentiation of these processes, it is not surprising that age differences are predicted in cognitive-motor dual tasks.

Despite this prediction, a growing number of walking and postural control studies have found that results vary depending on the tasks combined and the cognitive load of the component tasks (i.e., Li, Lindenberger, Freund, & Baltes, 2001; Huxhold, Li, Schmiedek, & Lindenberger, 2006; Lövdén, Schäefer, Pohlmeyer, & Lindenberger, 2008). For example, in a study of mildly challenging dual-task treadmill walking, younger and older adults showed cognitive dual-task facilitation and motor dual-task costs which were more pronounced in older adults (Fraser, Li, DeMont & Penhune, 2007). In a more challenging follow-up experiment where cognitive load was manipulated, both age groups incurred costs in both domains and were negatively affected by the increase of cognitive difficulty. Interestingly, only younger adults were able to adjust their stride length to accommodate the increase in cognitive demands (Abbud, Li, & DeMont, 2009; Li, Abbud, DeMont, 2009). The changing pattern of dual-task costs across experiments suggests that the choice of tasks and the cognitive load of the tasks chosen can have a large impact on the resulting pattern of performance. An added dimension of walking dual-task research is the potential influence of postural threat (Brown, Shumway-Cook, & Woollacott, 1999). It has been argued that older adults might adopt a “posture-first” principle, prioritizing walking and balance above all other tasks in order to avoid a fall (Woollacott & Shumway-Cook, 2002).

The potential confound of postural threat influencing age differences in dual-task performances is removed in fine motor dual-task research. In line with the walking literature, there are declines in fine motor control with age (Haaland, Harrington, & Grice, 1993; Krampe, 2002; Smith, Umberger, Manning, Slevin, Wekstein et al., 1999). In addition, motor measures (particularly fine and complex motor measures) have been shown to be as accurate as standard cognitive measures in delineating cognitively normal vs. cognitively impaired older adults (mild cognitive impairment and mild Alzheimer’s disease; Kluger, Gianutsos, Golomb, Ferris, George, et al. 1997). This close relationship between cognitive tasks and fine motor tasks in aging has been explored with the dual-task paradigm (Crossley and Hiscock, 1992). Using a within-study manipulation of cognitive load, Crossley and Hiscock (1992) compared young, middle-aged and older adults on their performance of a simple tapping task with a concurrent cognitive load. At the highest level of cognitive difficulty there were no age differences in cognitive performance, but older adults had larger decrements in simple tapping rates in comparison to younger and middle aged adults. This simple tapping study demonstrates age differences in fine motor dual-task performance that increase with cognitive load. Would the same be true in the dual-task performance that involves a fine motor sequence? Or would the increased complexity of sequential tapping increase the overall cognitive load and increase age differences? One study that directly contrasted simple and sequential tapping with a cognitive load (speech production) found age group differences in dual-task costs only for sequential tapping (Kemper, Herman, and Lian, 2003). This finding suggests that sequential tapping places an added load on older adults in comparison to simple tapping.

The few published studies on aging and dual-task fine-motor performance suggest that increasing the complexity of the motor task is more detrimental to older adults than young. However, the literature does not indicate if a similar pattern will emerge when cognitive complexity is varied. The current study was designed to address this gap in the literature. Our approach was to first assess what age differences would emerge when a cognitive task with low load (semantic judgments) was paired with sequential tapping (Expt. 1). We subsequently repeated the experiment using a within-subjects manipulation of cognitive load (Expt. 2) to explore possible boundary conditions for our results. We began with the prediction that age differences in sequential tapping would emerge during dual-task performances but cognitive performance would not differ between the groups.

Experiment 1

Method

Participants

Twenty younger adults (20-31 years) and 21 older adults (60-75 years) participated in the experiment. Younger adults were recruited through Concordia’s participant pool and the older adults were recruited from a pre-existing participant database. Younger adults received class credits for their participation, and older adults received a small honorarium. All participants were right-handed, fluent in English, had normal or corrected vision, had never suffered a stroke, and were screened for medical conditions (i.e., Parkinson’s disease, severe arthritis) and medications that would affect their movement. Individuals who reported hearing difficulties or who wore a hearing aid were excluded. The Forward Digit Span and the Digit Symbol Substitution Test of Wechsler Adult Intelligence Scale III (WAIS; 1981), as well as the Trail Making Test (A & B; Spreen & Straus, 1998), were administered to assess short-term memory, processing speed, and task switching, respectively. All participants were within a normal range for their age on these tests. Descriptive statistics for each group are presented in Table 1. All procedures were approved by the Concordia University Human Research Ethics Committee (sample consent form Appendix B).

Materials

Fine Motor Task. The fine motor task was a modified version of the multi-finger sequence task (MFST) used in Fraser, Li and Penhune (2009). The MFST is a serial reaction time task, in which a visual stimulus presented in one of four squares on a computer screen and participants tap in response to the stimulus with the four fingers of their right hand on four keys of a piano-like keyboard. The visual stimuli were presented repetitively in fixed ten tap sequence (4-1-3-4-2-3-1-2-4-3) or in random ten tap sequences. For the purposes of the current dual-task experiment, only the repeating sequence type was used. For each tap in the repeating sequence, the inter-tap interval was set at 1000 milliseconds (ms), in which the stimulus stayed on the screen for 600 ms and disappeared for 400 ms. Therefore the duration of a motor trial was ten seconds. In the previous experiment (Fraser et al., 2009) age equivalence in the performance of the sequence was achieved after ten presentations of the sequence, therefore for the current experiment 14 trials were presented during practice to ensure age-equivalence prior to the

Table 1. Descriptive Statistics of the Samples.

	Experiment 1		Experiment 2	
	Younger	Older	Younger	Older
Age	23.10 (3.16)	67.67 (4.33)	21.10 (2.15)	70.37 (4.96)
Years of Education	15.95 (2.09)	14.81 (4.18)	14.95 (0.89)	15.11 (3.26)
Digit Symbol	88.60 (13.82)*	73.85 (18.23)*	69.90 (19.10)*	56.42 (14.19)*
Trails B-A	24.42 (12.68)*	59.81 (32.92)*	27.50 (15.81)*	46.47 (30.75)*
Digits Forward	7.35 (1.04)*	6.48 (1.08)*	7.15 (1.09)	6.68 (1.11)
ERVT	-	-	7.93 (4.46)*	13.03 (4.94)*
WAIS math-raw	-	-	13.30 (2.92)	13.95 (2.90)
WAIS math-scaled	-	-	10.35 (2.08)	10.63 (2.81)

Note: Mean values and standard deviations (in brackets) presented. * p <.05 for age group comparisons. ERVT = Extended range vocabulary test and WAIS math subtest were administered in Experiment 2.

test phase. Thirty trials were presented in each of the four test runs. For both the practice and test sessions, participants completed half of the motor trials in isolation (single task block) and half with the semantic task (dual-task block). An example of each trial type (single motor, single cognitive, dual task) is presented in Figure 1. The visual stimulus in the sequence consisted of a 4.5-cm^2-cartoon animal (i.e., “Rolly the Hamster”) that was programmed in C-Sharp and shown on a 19-inch Dell desktop monitor. Each stimulus was displayed in one of four horizontally presented coloured 5 cm^2 frames that stayed on the screen for the total duration of each trial. The participants responded to the stimuli on an M-Audio O2 Midi Controller piano keyboard. Participants were instructed to ‘catch the animal’ by placing the four fingers of their right hand (i.e., index, middle, ring, and pinkie) on four marked keys, and the keyboard recorded the accuracy and reaction time of each key press.

Cognitive task: Semantic Judgments. For this task, participants were auditorially presented with word stimuli at random time intervals and they were asked to judge if the word they heard was living (e.g., mother) or non-living (e.g., chair). Word stimuli used in the current experiment were the same as those presented in Fraser et al. (2007). The trial time structure mimicked the motor trials, such that each trial lasted 10 seconds (see Figure 1). Further, all participants had a practice session in which they judged 30 words and four test sessions that contained 60 words each. Half of the words were presented in isolation (single task block) and half were presented with the fine motor task (dual-task block). Each list included an equal number of living and non-living words to judge. The digitized words consisted of two-syllable high-frequency distinct nouns (written

Figure 1. Graphic of the trials: single motor, single cognitive and dual task. Dashed lines represent taps. Numbers under the dashed lines represent the key the participant had to tap. The fingers that corresponded to the keys were index = 1; middle = 2; ring = 3; and pinkie = 4. The solid line represents the time line of each trial (10 seconds). Arrows represent word stimuli presented (i.e., mother, tractor, hammer).

Note. Word stimuli were presented auditorally at random intervals during the trial and a trial could contain one, two, or three words.

frequency > 1 word per million: Kuçera & Francis, 1967) and were spoken in a female voice. To minimize the predictability of the presentation of the words; a trial could contain one, two or three words. The minimum inter-stimulus interval (ISI) for each word presentation was 1500 ms and the maximum was 7000 ms. An algorithm programmed with Matlab software (The MathWorks, Inc.) produced ISIs that would result an equal distribution of the words across each ten second trial (equal numbers of words presented at the beginning, middle, or end of the trial).The words presented in the practice lists were not re-used in the test lists. All test words were presented twice with a minimum separation of two lists. The word stimuli were randomly ordered within each list and presented with customized software, C-Sharp, through a Dell Inspiron 1300 laptop. Participants heard the words through a Plantronics (Santa Cruz, CA) DSP-300 headset that also recorded vocal reaction times. Speech recognition software (Microsoft Speech API) identified participants' responses ("Yes" for living words or "No" for non-living words) and they were subsequently scored as correct or incorrect with Matlab software.

Procedure

The testing took place in the Adult Development and Aging lab at Concordia University. After informed consent, all participants underwent a task familiarization session. For the motor task, 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. For the semantic task, participants performed the word repetition baseline where they had to repeat thirty words that were presented auditorally. To ensure adequate hearing for the test phase, participants needed to score 90% or more on the word repetition baseline. All participants met this criterion.

Participants then had practice in each of the conditions: single task (semantic), single task (motor) and dual task (semantic and motor). They completed seven trials per condition. Once they practiced the tasks, they completed four counterbalanced test runs of single motor, single semantic and dual task. For each test run there were 15 trials per condition. For both the practice and test sessions, participants completed half of the motor trials in isolation (single task block) and half with the semantic task (dual-task block). For both the practice and test runs participants were instructed that both tasks were equally important and that they should try to respond quickly and accurately. After the test session, participants completed the Digit Symbol, the Trail Making tests, the Digits Forward test, the questions on emphasis, and a demographics questionnaire. Participants were debriefed and received course credit (younger) or an honorarium (older) for their time. The entire session lasted approximately 90 minutes.

Statistical Analyses

Four dependent variables were calculated: accuracy and reaction time (RT) for the cognitive task and accuracy and RT for the motor task. The mean correct RT (ms) for each trial type was calculated for each participant. The time window for valid motor responses had a 1000 ms duration which started 100 ms prior to the presentation of each stimulus, to allow for anticipated responses. For the vocal RT data, responses were excluded if they were +/- three *SD* from an individual's overall mean RT. Only a small proportion of the responses were considered outliers ($M_{\text{Older}} = .02$, $SE = .001$; $M_{\text{Younger}} = .01$, $SE = .001$). For the cognitive accuracy, motor accuracy, and motor RT, the data were checked for outliers based on the group mean. No such outliers were found.

Dual-task costs were calculated for each of the four dependent variables. In the case of RT, dual-task RTs were subtracted from single-task RTs for each individual. For accuracy, single task accuracy was subtracted from dual-task accuracy on an individual basis. The resulting difference scores represent four dual-task cost (DTC) scores: DTC motor accuracy, DTC motor reaction time, DTC semantic accuracy, DTC semantic reaction time. For each variable, planned contrasts ($\alpha = .05$) were conducted to assess age differences in dual-task costs. All posthoc analyses used a Bonferroni corrected *p*-value ($p = .025$).

Results and Discussion

Mean values for single and dual-task performances are reported in Table 2 and the dual-task costs for each domain are presented in Figure 2.

Fine Motor: Multi-Finger Sequence Task

Accuracy. Figure 2A depicts the motor accuracy DTCs. The *t*-test revealed significant age differences in motor accuracy DTCs, $t(39) = -2.23$, $p = .032$, such that older adults had higher motor accuracy DTCs ($M = .05$ %, $SE = .02$) than younger adults ($M = .006$ %, $SE = .005$). Given the age differences in accuracy DTCs, *t*-tests comparing these DTCs to zero were conducted for each age group. There younger adults' accuracy DTCs were not significantly different from zero ($p = .27$). In contrast, older adults' accuracy DTCs were significantly different from zero, $t(20) = 2.724$, $p = .013$.

Reaction times. Figure 2C displays the motor reaction time DTCs. The *t*-test for motor reaction time DTCs resulted in a significant age difference, $t(39) = -2.57$, $p = .014$. Again, older adults had higher motor reaction time DTCs ($M = 62$ ms, $SE = 12$) than younger adults ($M = 23$ ms, $SE = 10$). After Bonferroni correction, younger motor

Table 2. Mean single and dual-task performance values for younger and older adults

	Experiment 1		Experiment 2			
Cognitive Task	Semantic Judgments		Minus-1		Minus-7	
	Younger	Older	Younger	Older	Younger	Older
Accuracy						
Single	89.25	92.90	99.50	99.74	75.08	82.37
Dual	91.00	93.14	98.33	99.04	67.58	69.47
Reaction times						
Single	662.42	762.63	567.09	600.64	1584.96	1462.89
Dual	690.52	786.61	665.46	641.20	1647.08	1439.82
Fine Motor Task	Sequential Tapping					
	Younger	Older	Younger	Older	Younger	Older
Accuracy						
Single	96.90	94.76	97.82	93.13	96.97	91.30
Dual	96.35	89.90	97.43	86.86	84.28	69.96
Reaction times						
Single	281.89	405.48	290.54	413.03	294.92	391.59
Dual	307.28	466.98	313.59	447.24	377.82	486.62

Note: Accuracy values = percent correct (%). Reaction time values in milliseconds.

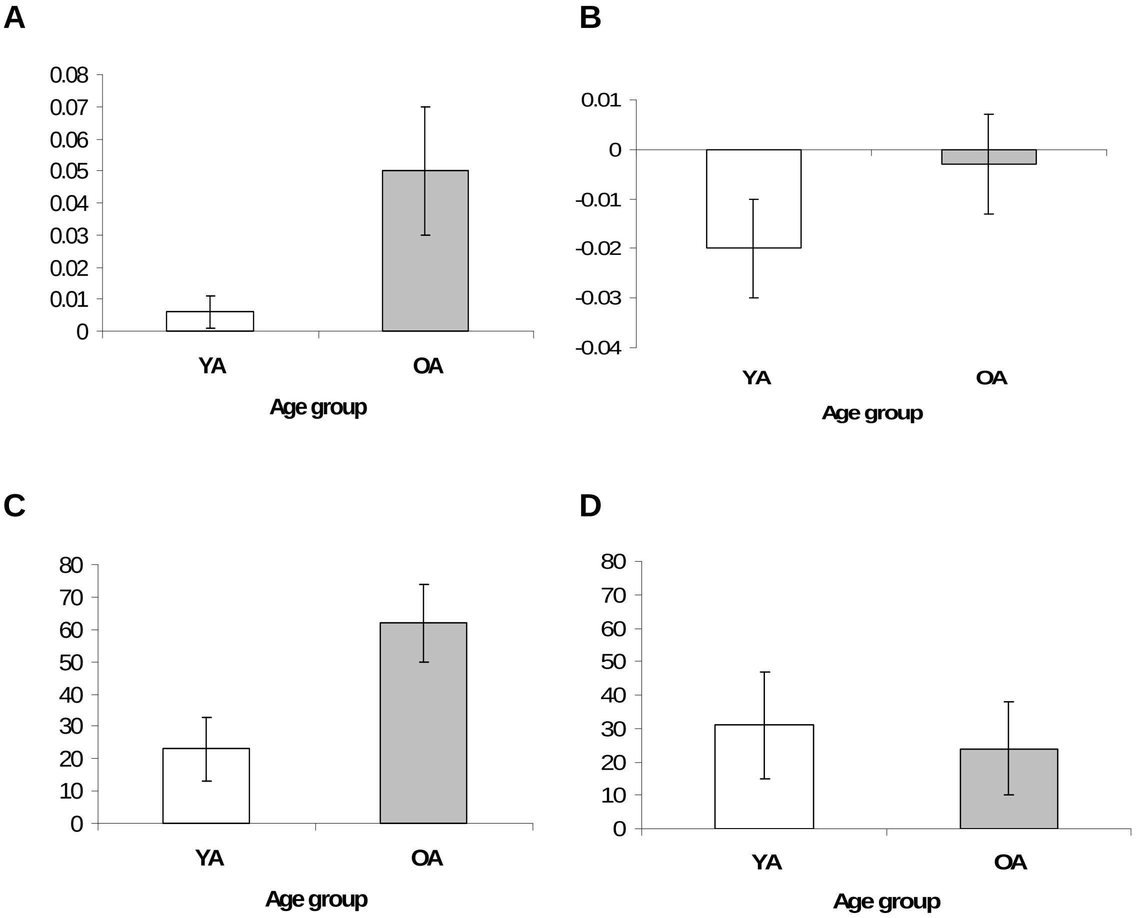

Figure 2. Experiment 1: **A:** Mean dual-task costs (DTCs) in motor accuracy (percent correct). **B:** Mean DTCs in cognitive accuracy. **C:** Mean DTCs in motor reaction time, in milliseconds (ms). **D:** Mean DTCs in cognitive reaction time (ms). Error bars are +/- 1 standard error of the mean.

Note: * = significant age difference in DTCs; + = DTCs are significantly greater than zero.

reaction time DTCs were not significantly different from zero (p = .034) and older adults' DTC values were significantly different from zero (p < .001).

Cognitive: Semantic Judgment Task

Accuracy. Figure 2B displays the cognitive accuracy DTCs. The t-test comparing younger and older adults on their cognitive accuracy DTCs was non-significant (p = .36). An additional analysis on the full sample revealed that the DTCs in accuracy were not significantly different from zero, t(40) = -1.240, p = .22. When split by age, neither younger nor older adults' accuracy DTCs were significantly different from zero (ps > .22). *Reaction times.* Figure 2D displays the cognitive accuracy DTCs. In line with the accuracy results, the t-test comparing younger and older adults' vocal reaction times DTCs was non-significant (p = .73). In this case, the t-test comparing vocal reaction time DTCs to zero was significant for the whole sample, t(40) = 2.647, p = .012. However, when split by age, neither younger (p = .07) nor older (p = .10) adults' vocal reaction time DTCs were significantly different from zero.

Testing for trade-offs: within and across domains

Within each domain (cognitive and motor) bivariate correlations between mean dual-task accuracy and reaction time scores were computed to test for speed-accuracy trade-offs. A positive correlation between speed and accuracy measures would be expected if participants were slowing to maintain accuracy levels or making more mistakes to maintain speed. Correlations between vocal accuracy and vocal reaction time (p = .98) and motor accuracy and motor reaction time (p = .23) were non-significant for younger adults. Older adults had significant negative correlations between motor reaction time and motor accuracy, r(19) = -.62, p = .003, and vocal reaction time and vocal accuracy, $r(19) = -.44$, $p = .05$. This negative relationship suggests that older adults who were fast were also highly accurate and those that were slow were less accurate. Across both age groups the lack of a significant positive correlation indicates that there was no speed/accuracy trade-off within domain.

To rule-out crossdomain trade-offs, bivariate correlations were conducted between motor accuracy and cognitive accuracy DTCs, as well as, motor reaction time and cognitive reaction time DTCs. A negative correlation between these DTCs would suggest that lower costs in one domain (i.e., cognitive) are associated with greater costs in the other domain (i.e., motor). For both accuracy and reaction time DTCs no significant trade-offs were found for either age group (*ps* > .65).

Summary

The results of Experiment 1 replicate the general findings of Crossley and Hiscock (1992) using a sequential tapping task. Beyond age differences in fine motor performances, Crossley and Hiscock (1992) demonstrated that these age differences increased when cognitive load increased. Would a manipulation of cognitive task difficulty cause similar age effects when combined with a sequential tapping task? This question was the basis of Experiment 2. In keeping with previous findings, we hypothesized that in Experiment 2, a high concurrent cognitive load would produce greater costs to sequential tapping a lower cognitive load (for both age groups), and that this difficulty manipulation would have a greater impact on the older adults' dual-task performances than the young.

Experiment 2

Method

Participants

Twenty younger adults (18-27 years) and 20 older adults (60-78 years) participated in the experiment. Recruitment and exclusion criteria were the same as in Experiment 1. In addition to the standardized tests administered in Experiment 1, all participants completed the Extended Range Vocabulary Test (ERVT; Educational Testing Service, 1976), and the Math subtest of the WAIS III, to assess vocabulary and math abilities, respectively. Descriptive statistics of the sample are presented in Table 1. All procedures were approved by the Concordia University Human Research Ethics Committee.

Materials

Fine Motor Task. The motor task was identical to that used in Experiment 1.

Cognitive task: Mental arithmetic. The cognitive task in this experiment had two levels of difficulty. For the Minus-1 level, participants subtracted one from randomly ordered two-digit numbers presented over headphones. For the Minus-7 level participants subtracted seven from each stimulus. Stimuli consisted of two-digit numbers ranging from 11 to 99, not including numbers ending with seven (e.g. 17, 27, 37...) or zero (e.g. 10, 20, 30...). Two lists composed of 30 stimuli were used during the practice session. Sixty new stimuli were randomly arranged into four lists to be used in the four conditions (single Minus-1, single Minus-7, dual Minus-1, dual Minus-7). The ISI range used in the current study (ISIs: minimum 2300 ms and maximum 5500 ms) was based on the average response times found in Abbud et al. (2009) for Minus-7. As compared with Experiment 1, the ISIs were lengthened here to accommodate the more complex cognitive tasks. In all other respects, the delivery of cognitive stimuli was the same as in Experiment 1.

Procedure

The testing took place in the Adult Development and Aging lab at Concordia University. After informed consent, all participants underwent the motor familiarization session described in Experiment 1. After the motor familiarization, all participants completed two practice blocks (15 trials each). In the first block, they completed a fixed order of Minus-1, single-task motor, dual Minus-1; in the second block they completed a fixed order of Minus-7, single-task motor, dual Minus-7. Participants were instructed that both tasks were equally important and that they should try to respond quickly and accurately. Prior to the test runs participants were asked to complete the Digit Symbol test.

Once they had practiced the component tasks they completed four counterbalanced test runs of the single motor, single cognitive and dual task. Runs 1 and 2 were always the Minus-1 difficulty level and runs 3 and 4 were always the Minus-7 difficulty level. Single cognitive was always presented first in runs 1 and 3 and single motor was always presented first in runs 2 and 4. The dual-task was always at the end of a run. Therefore, by counterbalancing runs 1-4, the difficulty manipulation was evenly distributed across the test session (i.e., with some participants having Minus-1, Minus-1, Minus-7, Minus-7; others Minus-7, Minus-1, Minus-1, Minus-7, etc.). For each of the four test sessions there were 30 fine motor trials, 15 performed alone (single task motor) and 15 performed concurrently with mental arithmetic (sequential tapping & Minus-sequential tapping & Minus-7). After the first two test runs, participants completed the Trail Making Test (A & B) and the Extended Range Vocabulary Test, followed by the two remaining test runs. Finally, the participants were asked the Emphasis question and they completed the Digits Forward and the arithmetic subtest of the WAIS. Participants were debriefed and received course credit (younger) or an honorarium (older) for their time. The entire session lasted 90-120 minutes.

Statistical Analyses

Dual-task costs were calculated for each dependent variable in each domain (motor and cognitive) and difficulty level (Minus-1 and Minus-7). For the vocal RT data, responses were excluded if they were +/- three *SD* from each individual's overall mean RT. Only a small proportion of the responses were considered outliers (M_{Older} = .008, *SE* = .001; M_{Younger} = .009, *SE* = .002). For cognitive accuracy, motor accuracy, and motor RT, the data were check for outliers +/- three *SD* from the group mean (younger and older) on single task performances. One older adult was removed based on this criterion. Consequently, analyses were conducted on 20 younger and 19 older adults. Mixed factorial ANOVAs ($\alpha = .05$) were carried out using the four dependent variables (DTCs) with difficulty level (Minus-1, Minus-7) as the within-subjects factor and age group (younger, older) as the between-subjects factor. All posthoc analyses used a Bonferroni corrected *p*-value (.025).

Results and Discussion

Mean values for single and dual-task performances are reported in Table 2 and dual-task costs for each domain are presented in Figure 3.

Fine Motor: Multi-Finger Sequence Task

Accuracy. Figure 3A depicts the motor accuracy DTCs for both difficulty levels. The analysis revealed a main effect of difficulty level, $F(1,37) = 44.33$, $p < .001$, $\eta^2 = .55$, such that the Minus-7 had higher costs (*M* = .17 %, *SE* = .02) than Minus-1 (*M* = .033 %,

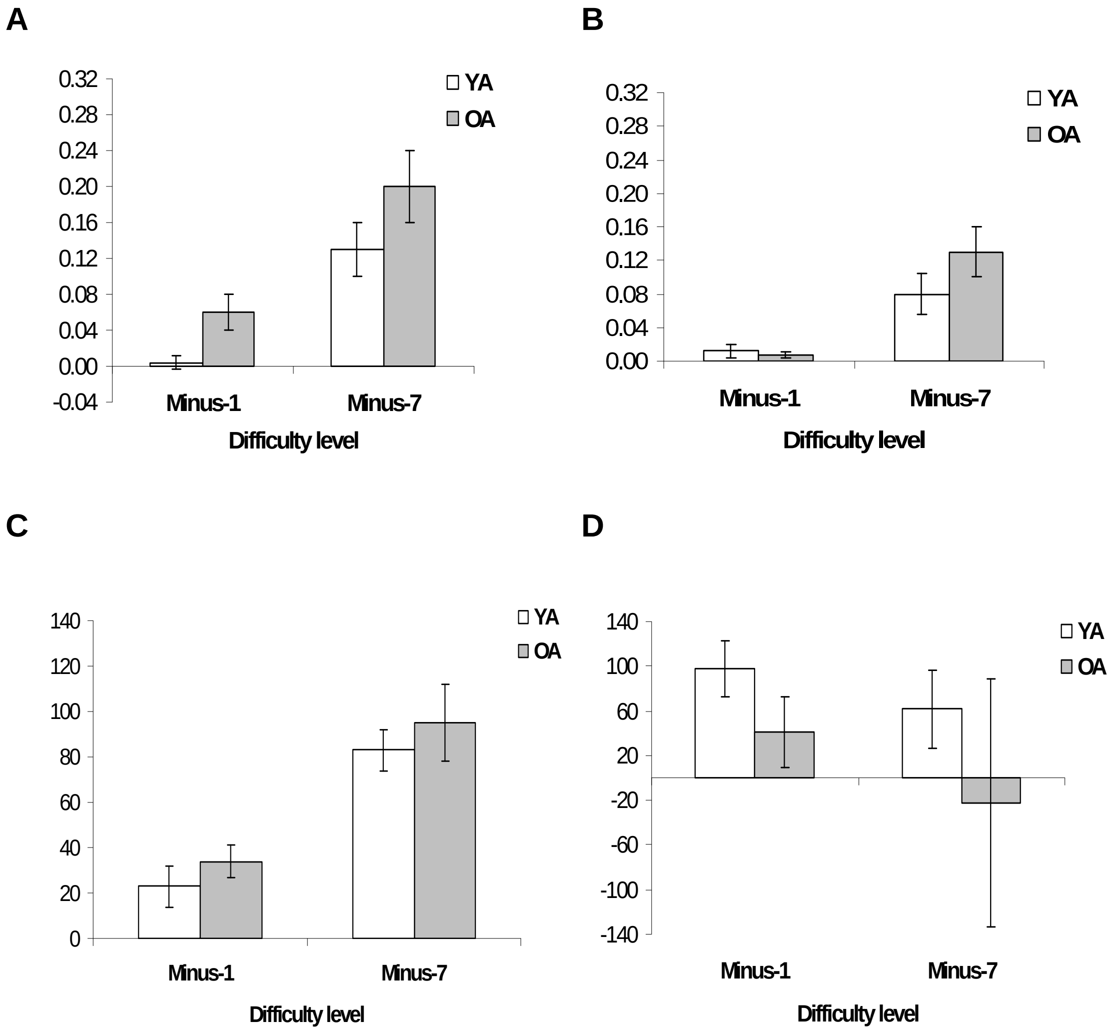

Figure 3. Experiment 2: **A:** Mean dual-task costs (DTCs) in motor accuracy by difficulty level (Minus-1 and Minus-7). **B**: Mean DTCs in cognitive accuracy by difficulty level. **C:** Dual-task costs (DTCs) in motor reaction times by difficulty level. **D:** Mean DTCs in cognitive reaction times by difficulty level. Error bars are +/- 1 standard error of the mean.

Note: * = significant age difference in DTCs; + = DTCs are significantly greater than zero.

SE = .01). In addition, there was a main effect of age group, $F(1,37) = 7.11$, $p = .01$, $\eta^2 = .16$, where older adults had higher DTCs in motor accuracy (*M* = .14 %, *SE* = .02) than younger adults (*M* = .07 %, *SE* = .02). The interaction was not significant ($p = .50$). Given the age differences in accuracy DTCs, t-tests comparing these DTCs to zero were conducted for each age group. The younger adults motor accuracy DTCs were not significantly different from zero ($p = .59$) for Minus-1 but were significantly different from zero for Minus-7, $t(19) = 4.934$, $p < .001$. For both difficulty levels, older adults' motor accuracy DTCs were significantly different from zero [Minus-1: $t(18) = 3.41$, $p = .003$; and Minus-7: $t(18) = 5.85$, $p < .001$].

Reaction times. Figure 3C displays the motor reaction time DTCs. The ANOVA for motor reaction time DTCs resulted in a significant main effect of difficulty, $F(1, 37) = 39.48$, $p < .001$, $\eta^2 = .52$, where Minus-7 resulted in higher DTCs (*M* = 89 ms, *SE* = 10) than Minus-1 (*M* = 29 ms, *SE* = 6). The main effect of age and the interaction were non-significant (*ps* > .35). Analyses of the reaction time DTCs for the full sample confirmed that the DTCs for both difficulty levels were significantly different from zero [Minus-1: $t(38) = 5.13$, $p < .001$; Minus-7: $t(38) = 9.38$, $p < .001$].

Cognitive: Mental Arithmetic

Accuracy. Figure 3B depicts the cognitive DTCs in accuracy for both difficulty levels. The mixed factorial ANOVA revealed a main effect of difficulty, $F(1, 37) = 23.33$, $p < .001$, $\eta^2 = .39$, on the accuracy DTCs, such that DTCs were higher on Minus-7 trials (*M* = .10 %, *SE* = .02) than on Minus-1 trials (*M* = .01 %, *SE* = .004). All other main effects and interactions were non-significant (*p*s > .14). Additional analyses on the full sample revealed that the DTCs in accuracy were significantly different from zero for both the Minus-1, $t(38) = 2.13$, $p = .04$, and Minus-7, $t (38) = 5.22$, $p < .001$, conditions. When split by age, younger adults' DTCs in Minus-1 were not significantly different from zero ($p = .16$) but they were significantly different from zero in Minus-7 ($p = .006$). Similarly, based on the Bonferroni corrected p-value, the older adults' DTCs were not significantly different from zero in the Minus-1 condition ($p = .04$) but were significantly different from zero in the Minus-7 condition ($p < .001$).

Reaction times. Figure 3D depicts the cognitive DTCs in accuracy for both difficulty levels. There were no significant effects in the cognitive reaction time data (ps $> .40$). Pooling together both age groups, the DTCs in the Minus-1 condition were significantly different from zero, $t(38) = 3.419$, $p = .002$, but the DTCs in the Minus-7 condition were not ($p = .72$). When split by age, only younger adults' DTCs were significantly different from zero in the Minus-1 condition ($p = .001$) and neither age group had DTCs that were different from zero in the Minus-7 condition (ps $> .09$).

Testing for trade-offs: within and across domains

At each level of difficulty, the mean dual-task scores within each domain were tested for a speed/accuracy trade-off. A positive correlation between speed and accuracy measures would indicate a trade-off. Younger adults had one significant negative correlation between dual-task motor reaction time and accuracy in the Minus-7 condition, $r(18) = -.69$, $p = .001$. Older adults had significant negative correlations in both difficulty levels for the motor task, Minus-1 condition, $r(17) = -.57$, $p = .01$, and Minus-7 condition, $r(17) = -.74$, $p < .001$. For both age groups, the cognitive dual-task correlations between accuracy and reaction time were non-significant for all conditions (ps $>.07$). Across both age groups the lack of a significant positive correlation indicates that there was no speed/accuracy trade-off within domain. Using DTCs, crossdomain trade-offs (i.e., responding quickly in motor task but slowing in cognitive) were tested with bivariate correlations between the cognitive and motor DTCs. Neither age group demonstrated any crossdomain trade-offs for any of the conditions (*ps* > .33).

Summary

Similar to the simple tapping findings of Crossley and Hiscock (1992) and the sequential tapping findings of Kemper et al. (2003), tapping sequentially while performing a cognitive task had a greater impact on older adults' motor performances than younger adults. The younger adults were able to maintain their motor accuracy in the Minus-1 condition whereas older adults demonstrated significant accuracy costs in both difficulty levels. Both groups slowed when sequentially tapping with a cognitive task but there was no age difference in the degree of slowing. In the cognitive measures, the pattern of results is similar for younger and older adults with the only exception being significant cognitive reaction time DTCs in the Minus-1 condition for the younger adults. The lack of speed/accuracy trade-offs and cross domain trade-offs suggest that younger adults were not slowing to maintain performance on another measure. In the Minus-7 condition, the lack of significant cognitive reaction time DTCs in combination with significant motor DTCs for both age groups in both measures might indicate a prioritization of cognitive task under the highest cognitive load.

General Discussion

The primary goal of this study was to assess how different levels of cognitive load affected age differences in sequential tapping. This study extends previous work on dual-task simple tapping (Crossley & Hiscock, 1992) and complex tapping (Kemper et al.

2003) with age differences found primarily in fine motor performances. The first experiment combined a low-load semantic judgment task with sequential tapping and older adults were slower and less accurate than younger adults on the sequential tapping task. In the second experiment, in which cognitive load was manipulated, there were age differences in motor accuracy, with older adults demonstrating costs in both difficulty levels whereas motor accuracy costs only emerged in the harder condition for younger adults. Since older adults demonstrate costs in sequential tapping even in the conditions of lowest load and these costs reliably emerge in motor accuracy performance, we propose that older adults require greater executive control processes in order to perform the sequential tapping task.

In both experiments there was an asymmetry in the pattern of results, such that dual-task costs occurred mainly in the motor domain. Across different levels of cognitive load, the cognitive tasks interfered with the sequential nature of the tapping task and older adults were more affected by this interference than younger adults. The interference from the cognitive task affected the older adults' fine motor performance even in the easiest condition and younger adults only faltered when task demands were too great. Although not as extensive as older adults, younger adults did incur some performance costs when performing the mental arithmetic task with sequential tapping. With the exception of the Minus-1 condition reaction time measure (cognitive and motor) all costs were in the harder Minus-7 condition. Perhaps mild cognitive loads taxed younger adults' coordinative processes (i.e., coordinating the performance of the two tasks). Whereas for older adults, all cognitive loads were sufficiently challenging that key press accuracy or response selection in the motor task was affected. Given that the sequence we presented was repeated throughout the each block of trials, younger and older adults may have encoded the sequence of key presses into a single action plan (Tubau, Hommel & Moliner, 2007). Findings with younger adults have demonstrated that execution of an action plan can be disrupted by visual and auditory verbal distracters. In addition, sequence learning and action plans have both been shown to involve the prefrontal cortex (Tubau et al., 2007). The prefrontal cortex and the executive control processes it subserves are known to decline with normative aging (Verhaeghen & Cerella, 2002). Therefore, in the current experiment because older adults rely more heavily on executive control functions for sequential tapping, they demonstrate greater performance costs than their younger counterparts. In support of this proposal, existing sequence learning research (Aizenstein, Butters, Clark, Figurski, Stenger et al., 2006) has found age differences in frontal activity during concurrent sequence learning, such that older adults show greater activity than younger adults in the left dorsolateral prefrontal cortex.

The results of the current experiment are also consistent with our previous findings in dual-task walking experiments which used the same cognitive tasks (Fraser et al., 2007; Li et al., 2009). In particular, Fraser et al. (2007) found age differences only in walking performance when performing the semantic task and Li et al. (2009) demonstrated maintenance of walking performance during the Minus-1 condition for younger adults but costs similar to older adults in the harder condition. Similarly, in Experiment 1, there was age equivalence in performance of the semantic task and age differences emerged in sequential tapping. Further, in Experiment 2, although younger adults slowed their sequential tapping in the Minus-1 condition they maintained their accuracy when older adults demonstrated accuracy costs and both groups had similar costs in the Minus-7 condition. These similarities suggest that gait and sequential tapping may draw on similar executive control functions. The age-related dual-task effects reported by Crossley and Hiscock (1992) may have been a reflection of age-related reductions in general dual-task coordination processes rather than an indication that simple tapping requires executive control. Indeed, previous research suggests that simple tapping does not rely on executive functions (Hausdorff, Yogev, Springer, Simon, & Giladi, 2005). The similarity of the current pattern of results with that of previous walking research (Fraser et al., 2007) also suggests that the walking findings were not primarily driven by postural threat.

Conclusions

Taken together, the findings extend the research on aging and dual-task fine motor performance in demonstrating that concurrent sequential tapping costs are greater in older adults due to the disruption of a planned execution of taps at the executive processing level. Under low cognitive load younger adults have a more proceduralized or automatic approach to the sequential tapping task that does not require executive control. In contrast, older adults demonstrate costs at every load level demonstrating cognitive penetration of motor task performance (Teasdale, Bard, LaRue & Fleury, 1993).

Chapter 4

General Discussion

General Discussion

The purpose of the current set of studies was to examine age differences in sequential tapping with concurrent cognitive tasks that vary in cognitive load. The goal of Study 1 was to test if the multi-finger sequence task could be performed equally well by younger and older adults. Results of this study confirmed that after one block of practice younger and older adults were equally accurate at tapping sequentially. Once age equivalence was established with the sequential tapping task, it was paired with a semantic task in Study 2 to evaluate age differences in sequential tapping with a low-load cognitive task. Despite age equivalence in single task accuracy on both cognitive and motor tasks, older adults had greater dual-task costs than younger adults on the motor task as measured by both accuracy and reaction time. Neither age group had significant performance costs on the cognitive task. Given the unidirectional nature of the age-related findings, a within-study manipulation of cognitive load (Study 3) was conducted to further assess boundary conditions for these age differences in dual-task performance. Similar to Study 2, age differences emerged in the motor domain. Older adults demonstrated significant costs in motor accuracy for both high and low levels of load and overall had greater dual-task costs than younger adults. Younger adults only incurred significant motor accuracy costs in the high load condition. Both groups had significant costs in their motor reaction time and in the high load condition and both age groups incurred significant cognitive accuracy costs. Across the dual-task studies, older adults incurred motor costs even at the lowest levels of load. This pattern of dual-task results across various cognitive tasks and different levels of load, leads to the proposal that older adults require greater executive control during sequential tapping than younger adults.

Age equivalence in single task sequential tapping

A first critical step for this thesis was to demonstrate age equivalence in a sequential tapping task. In line with existing findings (Daselaar et al., 2003; Howard & Howard, 1989, 1992) age equivalence with this particular sequential tapping task was achieved after one block of practice. In this study, the sequence of finger taps that participants learned was presented in a variable practice regime, where the learned sequence was interleaved with random sequences in each block. While variable practice had been applied to task switching paradigms (Kramer et al., 1999) and to gross motor learning research (Dick et al., 2000) it had not yet been exploited in the aging and sequential tapping literature. This novel design approach to sequence learning resulted in within-day learning that was comparable to studies that had participants practice in a blocked manner (Daselaar et al., 2003; Howard & Howard, 1989, 1992). The retention results differed such that older adults showed equivalent retention across days, whereas blocked practice findings (Spencer et al., 2007) reveal age differences in the retention of a learned tap sequence. Indeed, the variable practice regime implemented in the current study seems to have benefited the retention and maintenance of sequence learning across days. The results of this first study suggest that variable practice might particularly aid older adults in the retention of a fine motor sequence but a more direct test of different designs (variable versus blocked) is warranted.

Ultimately, the outcomes of this study allowed for the tailoring of the subsequent dual-task cognitive and fine motor pairings. First, since older adults' required one block of practice (10 trials) to achieve age equivalence in this task, Studies 2 and 3 were designed to give older adults the required amount of practice to reach age equivalent tapping accuracies prior to the test phase of the experiment. Additionally, since age equivalence had already been established with semantic judgments (Fraser et al., 2007) and mental arithmetic (Li et al., 2009), it was possible to examine age differences in dual-task performance with cognitive and fine motor pairings that had established single task age equivalence.

Dual- task sequential performance: Motor not cognitive costs

Once age equivalence in sequential tapping was established, it was possible to proceed with the first pairing of cognitive and fine motor tasks. In Study 2, we paired semantic judgments (living vs. non-living) with sequential tapping. In the case of both younger and older adults, dual-task costs emerged in sequential tapping performance; however the costs were greater in older adults. With learning on the sequential tapping task, it is likely that both younger and older adults develop an internally generated, ordered representation of the tap sequence, or an action plan. It has been proposed that executive control processes are needed to manage and control a single action plan (Tubau et al., 2007). Therefore when sequential tapping was paired with an additional cognitive task, it is likely that performance costs emerged due to processing capacity constraints on executive control mechanisms. That the sequential tapping costs were greater in older adults in comparison to younger adults suggests that these executive control processes are not as efficient in old age. Indeed, in their review of the literature on fine motor control and aging, Krampe suggests that sequencing and executive control components of fine motor control decline with age while low level timing mechanisms which require less overall processing capacity remain relatively intact (2002).

Many factors may influence the magnitude of dual-task costs in combined cognitive and motor tasks (Li & Lindenberger, 2002; Woollacott & Shumway-Cook, 2002). Cost may increase or decrease based on the individual task demands. While Study 2 established that cognitive and motor tasks with age equivalent single-task performance can result in age differences in dual-task sequential tapping, it remained unknown how different levels of cognitive load might impact these age differences in sequential tapping performance. To address this question, a within-study manipulation of cognitive load was designed. Study 3 paired two difficulty levels of mental arithmetic, Minus-1 (low load) and Minus-7 (high load), with the same sequential tapping task used in Studies 1 and 2. Age equivalence in single-task performance for the mental arithmetic task had already been demonstrated for both levels of load (Li et al., 2009). Despite selecting a task that showed single-task age equivalence, when sequential tapping was paired with the low-load mental arithmetic older adults demonstrated significant motor accuracy costs whereas younger adults only demonstrated significant motor accuracy costs when sequential tapping was paired with the high load mental arithmetic task. Both groups slowed significantly when tapping with a concurrent cognitive task but there were no age differences in the degree of slowing. Additionally, in the high-load condition both groups demonstrated cognitive accuracy costs, but there was no difference in the degree of cost. Once again, age differences emerged in motor task performance when attention was divided.

That older adults demonstrate motor accuracy costs even in the low-load condition may reflect a processing capacity limitation in aging that is occurring at the level of executive processes. Age-related declines in executive functions are well documented (Verhaeghen & Cerella, 2002) and there is evidence for dedifferentiation of cognitive and sensorimotor functions with aging (e.g., Baltes & Lindenberger, 1997). If older adults rely more heavily on executive processes to compensate for sensorimotor declines, then ultimately the resource pool available to manage a dual-task situation is more limited in an older population. In support of this proposition, recent neuroimaging research has demonstrated that in comparison to younger adults, older adults show increased activation and recruitment of additional brain areas (including the dorsolateral prefrontal cortex) when executing complex movements (Heuninckx, Wenderoth, & Swinnen, 2008). In addition, serial reaction time research exploring differences in patterns of activation when performing an explicit and implicit sequence simultaneously also found age differences in the patterns of activation in the prefrontal cortex (Aizenstein et al., 2006).

In comparison to the older adults' motor accuracy costs, younger adults did not demonstrate significant motor accuracy costs in the low-load condition. However, younger adults did show significant dual-task costs for cognitive reaction times for the low-load condition and older adults did not. Given the lack of evidence for performance trade-offs, one possible explanation for these significant cognitive costs in younger adults is that they had excess capacity to devote to the tasks at hand because of the low cognitive load. With their extra capacity they may have tested different strategies to maximize their mental arithmetic performance. Mental arithmetic research has demonstrated that younger adults tend to use more strategies than older adults when solving mathematical problems (Duverne & Lemaire, 2005).

The three studies contained in this thesis demonstrate that older adults need more time to learn a sequential tapping task (Study 1) and that they have more difficulty performing this task when their attention is divided (Studies 2 & 3). Even though Study 1 did not involve a divided attention situation and the participants were able to focus solely on the tapping task, older adults needed an additional block to reach the same levels of accuracy as their younger counterparts. Then in Studies 2 and 3, even after older adults were given ample practice to reach similar single task accuracy levels as the younger sample, they still demonstrated greater motor dual-task costs than younger adults. The current results converge with previous dual-task studies of simple tapping (Crossley & Hiscock, 1992), and extend the aging literature to sequential tapping coupled with a variety of concurrent cognitive tasks. Crossley and Hiscock (1992) proposed that a reduction in "general processing" resources with age was at the root of the age differences in fine motor control. Advances in research on the role of executive control in fine motor performance (Krampe, 2002) and the findings of this thesis suggest that executive function is at the root of age differences in fine motor control. Perhaps, the reduction in "general processing" resources that Crossley and Hiscock (1992) were alluding to could be encompassed by some or all of the processes described as executive functions. This could be considered a "general" decline in resources in that it encompasses several executive processes and is not limited to a specific process.

An alternate explanation for the current set of results relates to the demand characteristics of the component tasks. In particular, the finger tapping task required a fixed time window between stimuli in which to respond. In comparison, there were fewer cognitive stimuli in each trial and the response window for the cognitive task was slightly longer than for the motor task. This being said, a close examination of the mean single task performance levels (Table 2) demonstrates that for sequential tapping both age groups were above 91% accurate despite the temporal constraints. In addition, the time limit for each tap was 1000 ms and the longest mean response time across the single task conditions for both younger (294 ms) and older adults (413 ms) indicates that they had ample time to complete a tap prior to the next stimuli onset. Taken together, the data do not support the demand characteristics of the motor task as an explanation for the current data set.

Another possible interpretation for greater motor costs in older adults relative to younger adults is attentional allocation or task prioritization. It is possible that older adults prioritized their cognitive performance at a cost to their motor performance, whereas younger adults prioritized both tasks equally as instructed. This interpretation lacks support as the data reveals both younger and older adults maintained performance on the cognitive task while demonstrating costs on the motor task in the low-load conditions. Further, in the Crossley and Hiscock (1992) reported that both younger and older adults were able to allocate their attention as directed by the experimenter and that the age differences in fine motor performance were not influenced by differences in attentional allocation.

An additional goal of the thesis was to evaluate the correspondence between dual-task walking (Fraser et al., 2007; Li et al., 2009) and sequential tapping results from our laboratory, given that the same cognitive tasks had been used in both types of motor dual-task research. Despite an obvious absence of postural threat in the dual-task fine motor studies, older adults still showed greater dual-task costs for the motor vs. the cognitive task. This suggests that both walking and sequential tapping require greater executive control processes in an older population, even at low levels of load. Our research is complementary to the existing walking dual-task research (Woollacott & Shumway-Cook, 2002; Li & Lindenberger, 2002) and extends the proposition of executive control in gait to fine motor control. While there may be similarities in the underlying processes guiding motor control, it is impossible to know from the current data if sequential tapping is more or less attentionally demanding than walking. A study that includes walking and sequential tapping similar to Kemper et al. (2003) would be necessary to fully understand the degree of involvement of attention and executive control processes in motor tasks that require different motor skills.

Future Directions

While there are many routes this research may continue to take, there are a few that would help support the conclusions of this body of work. In particular, a more comprehensive neuropsychological battery including several measures of executive function would be useful in the evaluation of relationships between executive function measures and cognitive-motor dual-costs. Positive relationships between performance decrements on executive function tests and large dual-task costs in aging would provide additional support for the role of executive function in fine motor control. Similarly, neuroimaging data utilizing the same design and tasks might provide converging evidence for the role of executive functions in motor control if older adults demonstrate different patterns of activity than the young in the prefrontal cortex during single- and dual-task sequential tapping. In line with Heuninckx et al.’s findings, older adults might recruit the prefrontal cortex to a greater degree than younger adults during single-task sequential tapping (2008). Further, similar to Aizenstein et al. (2006), bilateral activation or additional prefrontal recruitment might be expected in the older adults and not in the young when sequential tapping is paired with a cognitive task.

Another way to examine the role of executive functions in fine motor control would be to train executive control processes and to assess the impact of training on fine motor control. Cognitive plasticity has been successfully shown in healthy older adults across a range of executive control processes (Ball, Berch, Helmers, Jobe, Leveck, et al., 2002; Bherer & Belleville, 2004; Erickson, Colcombe, Wadwa, Bherer, Peterson, et al. 2007, Karbach & Kray, 2009; Willis & Schaie, 2009) and work is underway to assess whether training of executive functions can positively influence gait parameters. Research that parallels this work and assesses the impact of cognitive training on fine motor control would also be beneficial. In both cases, if improving an older adult's ability to perform executive tasks (e.g., dual task) can improve their motor control, this would provide further evidence for the importance of executive functions in motor control. In addition, positive cognitive training outcomes would have important implications for the maintenance of independence in an older population and successful aging in general.

In conclusion, the results of the current dissertation highlight the complex nature of the interactions between cognitive and fine motor control in aging. With little additional practice, older adults could tap sequentially as well as younger adults. However, when sequential tapping was paired with a series of cognitive tasks of differing load older adults demonstrated performance decrements even in low-load situations. Given that single- and dual-task outcomes demonstrated age differences in sequential tapping, executive functions are proposed to be involved in this fine motor skill. These results are consistent with the literature on the involvement of executive control processes in gross motor control, and suggest that motor performance, even for well learned tasks is not free from cognitive demands.

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Appendix A

Sample Consent Form Study 1

CONSENT FORM TO PARTICIPATE IN RESEARCH (ADULT FORM)

Title of project:	Developmental contributions to motor skill learning
Researchers:	Virginia Penhune, Ph.D. (principle investigator) Sarah Fraser, Ph.D. Candidate (graduate student) Odelia Borten (research assistant)

This is to state that I agree to participate in a program of research being conducted in the Laboratory for Motor Learning and Neural Plasticity in the Department of Psychology at Concordia University.

A. PURPOSE

I have been informed that the purpose of this study is to advance our knowledge of how precise motor skills, similar to playing the piano, are learned and retained across the life-span.

B. PROCEDURES

This experiment includes two consecutive lab visits (24 hours apart). Each visit will last approximately one hour. In the first visit, I will play a computer learning game using an electronic keyboard. In this learning game, I will be instructed to “catch the animal” (appearing in one of four squares presented next to one another in a row on a computer) as quickly and accurately as possible, by pressing one of four keys on an electronic keyboard using four fingers of the right hand. I will be asked to asked to play this computer learning game for approximately 25 minutes (breaks will be provided to prevent fatigue and boredom). I will also be asked to give definition of words and remember series of numbers. In the second visit, I will be asked to play the same computer learning game as on the first visit for 25 minutes. I will also be asked to complete another computer activity. On this activity, letters will be presented on a computer screen and I will have to press as quickly as I can the space bar after each letter presentation, except the letter X. At the end of the second visit, I will be compensated $20 for my participation.

Advantages and disadvantages: Participation in this study has no personal benefits. There are no physical risks associated with participation in this experiment. Breaks will be provided to prevent fatigue and boredom. The only disadvantage of participation is the time you will spend doing the test and travelling to and from the laboratory. The investigator may end the study at any time for purely scientific reasons. In this case, compensation will be made for the part of the study completed.

C. CONDITIONS OF PARTICIPATION

I understand that my participation in this study is entirely voluntary and that I am free to withdraw my consent and discontinue participation at anytime without negative consequences. I further understand that all records and test results of this study will be kept strictly confidential. No one but the experimenters will have access to any information about me or my performance. In addition, my name will not be used in any report or publication.

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND VOLUNTARILY AGREE TO PARTICIPATE IN THIS STUDY.

Name (please print): ___________________________

Signature: ___________________________ Date: ______________________

Witness’ Signature: _______________________ Date: ______________________

For further information about this study either before or after it is completed, please feel free to contact Dr. Virginia Penhune at 514-848-2424 x. 7535 or by email vpenhune@vax2.concordia.ca, or Sarah Fraser at 514-848-2424 x. 2247 or by email safraser@vax2.concordia.ca.

If at any time you have questions about your rights as a research participant, please contact Adela Reid, Research Ethics and Compliance Officer, Concordia University, at 514-848-2424 x. 7481 or by email Adela.Reid@concordia.ca.

Appendix B

Sample Consent Form: Studies 2 and 3

CONSENT FORM TO PARTICIPATE IN RESEARCH (Study 2)

Title of project: Evaluating age differences in the concurrent performance of a fine motor task and semantic word judgments.

Researchers: Sarah Fraser, Ph.D. Candidate (graduate student)
Madeleine Ward (specialization student)

This is to state that I agree to participate in a program of research being conducted in the Adult Development and Aging Lab in the Department of Psychology at Concordia University.

A. PURPOSE

I have been informed that the purpose of this study is to advance our knowledge of how younger and older adults divide their attention.

B. PROCEDURES

In this experiment, I will be asked to perform two things: play a computer game using an electronic keyboard AND judge words I hear through a headset as living or non-living. For the computer game, I will be instructed to "catch the animal" (appearing in one of four squares presented next to one another in a row on a computer) as quickly and accurately as possible, by pressing one of four keys on an electronic keyboard using four fingers of the right hand. When I hear the words (one at a time) I will be asked to say, as quickly as possible, "Yes" if the item is living and "No" if it is non-living. I will perform these two things separately and at the same time. The entire experiment will last approximately 1 1/2 hours and I will be compensated $10.00 per hour for my participation.

Advantages and disadvantages: There are no physical risks associated with participation in this experiment. Breaks will be provided to prevent fatigue and boredom. The investigator may end the study at any time for purely scientific reasons. In this case, compensation will be made for the part of the study completed.

C. CONDITIONS OF PARTICIPATION

I understand that my participation in this study is entirely voluntary and that I am free to withdraw my consent and discontinue participation at anytime without negative consequences. I further understand that all records and test results of this study will be kept strictly confidential. No one but the experimenters will have access to any information about me or my performance. In addition, my name will not be used in any report or publication.

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND VOLUNTARILY AGREE TO PARTICIPATE IN THIS STUDY.

Name (please print): ____

Signature: ______________________________ Date: ______________________

For further information about this study either before or after it is completed, please feel free to contact Sarah Fraser at 514-848-2424 x. 2247 or by email sfraser@alcor.concordia.ca.

If at any time you have questions about your rights as a research participant, please contact Adela Reid, Research Ethics and Compliance Officer, Concordia University, at 514-848-2424 x. 7481 or by email Adela.Reid@concordia.ca.

Note: For Study 3, the form was altered from “judging words” to “performing mental arithmetic” and participants were also told “When I hear the two digit numbers (one at a time) I will be asked to subtract a one or a seven”. The remaining details of the consent form were similar to those of Study 2.