Simulation of Cognitive Aging and Effects of Cognitive Load on Finger Sequencing Performance

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Abstract

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The purpose of the current study was to examine the effect of cognitive load on fine motor reprogramming using a motor-cognitive paradigm. We propose that in the face of conflict, both executive control and motor control mechanisms are involved in the process of reprogramming well-learned motor behaviours, and these two mechanisms become more interconnected with increasing age. To explore this relationship, we used a dual-task paradigm to simulate the effects of cognitive aging in young adults. To assess motor reprogramming, nineteen young adults overlearned a sequence of key presses in a practice phase of the experiment. Occasional deviations of the practiced sequence were introduced in a test phase. To manipulate cognitive load, participants performed the motor task separately and concurrently with a Serial 7s subtraction test. A 3-D motion capture system was used to parse finger movements into planning and motor execution phases. It was hypothesized that under higher divided attention demands, participants' motor responses would be slowed down, and they would lose their ability to speed up their motor execution times. When key press responses were parsed into kinematic responses, the results showed that under both attention conditions, when presented with a deviation from a learned sequence, participants spent more time planning their movements. Participants were able to speed up their execution time on the violation transitions under single-task conditions; however, they lost this ability under dual-task conditions. In line with gross motor research, these findings suggest that cognitive capacity, reduced in the case of

older adults or young adults under divided attention conditions, influences the ability to flexibly adapt movements.

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Table of Contents

List of Tables

List of Figures

List of Appendices

Simulation of Cognitive Aging and Effects of Cognitive Load on Finger Sequencing Performance

Introduction

Coordination and integration of both cognitive and motor abilities is required for successful performance of many daily activities. In addition, coordination of simultaneous task performance is very common in human activities. For instance, individuals can prepare meal while talking on the phone, or they can ride a bicycle while listening to music. Previous research suggests that executive control processes such as response selection, initiation, execution, and termination are involved in the coordination of multi-tasking performance (e.g., Baddeley, 2002; Logan, 1985; Rubinstein, Meyer, & Evans, 2001). It has been shown that healthy aging is associated with declines in both executive control mechanisms (Verhaeghen & Cerella, 2002) and motor control processes (Krampe, 2002). As a result of this decline, older adults may experience difficulties coordinating motor and cognitive activities. Executive control mechanisms are also involved in reprogramming behaviours in the face of conflict. Recently, it has been shown that older adults have more difficulty suppressing well-learned motor behaviours than young adults (Trewartha, Endo, Li, & Penhune, 2009). Although extensive bodies of literature indicate that the linkage between sensory and cognitive domains increases with advanced age (e.g., Baltes & Lindenberger, 1997; Clay, Edwards, Ross, Okonkwo, Wadley, Roth, et al., 2009), the relative contribution of cognitive processes to fine motor performance in old age has not been fairly investigated. We propose that both executive control and motor control mechanisms are involved in the process of reprogramming well-learned fine motor behaviours when conflicts occur, and a link between these two mechanisms becomes more prominent with advanced age. To address this question, we used a dual-task paradigm to simulate the effects of cognitive aging in young adults. Concurrent fine motor and cognitive tasks were presented to reduce attentional capacity of the participants. If young adults show difficulty reprogramming well-learned behaviours in cognitively demanding dual-task situations, this would support the view that the interdependence between cognitive and motor abilities increases with task complexity due to decreased attentional resources available for each task.

Sensory and cognitive changes in old age. A number of studies have shown growing interdependence between sensory and cognitive domains in old age (e.g., Baltes & Lindenberger, 1997; Salthouse, Hancock, Meinz, & Hambrick, 1996). For example, Baltes and Lindenberger showed an increase in covariation between sensory (visual and auditory) acuity and intelligence in old age. The researchers reported that visual and auditory acuity accounted for 91.3% of the age-related variance in intelligence. At the same time, visual and auditory acuity were good predictors of intellectual functioning across the entire age range (25-103 years of age). Thus, the findings demonstrate that even though the link between sensory and intellectual functioning is amplified in old age, the mechanisms underlying the interdependence between these two domains are similar across the entire adult age range.

More recently, lifespan researchers have investigated a link between sensory and cognitive domains using a simulated sensory loss paradigm (e.g., Dickinson & Rabbitt, 1991; Murphy, Craik, Li, & Schneider, 2000). Murphy and colleagues (2000) compared young and older adults on their ability to remember auditorily presented word pairs.

Memory for the second word of each pair was tested under quiet versus noisy conditions. Under quiet conditions, both age groups demonstrated comparable results when asked to recall the most recently presented word pairs, presumably the information that was still in short-term memory. Recall of earlier word pairs was significantly impaired in older adults group. More importantly, under noisy conditions, the young adults exhibited memory scores similar to those shown by older adults performing under the quiet listening conditions. The noise exacerbated the memory performance of the older adults, again particularly for the early-presented word pairs, indicating a selective deficit in effortfully encoding information into long-term memory. The authors propose that the difficulties experienced by older adults were due to the interdependence between sensory and cognitive domains that increases with old age. That is, the sensory deficits experienced by older adults cause a greater reliance on top-down cognitive processes, which consequently detract from the effortful processing needed to encode information in long-term memory. The simulation of sensory aging, through the addition of background noise, forced young adults to adopt a similar compensatory strategy to decode the words, thus the link between sensory and cognitive domains was also demonstrated in the young group under increased noise conditions.

Motor-cognitive and executive processes in old age. Similarly to observed interaction between sensory and cognitive domains, motor-cognitive link has been also documented (Li & Lindenberger, 2002). Most of the tasks used to investigate motor-cognitive interaction addressed the role of executive control in motor processes. With advancing age, a decline in higher order cognitive functions such as executive control has been very well documented (West, 1996). One aspect of executive control that has been heavily studied in the basic and cognitive aging literatures is response suppression, or the inhibition of a well-learning or automatic response. One of the most frequently used tasks is the Stroop test (e.g., Spreen & Strauss, 2001). The incongruent version of the Stroop test requires individuals to suppress their dominant inclination of reading the words; instead, they are asked to name the colour of the ink in which the words are printed. The evidence from various studies indicates that older adults experience more inhibition failures than young adults (e.g., Earles, Connor, Frieske, Park, & Zwahr, 1997; Pilar, Guerrini, Phillips, & Perfect, 2008). These findings suggest that inhibitory processes are prone to age-related declines. Another cognitive task that is traditionally used to investigate inhibitory processes is the Hayling test (Burgess & Shallice, 1996b). The Hayling test consists of a series of sentences, each missing the last word. Participants are asked to listen to the sentences and complete each sentence with a word that does not fit. In this way, the test measures how well participants can inhibit the production of a dominant verbal response. Several studies have shown that older adults tend to produce more inhibition errors and take longer to complete the sentences than younger adults (Andrés & Van der Linden, 2000**;** Bielak, Mansueti, Strauss, & Dixon, 2006).

It has been shown that healthy aging is not only associated with declines in cognitive functions but also with declines in motor functions (Krampe, 2002). In addition, it has been proposed that motor and cognitive performance become more strongly correlated with increasing age (Baltes & Lindenberger, 1997; Li & Lindenberger, 2002). Recent studies on motor-cognitive performance indicate that the two domains become more interdependent in old age (for review, Woollacott & Shumway-Cook, 2002). The majority of such evidence comes from dual-task research that involves simultaneous gross motor and cognitive task performance. In a dual-task paradigm, participants are asked to perform two tasks separately and then concurrently. Dual-task performance costs are shown in many cases of simultaneous performance of two tasks, and the costs are greater for older adults compared with younger adults (Li and Lindenberger, 2002). For example, Mendelson, Redfern, Nebes, and Jennings (2010) paired cognitive tasks such as auditory and visual choice reaction time tasks with a standing balance task. They reported that cognitive resources appeared to be more important in the maintenance of balance in older adults than in young adults. Similarly, van Iersel, Kessels, Bloem, Verbeek, and Olde Rikkert (2008) used a dual-task paradigm to investigate the involvement of cognitive processes in gait and balance of older adults. The results of their study support the view that executive functions are associated with gross motor impairments, thus, successful performance of motor tasks depends on successful executive integrity. Fraser, Li, DeMont, and Penhune (2007) reported that in a study of a dual-task treadmill walking, older adults experienced more pronounced motor dual-task costs than younger adults. Taken together, gross motor studies suggest that motor performance relies on executive processes and requires more cognitive resources in old age.

Cognitive aging and fine motor performance. Although the relationship between cognitive tasks and gross motor tasks in aging has been extensively investigated, fewer studies have been conducted examining the link between fine motor and cognitive performance in old age. Some evidence of interdependence between cognitive and fine motor mechanisms comes from more recent studies. One study investigating the role of executive control in fine motor performance in old age was conducted by Fraser, Li, and

Penhune (2010). There, young and older adults performed a sequential finger tapping task separately and concurrently with either a semantic judgment task (Expt. 1) or a mental arithmetic task (Expt. 2). In the second experiment, under low cognitive load conditions in dual-task trials, older adults demonstrated slower and less accurate fine motor performance than younger adults. Interestingly, when the difficulty of the mental arithmetic task increased, both age groups revealed motor performance decline. These results support the view that executive functions play an important role in fine motor performance similarly to gross motor performance. Importantly, the link between these two domains appears to increase with advanced age.

Another study that investigated involvement of cognitive processes in fine motor mechanisms was conducted in our laboratory (Trewartha et al, 2009). A finger sequencing task was used to examine age differences in response inhibition. A number of researchers suggest that a sequential key press paradigm may be optimal for studying the role of cognitive control in motor performance for several reasons (e.g., Rhodes, Bullock, Verwey, Averbeck, & Page, 2004; Verwey, Abrahamse, & de Kleine, 2010). Firstly, a simple key press takes little time to execute; thus, the response time is more likely influenced by the underlying cognitive processes than when the execution requires a more complex motor response (Verwey et al., 2010). Secondly, a sequential key press paradigm, which is usually fairly short, may be considered as a building block of a more complex motor action (Wolpert & Kawato, 1998). Traditionally, a serial reaction time (SRT) task has been used to investigate the underlying processes of motor sequence learning (Nissen & Bullemer, 1987; Robertson, Pascual-Leone, & Miall, 2004). In a SRT task participants are presented with a series of visual stimuli and are asked to press a corresponding key when cued. Over training, participants learn to make key presses more quickly and accurately. However, when an unpractised element or sequence is introduced, their performance slows down. In our previous study (Trewartha et al., 2009), during the training phase participants were taught a repeating sequence of key presses. During the test phase they had to perform a motor response that deviated from the well-learned response. Using kinematic measures, we decomposed responses into planning and execution time. Planning time was defined as the time between the onset of the stimulus and the onset of the finger movement. Execution time was defined as the time between finger movement onset and completion of the key press. Motor responses differed significantly between younger and older adults. Before movement initiation, both age groups required longer planning time when encountering new, unexpected sequences during the test phase. However, when faced with these new, unpractised trials, only the young adults were able to speed up their execution time. When interpreting the results, we argued that only the older adults group was not able to reprogram or adjust its execution time, because fine motor and cognitive processes become more interdependent in an old age. However, at this point it is still not clear whether older adults' inability to reprogram their responses and speed up their execution time was due to declined cognitive processes or declined motor processes. As was previously discussed, according to the sensorimotor interaction research it is possible that cognitive aging prevented older adults from adjusting their fine motor execution time.

To address this question, the main goal of this study was to investigate whether age-related cognitive decline contributes to older adults' inability to reprogram their well-learned motor behaviours. The approach taken was to simulate cognitive aging by adding a cognitive load to the response inhibition paradigm used in our previous study (Trewartha et al., 2009). We focused on testing young adults, reasoning that their motor abilities should be optimal. If an additional cognitive load resulted in performance resembling the older adults in the previous study, we could have more confidence in interpreting that result as a consequence of reduced cognitive capacity.

In the present study, kinematic measures of fine motor performance of the modified SRT task were used. We experimentally reduced younger adults' cognitive capacity by asking them to concurrently perform a Serial 7s subtraction test (SST) singly, or concurrently with the sequencing task. It was expected that under dual-task conditions, participants' fine motor responses would be slowed down, reflecting higher divided attention demands. Secondly, we reasoned that if the older adults in the earlier study (Trewartha et al., 2009) performed poorly because of declining executive control processes, then in the present study, young adults would lose their ability to speed up their motor execution times in the dual-task condition.

Method

Participants

Nineteen young adults between the ages of 19 and 29 took part in this study (*M* age = 21 years, *SD* = 2.32). Of the 19 participants included in the study, 17 were women and 2 were men. Prior to a testing session, all participants were screened by telephone interview (see Appendix A). Eligible participants had less than 3 years of musical experience and had not practiced for the last 10 years. All participants were right handed, had no history of neurological disorder or injury that could affect sensory, motor or cognitive functioning. All participants were recruited from the Concordia University Participant Pool Website and received course credit in exchange for their participation. All participants provided written informed consent prior to any research activity and all procedures met Concordia University ethical guidelines (see Appendix B). The Digit Symbol Substitution subtest of Wechsler Adult Intelligence Scale IV (WAIS; Wechsler, 2008), the Stroop test (adapted from Spreen & Strauss, 2001), and the Comprehensive Trail Making Test (Reynolds, 2002) were administered to assess processing speed, controlled attention, and task switching, respectively. Performance on these tests was within age-normative ranges. Descriptive statistics is presented in Table 1.

Table 1

Means and Standard Deviations of the Neuropsychological Tests

Neuropsychological Tests	*M* (*SD*)
CTMT Simple vs. Complex	5.61 (5.91)
Stroop Interference	0.54 (0.22)
Digit Symbol	92.63 (15.55)

Note. Mean values and standard deviations (in parentheses) are presented. Comprehensive Trail Making Test (CTMT) score is based on the difference between the complex and simple task conditions; the difference between the seconds per item completed on the Congruent and Incongruent conditions of the color Stroop test; Digit Symbol values of the Wechsler Adult Intelligence Scale (WAIS-IV) are based on the total number of symbols correctly completed in 120 s.

Apparatus

Participants were instructed to make a series of key-press responses on a custom-built keyboard. In order to help participants in positioning their fingers on the correct keys, the keyboard was made with only four keys (Figure 1). To make the key press responses, participants were instructed to use four fingers of their right hand. Participants were instructed to follow the visual stimuli which were presented on a computer screen. The stimuli consisted of four boxes that changed colour from grey to pink. The boxes mapped in a one-to-one manner onto each of four fingers (from left to right). A 3-D motion capture system (VZ3000; Phoenix Technologies, Burnaby, British Columbia, Canada) was used to record kinematics of the finger movements. Finger motions were captured using the light-emitted diode (LED) markers that tracked the x, y, and z positions of each of the fingers.

Materials

Motor task: A finger sequencing task. For the fine motor task, participants imitated sequences of key presses on a custom-build keyboard that were cued by visual stimuli presented on a computer monitor. To imitate the sequences participants used four fingers of their right hand (the index, middle, ring, and pinkie). The visual stimuli consisted of four blocks (3-in. (7.62 cm) X 3-in. (7.62 cm)) against a grey background (Figure 1) which were displayed in the middle of the computer screen. The stimulus duration of each sequence was 16000 ms, the interstimulus interval (ISI) was 800 ms, and a pause between each sequence was 3000 ms. There was no sound accompanying the key presses and no feedback was given during the experimental trials. Each participant was tested under a number of different experimental conditions. There were four phases of the experiment: familiarization, practice, learning, and testing trials. Depending on the phase of the experiment, the structure of the sequences changed.

Illustration of the Apparatus Used in the Experiment

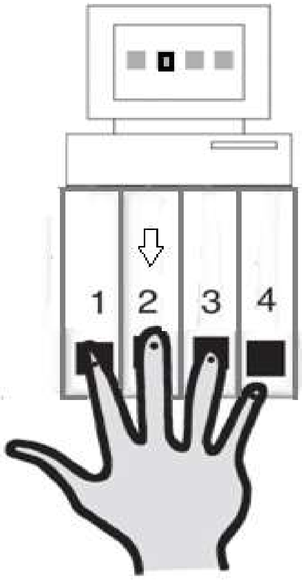

Figure 1. Illustration of the computer-keyboard setup used for the fine motor task. The participants were instructed to put each of their four fingers on Velcro pads attached to the custom-built keyboard. Two motion capture cameras were placed in front of the computer-keyboard setup. One light-emitting diode (LED) marker was placed on each fingernail of the right hand. The arrow on the illustrated keyboard and the dark square on the illustrated computer screen indicate the correspondence between the finger and the square. Numbers on the keys are for illustration purposes only.

Cognitive task: *The Serial 7s subtraction test.* This task is commonly used in neuropsychological assessment as a high processing load task. For this task, participants were presented auditorially with a randomly generated number between 86 and 99. They were instructed to subtract 7 from that number, and continue to subtract 7 from their answer, reporting the result verbally, until told to stop. Each cognitive task trial lasted for 16 seconds.

Procedure

After completing a battery of neurocognitive tests, participants were given instructions about all the upcoming tasks. The first part of the testing session consisted of a familiarization phase in which participants familiarized themselves with the equipment. Next, participants had to complete a motor task practice phase and one trial of an SST. During each testing session, participants first completed a block of each of the single tasks; a single motor and a single cognitive task. Dual-task condition was introduced in order to experimentally reduce cognitive capacity of our participants. In dual-task trials participants had to concurrently perform a motor task and a cognitive task. To complete the testing session, another block of each of the single-task trials was introduced. In order to minimize any practice or fatigue effects the order of the motor and cognitive single tasks within each block was counterbalanced between/within participants.

To ensure that participants were comfortable with the equipment and to orient them to the box-to-key-to finger mapping, the first familiarization phase consisted of a simple 24-element sequence (1, 2, 3, 4, 1, 2, 3, . . .). The next part of the motor task consisted of a practice phase in which participants were instructed to follow the boxes that changed colours as quickly and accurately as possible. The practice phase consisted of 10 trials of 10 elements long random key presses. The design of this phase was slightly modified from the original Trewartha et al. practice phase (2009). In that study, participants had to achieve 85% accuracy during the practice phase in order to continue to the next phase. This allowed to ensure that all participants began the next experimental phase at a relatively equal skill level. The results of that study revealed that all participants achieved the criterion of 85% of correct key presses after 7 trials.

After the practice session, each participant was presented with either a single cognitive task or a single motor task. The order of these two tasks was counterbalanced between participants. Single motor task consisted of two phases: a learning phase and a test phase. Motor sequences for the learning phase consisted of 20 elements which included 10 pairs of the same key presses (e.g., 2,1,2,1...). These overlearned pairs of key presses were referred to as critical transitions (Trewartha et al., 2009). Each learning phase was followed by a test phase which consisted of a semi-random sequence of 20 elements. The elements consisted of two pairs of the critical transitions from the learning phase, two pairs of violation transitions, and some random key presses. The violation trials started with the same key as the critical transitions but ended with a different key. Thus, during the violation trials participants had to suppress their overlearned behaviour. In order to overlearn the pair, participants were assigned the same critical transition for the entire experiment.

Results

One of the main goals of this study was to examine whether reducing cognitive capacity using a cognitive load manipulation would cause young adults' fine motor performance to resemble older adults' performance observed in the previous work from our laboratory (Trewartha et al., 2009). It was expected that under no cognitive load conditions, on violation transitions, young adults would reveal increased planning time but decreased execution time, and under dual-task conditions, on violation transitions, young adults would lose their ability to speed up their execution time and compensate for longer planning time. To evaluate the effects of the dual-task load, three dependent variables were calculated for the fine motor task: accuracy, reaction time, and execution time. For each dependent variable, we conducted a 2 X 2 - Cognitive Load (single- vs. dual-task) x Transition Type (critical vs. violation trial) - repeated measures ANOVA. In addition, we used a repeated measures ANOVA to look at the cognitive accuracy under two cognitive load conditions (single-task vs. dual-task).

A previous experiment in our laboratory (Trewartha et al., 2009) examined the effect of the critical and violation transitions on the kinematic components; comparing critical transitions during the learning phase with violation transitions during the testing phase. We argued that the critical transitions from the learning phase represent optimal performance which is free from interference from violations. In the current study, we adopted the same analytical technique, allowing us to compare young adults' kinematic data in this study to older adults' data from the previous experiment.

Kinematic Analyses

We analyzed the motion capture data to examine the effects of cognitive load manipulation and transition type on key press accuracy. The analysis of accuracy scores revealed no significant effect of cognitive load, $F\ (1,18) = 2.97$, $p =.102$, $\eta^2 = .142$ or transition type, $F\ (1, 18) = 2.77$, $p = .113$, $\eta^2 = .133$ and no interaction, $F\ (1, 18) = 0.19$, $p = .669$, $\eta^2 = .01$. This indicates that cognitive load and transition type had no effect on accuracy. This lack of variance in accuracy data is advantageous, because it allows a clearer interpretation of the time-based data.

A similar ANOVA was conducted to evaluate the effects of cognitive load on planning time. Planning time was defined as the time from the visual stimulus presentation to the finger movement initiation. The transition type main effect was significant, $F\ (1, 18) = 59.58$, $p < .001$, $\eta^2 = .768$. Bonferroni corrected comparisons revealed that planning time for the critical transitions ($M = 85.39$, $SEM = 18.05$) was significantly shorter than for the violation transitions ($M = 235.95$, $SEM = 10.07$) for both levels of cognitive load. There was no significant effect of attentional load and the interaction between attention and transition type was nonsignificant. Consistent with our previous study (Trewartha et al., 2009), the planning time findings suggest that young adults exhibited longer planning times when violations of the well-learned responses occurred (see Figure 2).

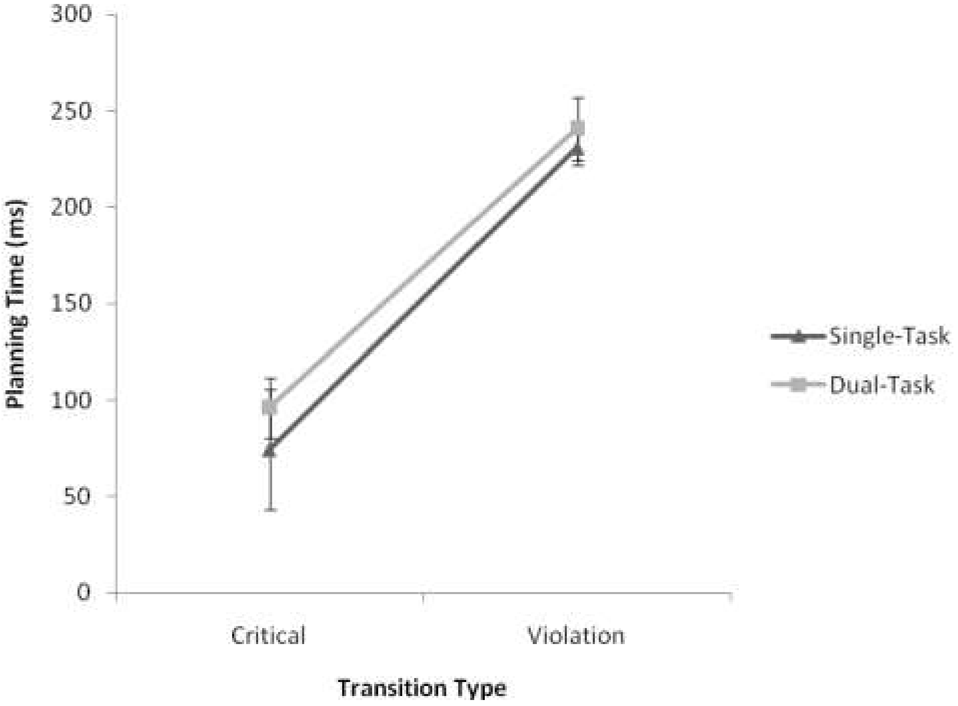

Figure 2. Mean planning time of key presses for critical transitions during learning blocks and violation transitions during testing blocks for single-task and dual-task conditions. Error bars represent ±1 standard error of the mean.

A final ANOVA using execution time as the dependent variable was conducted in order to evaluate the effects of transition type and cognitive load on execution time. Execution time was defined as the time from the beginning of the finger movement to the full key depression. The analysis revealed that there was a trend toward a significant interaction between attention and transition type, F (1, 18) = 3.300, $p = .086$, $\eta^2 = .155$. Planned comparisons showed that in the single-task condition, execution time for violation transitions (*M* = 226.62, *SEM* = 8.94) was significantly shorter than for critical transitions (*M* = 267.49, *SEM* = 10.01), F (1, 18) = 12.417, $p = .002$, $\eta^2 = .408$, but this pattern of movement kinematics was not observed under the dual-task condition, F (1, 18) = 3.097, $p = .095$, $\eta^2 = .147$ (see Figure 3). Means and standard deviations of planning time and execution time for both levels of cognitive load are presented in Appendix C.

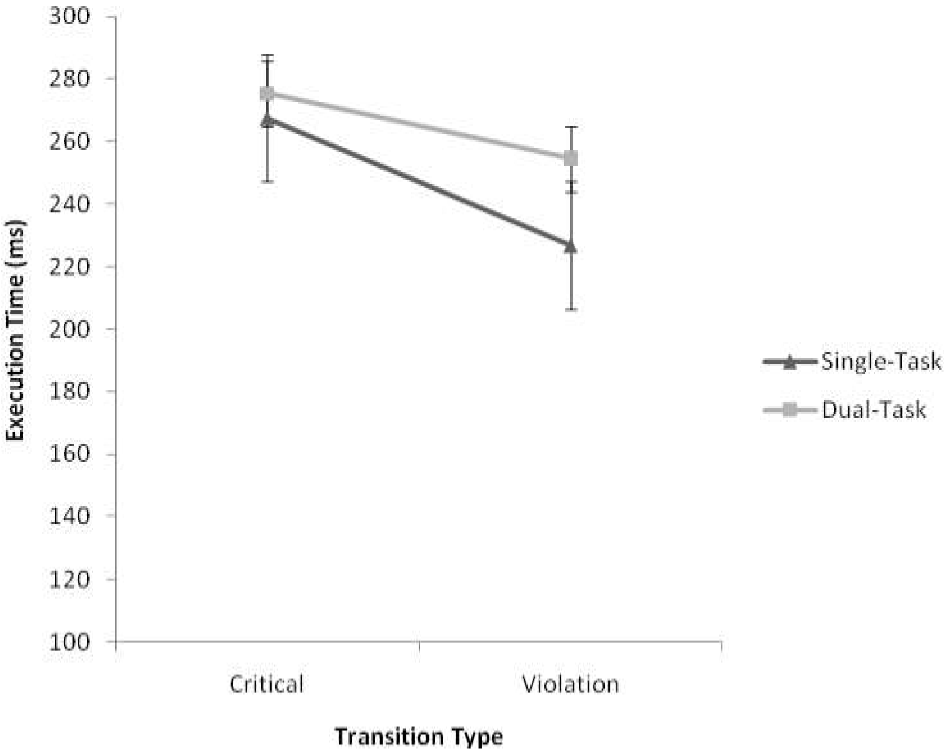

Figure 3. Mean execution time of key presses for critical transitions during learning blocks and violation transitions during testing blocks for single-task and dual-task conditions. Error bars represent ±1 standard error of the mean.

An additional analysis was conducted only using the violation trial data to investigate the potential compensatory relationship between planning and execution times. It was expected that under single-task conditions young adults would exhibit a negative correlation between planning and execution times, such that longer planning times would be related to shorter execution times, whereas under dual-task conditions they would exhibit a positive or null correlation. To do this, we calculated the correlation between pairs of planning and execution times for each participant for each condition. To be able to compare the correlations across participants and conditions, we transformed the correlation coefficients to *z*-scores using the Fisher's *r* to *z* transformation. The *z*-values were then compared to 0 in one-sample *t*-test, one for the single-task data and one for the dual-task data. Under single-task conditions, the average *z*-transformed correlation was significantly less than zero (*M*zr = - 0.69), $t(18) = -6.46$, $p < .001$. Under dual-task conditions, the average *z*-transformed correlation was also significantly less than zero (*M*zr = - 0.37), $t(18) = -2.97$, $p = .008$. These results indicate that under no cognitive load conditions, young adults shortened their execution time to compensate for longer planning time. Contrary to our predictions, participants were also able to shorten their execution time under higher cognitive load conditions. Importantly, the magnitude of the correlation under dual-task conditions is only 54% as large as the correlation under single-task conditions.

Cognitive Analysis

To manipulate cognitive resources of our participants, they were asked to subtract 7 from auditorially presented number. Although subtract 7 task can be regarded as a measure of fluency and speed of calculation, we measured performance on the task as a percentage of correctly subtracted numbers. A repeated-measures ANOVA comparing cognitive accuracy under single-task (*M* = 4.76, *SEM* = 0.38) and dual-task (*M* = 4.25, *SEM* = 0.30) conditions was significant, *F*(1, 18) = 5.338, *p* = .033, η^2 = .229. Such a finding means that under single-task conditions, young adults' cognitive performance was more accurate than under dual-task conditions.

Discussion

In this study we evaluated the importance of attention in fine motor performance. Based on the assumption that age-related reduction of cognitive capacity influences fine motor performance, we proposed that simulating cognitive aging by experimentally increasing the cognitive load would result in a deterioration of performance on the fine motor task in young adults. The motion capture analyses revealed that when presented with the violation transitions, the participants were slowed in terms of planning time, relative to their responses to the expected transitions. More interestingly, young adults' execution time on violation transitions became shorter than on critical transitions under single-task conditions, consistent with previous work in our laboratory (Trewartha et al., 2009). With the addition of a concurrent cognitive load, which served to limit the cognitive capacity available for the motor task, our participants were less able to shorten their execution time in response to the violation transitions. Together, these results provide more conclusive evidence for the view that cognitive capacity, reduced in the case of older adults or young adults under dual-task conditions, influences the ability to flexibly adapt movement in the face of conflict.

Cognitive – sensorimotor interactions. The results of this study extend previous work that investigates connections between sensory and cognitive domains in old age. It has been suggested that in old age there is an increase in interdependence between sensory and cognitive domains due to a greater reliance on common resources (e.g., Lindenberger & Baltes, 1994; Murphy et al., 2000). Although a growing number of studies have examined the age-related changes in relationship between cognitive and sensory performance, this relationship has not been investigated extensively in the context of cognitive and fine motor performance. The results of the current experiment are consistent with the previous gross motor studies where an age-related increase in cross-talk between cognitive and motor performance has been observed (e.g., Fraser et al., 2007; Mendelson et al., 2010). In the current study, young adults' fine motor performance deteriorated under more challenging attentional conditions, which supports the hypothesis that the interdependence between fine motor and cognitive processes increases with old age when attentional resources of older adults become scarce.

Within the topic of cognitive-motor interactions, the present study focused on response suppression. The majority of response suppression studies suggest that young adults can stop the execution of prepotent responses, while there is a decrease in the efficiency of inhibitory processing in old age (Kramer, Humphrey, Larish, & Logan, 1994; Potter & Grealy, 2008). For example, Williams, Ponesse, Schachar, Logan, and Tannock (1999) found that young adults were able to suppress the execution of motor responses such as pressing a key, and hand movements such as typing (Logan, 1982). In an aging study that used kinematic analysis, Potter and Grealy (2008) used a gross motor task in which participants copied wiping movements. The researchers assessed the types of motor errors made by participants and found that older adults produced more inhibition failure errors than younger adults. Interestingly, in the present study, there was no observed attentional load effect on the execution time for prepotent responses, but we observed a load effect on the execution time for violation transitions. These results suggest that only violation responses were vulnerable to distraction while well-learned responses remained preserved. This is important, as it shows that unpractised responses are more sensitive under decreased cognitive resources than well-practiced responses.

The relative contribution of cognitive and motor processes. Whereas previous research on response suppression has relied solely on keyboard response times or movement accuracy, our approach of partioning the response into planning and execution time allows a distinction to be made between the cognitive and motor contributions to the observed keyboard response time. Importantly, the simulation of cognitive aging in young adults permitted us to examine the contribution of cognitive capacity independent of reductions in motor processes that might also be affected in old age.

It should be emphasized that the flexible motor adaptation exhibited by young adults under single-task conditions could easily be attributed to motor processes. Similarly, the inability of older adults in our previous study (Trewartha et al., 2009) to adapt their execution times might be attributed to declining motoric factors such as a loss of fast-twitch muscles (Ketcham & Stelmach, 2001). Despite well-documented evidence for age-related physical changes, the present evidence suggests that there is a significant cognitive contribution to the observed motor adaptations.

Divided attention effects. Another important question that we addressed in the current experiment was whether by manipulating attentional demands, we would be able to simulate the effects of cognitive aging in our young participants. Our dual-task kinematic results extend the results of divided attention and aging research. The literature indicates that older adults have more difficulty than younger adults carrying out two simultaneous tasks. One such study of divided attention and aging was conducted by Broadbent and Heron (1962). In the study, participants were asked to mark out all instances of a given digit while at the same time listen to a series of letters and identify the repeated letter. The findings revealed that young adults maintained high accuracy on both tasks, while older adults were unable to carry on the two tasks simultaneously. More specifically, older adults maintained their performance on the digit task on the expense of the letter detection task. In contrast, the results of the current study showed that when attentional resources were taxed, even young adults lost their ability to successfully carry out two tasks simultaneously. Specifically, we manipulated the cognitive load of young adults by introducing a concurrent cognitive task and found that under more cognitively demanding conditions their fine motor performance resembled that of older adults in our previous study (Trewartha et al., 2009). In cognitively challenging situations, young participants exhibited more difficulty reprogramming their fine motor movements on violation transitions and adjusting their execution time to overcome slowed planning time. Although young participants were still able to demonstrate preserved execution abilities, there was only a slight trend toward shortening of the execution time.

Our previous study (Trewartha et al., 2009) is one of the first attempts to decompose the underlying cognitive and motor processes involved in human ability to modify fine motor performance when unexpected events occur. When interpreting our findings, we suggested that because young adults were able to shorten their execution time to compensate for longer planning time for violation transitions, they would exhibit a negative correlation between these two kinematic measures. Accordingly, in the current experiment, we were able to show that execution time was negatively correlated with planning time under single-task conditions, which supports our prediction that by shortening their execution time young adults were compensating for longer planning time. Interestingly, under dual-task conditions, young adults' average *z*-transformed correlation between planning and execution time was also statistically different from zero, although the magnitude of this relationship was substantially less than under single-task conditions. These results indicate that there was a slight trend toward shorter execution time under higher cognitive load conditions, which means that young adults were still able to compensate somewhat for deviations when their attention was divided. This slight discrepancy from the previous older adults' findings could be due to current young adult sample having intact neuromuscular functioning in contrast to Trewartha and colleagues' sample of older adults (Ketcham & Stelmach, 2001).

Cognitive task effects and characteristics. As was previously mentioned, the research on fine motor-cognitive dual-task performance mostly focuses on motor performance, thus we had no strong a priori hypothesis concerning the cognitive measures. The results of the current study revealed that participants' performance on the cognitive task significantly declined with increased cognitive load. The results of the Fraser and colleagues study (2010) showed that the pattern of cognitive results under more demanding cognitive conditions was similar for younger and older adults. The researchers proposed that under the highest cognitive load, both age groups were prioritizing cognitive performance over tapping performance. Nevertheless, recent literature on motor-cognitive and aging studies suggests that when given a choice older adults prefer to prioritize motor tasks as compared to younger adults who choose to prioritize their cognitive abilities (Doumas, Rapp, & Krampe, 2009; Li, Lindenberger, Freund, & Baltes, 2001). The results of our cognitive data revealed that, by manipulating attentional load, we were able to simulated the effects of cognitive aging in our young participants and replicate the findings of the recent studies on motor-cognitive performance and aging.

Dividing attention between two tasks has been a standard method for manipulating cognitive load (Li & Lindenberger, 2002). However, other research has revealed that the magnitude of dual-task costs is influenced by the nature of the cognitive tasks chosen. For instance, standing balance is more impaired by a concurrent spatial task than a verbal memory task (e.g., Maylor, Allison, & Wing, 2001). As a general principle, the more structural interference between two concurrent tasks, the greater the probability of cross-talk. Along these lines, one can consider the characteristics of the task used in the present study. The SST has been widely used in mental status examination for dementia (Karzmark, 2000). The test was first described by Kraepelin (1990), who regarded it as a test of attention. However, it has also been perceived as a measure of arithmetic learning and performance (Manning, 1983). For example, Karzmark (2000) argued that the SST performance is as strongly linked to basic arithmetic skills as it is linked to concentration processes. Williams, LaMarche, Alexander, Stanford, Fielstein, and Boll, (1996) viewed the test as a measure of information processing rather than pure attention. Despite these disagreements between the researchers as to the various hypotheses regarding the nature of the test, the SST is viewed as a measure of concentration (Lezak, 1995).

In a study that examined concurrent SST and gross motor performance, (van Iersel et al., 2008), participants were asked to walk while performing two different cognitive tasks: the SST and a verbal fluency test (animal word generation). The results of the study showed that both cognitive tasks negatively influenced gait and balance. However, multiple regression analysis revealed that this effect was largely due to the verbal fluency test. The researchers argued that although both cognitive tasks rely on executive functioning, the verbal fluency test may be using more cognitive resources as compared with the SST. In contrast, our current results suggest that the SST can be used to disrupt motor performance, at least fine motor performance involving expected and unexpected finger sequences. Interestingly, in the present study, the load effect was non-significant for the execution time during critical transitions, but was significant for the execution time during violation transitions. These results suggest that only violation responses were vulnerable to distraction while well-learned responses remained preserved. It may be that gross motor tasks such as steady state walking or balancing are executed more automatically and therefore proved to be unaffected by concurrent SST performance.

Future directions. Concerning the influence of cognitive load on motor performance, Woollacott and Shumway-Cook (2002) proposed that the nature of the cognitive task might have an effect on arousal. The researchers suggest that task related changes in dual-task performance could be attributed to increased arousal or anxiety, rather than attentional control. Thus, arousal can be considered as a potential confounder in our study. In addition to measuring attentional control, it would be beneficial in the future to measure arousal levels and its effects on dual-task performance. Additionally, further studies integrating computerized cognitive task presentation might allow us to assess the contributions of the cognitive processes to fine motor performance. Manipulating the exact presentation of the cognitive stimuli might help us better understand the involvement of cognitive processes in different phases of fine motor performance.

Conclusion. Taken together, in the current study, we used 3-D motion capture system in order to investigate the effects of simulated cognitive aging on kinematic signatures of fine motor performance in responses to well-learned and unexpected events. Similarly to sensory-cognitive integration and aging studies (Li & Lindenberger, 2002), we suggest that older adults require greater executive control processes in order to perform fine motor responses. We predicted that under increased attentional demands our young participants would reveal fine motor performance similar to older adults' performance observed in our earlier study (Trewartha et al., 2009). The results of the present study are in line with the findings of the sensory-cognitive integration studies. Current results indicate that under single-task conditions, young participants were slower to initiate the key presses when unexpected transitions occurred, while at the same time, they were able to speed up their key presses on those unexpected transitions. However, when attentional resources were limited under dual-task conditions, this compensation strategy decreased. These findings suggest that the pattern of aging effects in motor execution time may have come about primarily because of reduced cognitive capacity and not diminished neuromuscular or physiological capacity. Our findings complement the literature on the effects of simulated sensory loss on cognitive performance.

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Appendix A

Telephone Screening Survey

Telephone Screening Procedure: MocapDT study (2009-2011)
For Younger Adults

Introduce yourself: "Hi, my name is ______. I am calling from the Dept. of Psychology at Concordia University. You expressed an interest in participating in the multi-tasking experiment we are conducting. Are you still interested in participating?
[If "NO", then ask them if it would be Ok if we call them back another time for another study]

[If Yes…] Do you have approximately five minutes now for us to screen you to ensure your eligibility to our experiment? **[If "NO", then when would be the best time for us to contact you again?**
[If Yes…] First let me tell you a little bit more about the study. "The study is related to motor learning. You will be asked to reproduce a series of key presses on a piano keyboard. Before we book an appointment, I have a few general health questions and questions about musical experience and handedness that are relevant to this study. **[If yes to any of the following then suggest that this study may not be the right one for them but perhaps they wouldn't mind if we called them for another study]**

(1) **How old are you?** (Exclude if younger than 18 or over 35 say: for this particular study we are looking for a specific age group and unfortunately you are not in that group but if you don't mind, I'll keep your name on our phone list for other studies)

(2) **Ask them musical experience questions (on separate sheet..)**
  - **if musical experience was over 10 years ago, included**

(3) **Are you color blind? (If yes, exclude…And say:** for this particular study the colors are used frequently and so it would be better if I saved your name for another study…is that Ok?

(4) **A. Have you had a serious injury to your hand/arm or medical illness that would affect your cognition, attention or motor function?**
B. Are you taking any medication that could affect your motor abilities? If they tell you a certain medication, ask them what they are taking it for… (**IF YES**…this study requires a lot of repetitive movements of the hands/fingers and so it may not be the best study for you, would you mind if we keep your name on our list for other studies?)

(5) **Have you had any severe head injuries?** (Exclude if person had a significant head injury and were actually hospitalized or were unconscious for more than 24 hrs).

(6) **Are you right handed?** If they are not sure ask them which hand do they normally hold a pair of scissors in, which hand do they hold a knife when cutting bread?
(**IF NO**…for this particular study we are looking for specifically for right handed individuals. If you like we could call you back for the next study…)

After questions are asked…if they fit the study criteria then…

Everything sounds good. We are testing for the next couple of weeks, is there a day/time that is convenient to come in?

Warn them to refrain from excessive alcohol consumption: “For this particular study, we ask participants not to drink any alcohol or any other substances that may slow you down 24 hours prior to the study days, since alcohol in particular is known to affect motor learning. If you had a couple of beers the night before, we ask you to call us so we can reschedule the session.” (the main thing with this question is that the person should understand that they shouldn’t overindulge)

And don’t forget to tell them that they can contact us if they have further questions. Give them our telephone number (848-2424, extension 2247). The study is being conducted at the Li lab (Loyola Campus, PY-080-1). For this study we would need you to come in for approximately 1.5 hrs.“You will be given 2 participant pool credits or monetary reward for your time and participation.”

Thank-you very much-we’ll see you on (repeat date, time and meeting place). We’ll e-mail you the day before to confirm.

Name:______________________________

ID:________________________________

(2) Musical Training/ Experience

* Have you ever played a musical instrument (including voice/dance)? **YES** ☐ **NO** ☐

(The following questions are letter coded with respect to the first question, e.g. years of playing for instrument "a", instrument "b", etc.)

If yes, which instrument(s) (including voice) in order of concentration:
a) _________________________, b) ____, c) ____________________________________

* How old were you when you first started playing/singing/dancing? a) _______, b) _______, c) _______

* How did you learn to play/sing/dance? a) _______________, b) _________________, c) ____________

* For how many years did you play/sing/dance?

0-3 yrs: a) ☐ b) ☐ c) ☐

4-8 yrs: a) ☐ b) ☐ c) ☐

9-13 yrs: a) ☐ b) ☐ c) ☐ **ADD YRS**:

____

14 + yrs: a) ☐ b) ☐ c) ☐

If stopped, at what age did you stop? a) _____________, b) _____________, c) _______________

* Are you currently practicing? a) YES ☐ NO ☐ b) YES ☐ NO ☐ c) YES ☐ NO ☐

(What is important here is that the person is excluded if they are currently practicing a musical instrument or have had more than three years of musical experience)

If they are currently practicing or have 3+ years musical experience then again tell them

that for this study we aren’t using people with music experience because we know that they perform better than people without musical experience on this task…perhaps they would like to come in for another study

Appendix B

Consent Form

ID#_________

CONSENT FORM TO PARTICIPATE IN RESEARCH

This is to state that I agree to participate in a research study being conducted by Yana Korotkevich (B.A.) under the supervision of Dr. K. Li and Dr. V. Penhune in the Department of Psychology at Concordia University.

A. PURPOSE

I have been informed that the purpose of the research is to understand the differences between younger and older adults on a finger sequencing task with a varying workload demand.

B. PROCEDURES

The research will be conducted in the laboratory PY- 080-1 at Concordia University. Each participant will be asked to fill out a demographic and health questionnaire, as well as some paper and pencil tasks. The experiment will consist of two tasks: a finger sequencing task that involves motor function and a number monitoring task that involves cognition. The testing session will last approximately 90 -120 minutes.

C. CONFIDENTIALITY

Participation in this study guarantees confidentiality. The participant's name or other identifying information will not be attached to the response forms, and the signatures and names on the consent forms will be collected and stored separately by the supervising professor. The participant is free to refuse to answer any question that makes him or her uncomfortable answering.

D. CONDITIONS OF PARTICIPATION

- I understand that I am free to withdraw my consent and discontinue my participation at anytime without negative consequences.
- I understand that the results from this study may be published.
- I understand that my participation in this study is CONFIDENTIAL.

E. COMPENSATIONS

- I understand that I will be given 1 participant pool credit or $10.00 per hour as compensation for my time.

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: ____

Please call me again for participation in other research YES ☐ No ☐

If at any time you have questions about your rights as a research participant, please contact the Research Ethics and Compliance Advisor, Concordia University, Dr. Brigitte Des Rosiers, at (514) 848-2424 x7481 or by email at *bdesrosi@alcor.concordia.ca.*

Appendix C

Means and Standard Deviations of Planning Time and Execution Time During Single-task and Dual-task Conditions

Means (ms) and Standard Deviations of Planning Time and Execution Time During Single-task and Dual-task Conditions

	Planning Time		Execution Time	
	M	*SD*	*M*	*SD*
SM Practice - critical	74.486	31.32	267.486	10.01
SM Test - critical	181.815	9.14	242.017	11.62
SM Test - violation	230.888	8.97	226.621	8.94
DT Practice - critical	96.294	15.71	275.378	11.31
DT Test - critical	184.658	18.24	261.571	15.05
DT Test - violation	241.016	16.23	254.551	13.71