Contribution of Cognitive Processes to Fine Motor Reprogramming and Adaptation Processes and Effects of Musical Expertise on Motor Processes in Advanced Age

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ABSTRACT

Contribution of cognitive processes to fine motor reprogramming and adaptation processes and effects of musical expertise on motor processes in advanced age

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It is known that aging is associated with normative declines in both motor and cognitive processes, specifically, executive functioning. It is also known that these two processes become increasingly interdependent with advanced age. However, due to this increased interdependence between motor and cognitive processes, it remains challenging to disentangle the concurrent contributions of cognitive and motor aging. Numerous aging studies show an association between frequent cognitive stimulation and preserved cognitive abilities (e.g., enhanced executive functioning). What has been less often evaluated is whether specific skills influence cognitive and motor processes in old age. The primary objective of the current dissertation was to explore the association of executive functioning and musical experience to fine motor reprogramming and adaptation processes in advanced age. Firstly, we explored the involvement of three aspects of executive functioning: divided attention, response reprogramming/inhibition, and adaptation in fine motor performance of older adults. Secondly, we investigated the prediction that musical experience might be associated with enhanced cognitive processes involved in motor performance. To address these goals, participants overlearned repeated pairs of key presses to establish a pre-potent motor response. Participants' performance on the pre-potent responses was compared to conflicting responses. Kinematic analyses were used to disentangle reaction time into broadly cognitive, measured by planning time (PT), and motor, measured by execution time (ET), components. The main goal of Study 1 was to investigate the contribution of cognitive and motor processes involved in fine motor reprogramming of younger and older adults. To this end, a dual-task paradigm was used to simulate the effects of cognitive aging in young adults. With the addition of a cognitive load, the ET of younger adults became more similar to that of older adults and as compared to full attention conditions. In Study 2, the same dual-task paradigm was adapted to investigate the association of musical expertise with cognitive and motor reprogramming processes of older adults. With increased attentional load, musicians and non-musicians showed no differences in ETs. However, as opposed to musicians, non-musicians slowed down their PTs for well-learned stimuli. These findings suggest that musical experience was more beneficial to cognitive (PT) components rather than the more motor (ET) components of fine motor performance. Study 3 was designed to explore the contribution of musical experience to motor adaptation processes in older adults. In this study, previous exposure to conflict helped older musicians to adapt their motor responses, while older non-musicians failed to show motor adaptation effects with increasing conflict frequency. In conclusion, these findings provide compelling evidence that age-related declines in fine motor response reprogramming may be related to reduced cognitive capacity. These data also provide evidence for an association between musical experience and enhanced motor reprogramming and motor adaptation skills in older age. Notably, the observed benefits of musical experience were found in the cognitive aspects of performance and not the motor components. Together, the reported studies advance the current understanding of how cognitive processes play a role in fine motor performance. The work has implications for how to maintain or improve functional independence in late life.

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Chapter 1: General Introduction

Clinical and neuropsychological studies conducted with older individuals confirm that advanced age is associated with inevitable changes in cognitive and motor processes (e.g., Braver & West, 2008; Krampe, 2002; Smith, Umberger, Manning, Slevin, Wekstein, Schmitt, et al., 1999). Unfortunately, these age-related changes may interfere with the individual's day-to-day life and usual activities, and lead to reduced quality of life. One of the important characteristics of human behaviour is flexible adaption to novel or changing environmental demands. Effective self-regulation and action completion requires reprogramming of motor responses when occasional deviations or anomalies occur. Previous studies conducted in our laboratory (e.g., Trewartha, Endo, Li, & Penhune, 2009) revealed that motor reprogramming was one of the abilities that declined in older age, and this decline in motor reprogramming was related to reduced cognitive processes. However, due to the increased correlations shown between motor and cognitive processes in old age, termed *ability dedifferentiation* (Baltes & Lindenberger, 1997), it is challenging to disentangle the concurrent contributions of cognitive and motor aging. Researchers have attempted to identify experiences that may help to maintain cognitive and motor functioning in old age. Today, there is general agreement that active engagement in cognitively and socially stimulating activities can help delay the onset of cognitive and motor decline (e.g., Hall, Lipton, Sliwinski, Katz, Derby, & Verghese, 2009; Hertzog, Kramer, Wilson, & Lindenberger, 2008; Tortosa-Martinez, Zoerink, & Manchado-Lopez, 2011|). Evidence for the influence of stimulation and experience-induced changes continues to accumulate. It has been suggested that because music engages a number of systems, for example, motor, visual, and auditory functions (Schlaug, Norton, Overy, & Winner, 2005), it may stimulate brain regions, and this stimulation may protect from cognitive and motor decline

(Monaghan, Metcalfe, & Ruxton, 1998; Zatorre & McGill, 2005). A goal of this dissertation was to examine the contribution of cognitive processes to motor reprogramming and adaptation processes with a goal to understand whether the source of age-related decline in response reprogramming is due to cognitive or motor age differences, or both. A second goal was to examine the effects of musical expertise on fine motor processes in advanced age. To address these goals, in the first experiment a dual-task paradigm was used to simulate the effects of cognitive aging in young adults with a goal to investigate the contribution of cognitive and motor processes involved in fine motor reprogramming. For the second experiment, we used a similar dual-task paradigm to investigate the effects of musical expertise on cognitive and motor reprogramming processes of older adults. The third experiment was designed to extend this work and explore the contribution of musical experience to motor adaptation processes in older individuals. Background literature relevant to cognitive and motor processes in advanced age, as well as findings on the advantages of musical experience on cognition, are reviewed in the following sections.

1.1 Cognitive aging

A large body of research shows that there are age-related declines in a number of areas such as fluid intelligence, episodic and prospective memory, working memory, perceptual speed, selective and divided attention, and executive functions (see McDowd & Shaw, 2000; Salthouse, 1994; Salthouse, 2004; Zacks, Hasher, & Li, 2000; Vaughan & Giovanello, 2010). In contrast, some areas, such as semantic and implicit memory remain relatively stable (Graf, 1990; Light, 1992). A number of different theories have been proposed to explain age-related declines in cognitive processes. Resource theories contend that cognitive resources like attention (e.g., Craik

1983, 1986; Craik & Byrd, 1982) and working memory capacity (e.g., Light, Zelinski, & Moore, 1982) decline with increased age and become less efficient with increased processing demands. For example, it has been suggested that older adults' reduced performance on dual-task paradigms (i.e., simultaneously performing two tasks) could be explained by decreased general processing resources (Wright, 1981).

The generalized slowing account of aging, which is a more specific resource reduction approach, is based on consistent findings of reduced perceptual speed in old age (Cerella, 1985; Myerson & Hale, 1993; Salthouse, 1996). According to this account, the cognitive declines in old age are a consequence of a decrease in the efficiency of information processing in the central nervous system. More specifically, it suggests that reduced perceptual speed in advanced age may account for the reductions in performance on a broad range of cognitive measures (e.g., Salthouse, 1991; Salthouse & Babcock, 1991; Salthouse & Meinz, 1995). To explain these age-related declines in processing speed, a two-step mechanism has been proposed. First, early cognitive operations, necessary for successful task completion become slower, which then leads to reduced time available for later operations (Salthouse, 1996). Thus, cognitive performance may decline because certain late processing operations cannot be completed as a result of unfinished early cognitive operations.

A third major hypothesis relevant to sensorimotor and cognitive aging is the dedifferentiation hypothesis. This hypothesis proposes that across development in childhood, cognitive abilities become more distinct (i.e., differentiated), but as adults age, cognitive abilities become more closely related (i.e., dedifferentiated; e.g., Anstey, Hofer, & Luszcz, 2003; Baltes, Cornelius, Spiro, Nesselroade, & Willis, 1980). According to Anstey and colleagues, with increased age the boundaries between various cognitive domains fade, and they become more interconnected or dedifferentiated. This hypothesis was proposed to explain the convergence of abilities within and across domains, for example, sensory and cognitive domains (Baltes & Lindenberger, 1997). Further, a large body of correlational research also supports the idea that advanced age is associated with increased covariation between cognitive and sensorimotor performance (e.g., Baltes & Lindenberger, 1997; de Frias, Lövdén, Lindenberger, & Nilsson, 2007; Germain & Collette, 2008; Ghisletta & de Ribaupierre, 2005). Experimental studies that manipulate the cognitive resources available for task performance by combining cognitive and sensorimotor tasks also support the dedifferentiation hypothesis (Li & Lindenberger, 2002). However, Li and Lindenberger (2002) suggested that the dedifferentiation and resource reduction theories should not be conceptualized as mutually exclusive. Increased interdependence across various domains in older age may be a result of a reduction of available resources. Consequently, a more comprehensive model of age-related changes may include a combination of these models.

1.2 Executive functions in old age

Age-related declines have been observed in various areas including executive functions. In recent decades, researchers have increasingly focused on understanding the age-related changes in executive functions due to two main reasons. Firstly, the concept of executive function is complex, and includes multiple abilities, such as the simultaneous performance of multiple tasks, planning, problem-solving, coordinating, sequencing, shifting, inhibition of irrelevant information, and adapting or updating behaviours in response to environmental changes (Banich, 2004; Hasher & Zacks, 1988; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Rabbitt, 1997; Salthouse, Atkinson, & Berish, 2003). Age-related declines have been consistently observed in various executive functions such as working memory (e.g., Bopp & Verhaeghen, 2005; Salthouse, 1994; Verhaeghen & Salthouse, 1997), updating (e.g., Vaughan, Basak, Hartman, & Verhaeghen, 2008; Verhaeghen & Basak, 2005), task switching (e.g., Salthouse, Fristoe, McGuthry & Hambrick, 1998; Verhaeghen & Cerella, 2002), and cognitive inhibition (e.g., Hasher & Zacks, 1988; Hasher, Zacks & May, 1999). Age-related declines in simultaneous performance of multiple tasks (dual-task performance), self-monitoring and pre-potent or dominant response suppression are of particular interest for this dissertation. Secondly, it has been shown that executive functioning could be enhanced by cognitively stimulating activities (e.g., Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007; Diamond & Lee, 2011; Zuk, Benjamin, Kenyon, & Gaab, 2014). This suggests that age-related declines in executive functions could be delayed or modified through various interventions or training activities.

Executive control processes are often linked to frontal lobe functioning, which frequently shows significant declines with advanced age (Hertzog et al., 2008; Shallice & Burgess, 1991). West (1996) proposed the frontal lobe hypothesis of cognitive aging based on evidence that performance on tasks measuring frontal lobe functioning declines with age, while performance on tasks measuring non-frontal functioning remains relatively stable (Ardila & Rosselli, 1989; Whelihan & Lesher, 1985). It has been also observed that cognitive processes supported by the frontal lobes and the prefrontal cortex usually begin to decline at an earlier age compared to cognitive abilities supported by non-frontal areas (Albert & Kaplin, 1980; West, 1996).

1.3 Response inhibition

One commonly studied component of executive function is response inhibition, the ability to stop or suppress an automatic, well-learned, or pre-potent response (Logan, 1994; Miyake et al., 2000). Inhibition is central for everyday functioning, since it involves selective suppression of irrelevant information in order to maintain attention on currently relevant information. The Stroop interference task is a common method of measuring inhibitory processes (Stroop, 1935). The Stroop task measures individuals' ability to stop or inhibit responses or behaviours that conflict with automatic responses. A classic Stroop task requires individuals to name the ink colours in which words are printed. Typically, when a word is printed in incongruent ink colour, for example, the word RED printed in yellow ink, or its meaning is incongruent to the colour (e.g., lemon printed in red ink) response latencies and error rates will increase compared to the baseline condition, which is reading the written colour names. This slowdown in response latencies with conflicts is known as the Stroop effect, or Stroop interference. The Stroop effect is commonly attributed to difficulty in suppressing automatic, pre-potent, responses such as reading, in favour of a less automatic response, such as naming the colors of words (for review see MacLeod, 1991).

Various other approaches used to evaluate response suppression processes in old age commonly reveal significant declines in inhibitory function with advanced age. Large age-differences were found on the anti-saccade task (Butler & Zacks, 2006), the Stroop task (e.g., Pilar, Guerrini, Phillips, & Perfect, 2008; Spieler, Balota, & Faust, 1996; West & Alain, 2000), the flanker task (e.g., Zeef & Kok, 1993), the Simon task (e.g., Maylor, Birak, & Schlaghecken, 2011; van der Lubbe & Verleger, 2002), stop-signal paradigm (e.g., Rush, Barch, & Braver, 2006), and the Go/No-Go task (e.g., Nielson, Garavan, Langenecker, Stein, & Rao, 2001). In contrast to the findings reviewed above, other studies provide mixed evidence or reveal age-equivalent performance on tasks measuring response inhibition (e.g., McDowd, 1997; Verhaeghen & DeMeersman, 1998). For instance, in a meta-analytic review of 14 studies, Verhaeghen and DeMeersman observed that younger and older participants demonstrated large but comparable Stroop interference effects. To explain this inconsistency, a number of moderating factors have been proposed. Guerreiro, Murphy, and Van Gerven (2010) suggested that age-related inhibitory control deficits might be specific to one modality only. For example, deficits in the visual modality will not necessarily transfer to the auditory modality and vice versa. Another group of researchers suggested that increased working memory load could interfere with task performance by taxing the inhibitory functioning of older adults (McCabe, Robertson, & Smith, 2005).

Another moderating factor contributing to the decline in pre-potent response suppression in older age is related to weakening in reprogramming processes, or flexible adaptation processes. Although response reprogramming is closely related to response suppression, it is less commonly investigated in cognitive aging research. Both response suppression and response reprogramming require conflict monitoring, detection, and inhibition of responses, but unlike response suppression, reprogramming also requires the execution of a new response when conflict is detected. Researchers in our laboratory have used movement kinematics during pre-potent movement inhibition tasks to study the nature of pre-potent response reprogramming in elderly adults (e.g., Trewartha et al., 2009; Trewartha, Penhune, & Li, 2011; Trewartha, Spilka, Penhune, Li, & Phillips, 2013). In this paradigm, participants are trained to produce a repeated motor response to a particular stimulus, such that their responses become prepared or programmed in advance (Keele, 1968; Lashley, 1951). Occasionally, a new stimulus is introduced and participants have to suppress the well-learned motor response and reprogram a new one. During this stage, participants need to distinguish between two alternative responses (i.e., pre-potent and new response) and reprogram or revise their motor response to produce compatibility between stimulus and response. Various paradigms (e.g., a stimulus precuing paradigm; a line drawing task) have been used to demonstrate that older adults need more time to reprogram and complete their responses as compared to younger participants (e.g., Amrhein, Stelmach, & Goggin, 1991; Bellgrove, Phillips, Bradshaw, & Gallucci, 1998).

In sum, the extant literature on aging, executive functions, and inhibition or reprogramming, indicate consistent reductions in these abilities, with few exceptions. Notably, most of the commonly used measures of executive functions require speeded motor responses and to some extent, response inhibition or reprogramming. Despite the abundant evidence showing ability dedifferentiation and slowing with age, few studies have been designed to disentangle the relative contributions of motor aging and cognitive aging. The current work therefore addresses this gap.

1.4 Changes in motor performance with aging

Evidence from motor performance and aging research suggests that there is a decline in motor control and performance with increased age (e.g., Ketcham & Stelmach, 2001; Krampe, 2002; Seidler, Bernard, Burutolu, Fling, Gordon, Gwin, et al., 2010; Smith al., 1999). Motor skills can be divided into two groups: gross motor skills, which refer to the larger movements (e.g., arms, legs, or the entire body) and fine motor skills, which refer to smaller actions, (e.g., fingers, lips, or tongue movements). Age-related changes have been observed in both gross motor and fine motor control. For example, Haaland and colleagues (1993) found that older adults were slower compared to younger adults when planning aiming movements. Similarly, with locomotor research, older adults show slower and more variable gait than young adults (Hausdorff, Springer, Simon, & Giladi, 2005; Li, Krampe, & Bondar, 2005; Woollacott & Shumway-Cook, 2002) and these aspects of gait are related to executive functioning (e.g., Stroop interference) suggesting a specific role of executive functions in motor control. Age differences in fine motor performance were observed in visual-motor sequencing tasks (e.g., Howard &

Howard, 1989, 1992), rhythmic tapping tasks (e.g., Krampe, Engbert, & Kliegl, 2001), and dual-task paradigms (Albinet, Tomporowski, & Beasman, 2006; Crossley & Hiscock, 1992; Kemper, Herman, & Lian, 2003). For example, older adults showed greater variability, lower accuracy, and slower performance compared to younger adults on key press performance (e.g., Krampe, 2002; Smith et al., 1999).

One common paradigm to investigate the underlying processes of fine motor performance is the serial reaction time task in which participants are cued to reproduce finger movements (Nissen & Bullemer, 1987; Robertson, Pascual-Leone, & Miall, 2004). Typically, age-equivalent results have been observed over training or learning, in that young and older participants' responses become faster and more accurate over time at similar rates (e.g., Daselaar, Rombouts, Veltman, Raaijmakers, & Jonker, 2003; Howard & Howard, 1989; 1992). In contrast to serial reaction time studies that encourage overlearned or automatic response patterns, age differences are more sizeable when sequential anomalies are introduced, and response reprogramming is needed. As mentioned (Trewartha et al., 2009), we have used a cued finger sequencing task to investigate kinematic measures of motor responses that deviated from the well-learned responses. Under these conditions, motor responses differed significantly between younger and older adults, such that both groups had longer planning time when encountering unexpected stimuli but only the young adults were able to speed up their execution time. These results suggest that the older adults were not able to adjust their execution time, most likely because fine motor and cognitive processes become more interdependent in old age.

1.5 Interdependence between cognitive and motor processes in old age

Numerous studies have shown that motor and cognitive domains become highly integrated and interdependent with increasing age (Li, S.-C. & Dinse, 2002; Li, K. Z. H. &

Lindenberger, 2002), and age-related declines in these domains co-occur. For example, in a study of hand and foot movements, older adults showed increased activation of brain areas associated with both executive and motor processes (i.e., prefrontal, premotor, and pre-supplementary motor area) compared to younger adults (Heuninckx, Wenderoth, Debaere, Peeters, & Swinnen, 2005; Heuninckx, Wenderoth, & Swinnen, 2008).

Further evidence of greater covariation between cognitive and motor tasks with advanced age comes from studies using dual-task paradigms in which participants perform two tasks simultaneously (e.g., Lindenberger, Marsiske, & Baltes, 2000; Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997). Dual-task paradigms are a common method of investigating the interaction between cognitive and sensorimotor processes in old age. To quantify the cost of dividing attention (dual-task cost), participants' performance when performing each task alone (single-task condition) is compared to their performance when performing both tasks simultaneously (dual-task condition). Typical results from both fine and gross motor literatures reveal that older adults experience larger dual-task costs compared to younger adults (Fraser, Li, & Penhune, 2010; Li, Lindenberger, Freund, & Baltes, 2001; Verhaeghen & Cerella, 2002; but see Brauer, Woollacott, & Shumway-Cook, 2001; Hartley & Maquestiaux, 2007). In the gross motor domain, when comparing young and older adults on a dual-task walking and memory task, Lindenberger and colleagues found that older adults showed greater dual-task costs for both memory and walking performance (Lindenberger et al., 2000). In an extension of this study, researchers found that the age differences in dual-task costs were greater for cognitive performance than walking performance (Li et al., 2001). Other studies found that concurrent attentional demands had a larger impact on postural stability and walking in older than in younger adults (e.g., Chen, Schultz, Ashton-Miller, Giordani, Alexander, & Guire, 1996; Maylor & Wing, 1996; Sparrow, Bradshaw, Lamoureux, & Tirosh, 2002).

Studies on fine motor control in elderly adults also show that older adults may be more compromised by concurrent cognitive and motor tasks compared to younger adults. For example, Kemper and colleagues assessed younger and older adults on their ability to repeatedly tap a simple four-finger sequence and simultaneously engage in a speech production task (Kemper et al., 2003). Performance on this task was compared with a simple tapping task or a simple walking task. The largest dual-task costs, favoring the young group, were observed on the sequential tapping task when combined with the speech task, compared with simple tapping or walking tasks. In another study, Crossley and Hiscock (1992) compared young and older adults on their ability to concurrently perform a speeded finger tapping task with a range of cognitive tasks: reading, speaking, and maze-completion. Young and older groups differed in the magnitude of their dual-task costs within the tapping domain, but not within the cognitive domain. The studies reviewed above as well as other aging studies (e.g., Albinet et al., 2006; Fraser et al., 2010) suggest that fine motor task performance declines in advanced age. Age differences observed in studies of fine motor dual tasking suggest that performance of motor tasks in old age may be more attentionally demanding than in earlier years. These results also suggest that motor task performance in older age may require recruitment of additional cognitive resources that are not necessary for younger adults (Li & Lindenberger, 2002; Seidler, et al., 2010).

The foregoing review of cognitive and motor aging suggests a pattern of uniform and interconnected declines in these two domains of functioning. The subset of cognitive processes known as executive functions warrant particular attention given their marked age-related decline and implication in gross and fine motor functioning. Despite the ubiquity of these declines in old age, there exists substantial individual variation in the degree of change. This suggests that external factors, such as lifestyle, occupational experience, or deliberate practice, may contribute to the observed variation in performance levels. The following sections review literature on these protective factors.

1.6 Aging and cognitive enrichment

A number of studies have revealed that older adults who maintain an active lifestyle and engage in intellectually stimulating activities maintain their cognitive abilities and show reduced functional impairment compared to those who are relatively inactive (see Hertzog et al., 2008 for review). An enriched lifestyle may be associated with slower rates of normal age-related brain changes and enhanced levels of cognitive and intellectual functioning (e.g., Hultsch, Hertzog, Small, & Dixon, 1999; Scarmeas & Stern, 2003; Singh-Manoux, Richards, & Marmot, 2003). For example, Scarmeas and colleagues (2001) assessed older individuals who engaged in a variety of activities, including intellectual activities (e.g., reading, playing games, and going to classes), and social activities (e.g., visiting with friends or relatives). It was found that active involvement in these activities protected older adults from earlier onset of pathological changes. Further, engagement in cognitively stimulating activities in older age has been linked to delays in the cognitive changes associated with cognitive impairment or dementia (e.g., Alexander, Furey, Grady, Pietrini, Brady, Mentis, et al., 1997; Fratiglioni, Paillard–Borg, & Winblad, 2004; Middleton, Kirkland, & Rockwood, 2008; Scarmeas, Levy, Tang, Manly, & Stern, 2001; Valenzuela & Sachdev, 2006). The explanation for these finding may rest on the old adage “use it or lose it” (Hultsch et al., 1999). Recently, it has been suggested that music is one of the leisure activities that might delay the onset of age-related cognitive changes (Hanna-Pladdy &

Gajewski, 2012) and decrease the risk of developing dementia (Verghese, Lipton, Katz, Hall, Derby, Kuslansky et al., 2003).

Nested within the literature on general enrichment and engagement effects, the cognitive reserve hypothesis was introduced to explain the observed association between protective effects of enriched lifestyle and better cognitive functioning in the face of neural degeneration in older age (Stern, 2002; 2009). Higher reserve is commonly defined by more years of education, better occupational status, higher premorbid IQ, and greater engagement in mental and leisure activities. Stern (2002, 2009) suggested that cognitive reserve, which encompasses two distinct processes: neural reserve and neural compensation, may explain individual differences in how the brain uses cognitive resources with a goal of maintaining and/or maximizing its function. It has been suggested that more efficient cognitive networks and more flexible network selection are associated with higher neural reserve. By contrast, neural compensation refers to the activation or recruitment of additional brain structures or networks, and utilization of cognitive strategies that are less commonly used by healthy individuals (Stern 2002, 2009; Steffener & Stern, 2012). Together, these processes within the Cognitive Reserve framework offer a model of underlying mechanisms that result in neuroprotective benefits against cognitive decline and impairment.

1.7 Aging and expertise

As previously stated, numerous studies have shown that frequent engagement in cognitively stimulating activities may be associated with preserved cognitive abilities in advanced age (e.g., Wilson, Barnes, & Bennett, 2003; Wilson, Mendes De Leon, Barnes, Schneider, Bienias, Evans, et al., 2002). Nevertheless, research that evaluates what specific skills and/or training might contribute to better cognitive processing in advanced age is relatively limited. In contrast to research on cognitively stimulating or leisure activities, research on expertise investigates the role of deliberate and continued practice of specific skills and its effect on the maintenance of skilled-related and general cognitive performance in advanced age. Two interesting questions might be addressed when investigating the contribution of specific skills to cognitive processes: a) what are specific types of training that might contribute to better cognitive outcomes, and b) does specific expertise lead to preservation in the area of expertise and does it transfer to other functions. A number of studies on cognitive aging and expertise revealed that despite normal age-related decline in various functions, older adults may continue demonstrating enhanced performance in the area of their expertise as well as other cognitive functions (Krampe & Ericsson, 1996).

One of the earliest studies showing an association between expertise and preserved cognitive abilities examined older and younger expert chess players (Charness, 1981). In this study he observed that the quality of chess moves was unrelated to age of the players, but rather their skill level. Despite the fact that older experts generated fewer total moves compared to younger chess players, they selected equally proficient moves. Another study examined younger and older professional typists (Salthouse, 1984). It was observed that although older typists were slower in tasks such as finger-tapping, choice reaction time, and cognitive processing speed, their typing speed was similar to that of younger typists. Moreover, older typists revealed increased attention to characters ahead of the currently typed character (preview span), whereas this compensatory behaviour was not observed in younger typists. The above reported results suggest that although there may be age-related declines in general motor and cognitive processes, older adults may still maintain enhanced cognitive performance in the area of their expertise.

1.8 Musical training, positive aging, and expertise

Another area of expertise that has recently attracted attention is musical experience. In comparison with other areas of expertise, such as typing or chess playing, musical experience involves continuous training of multiple domains such as motor, visual, and auditory. Musical experience may begin very early in childhood and continue across the entire lifespan, unlike other occupational or leisure activities. Much of the work on music and its effects on older adults has focused on frail individuals (for a review see Koger, Chapin, & Brotons, 1999) and less is known about the effects of music on older adults who are healthy. Moreover, the effects of musical expertise have been studied in the domains of social and emotional well-being and auditory processing in older adults (e.g., Hays, 2005; Hays & Minichiello, 2005), but less is known about the effects of musical engagement on general motor processes and cognitive processes that are less closely related to musical skills.

Evidence for music-related changes in brain organization includes the findings that musicians have larger volume of the anterior corpus callosum (Schlaug, 2001), greater grey matter volume in motor and parietal areas (Gaser & Schlaug, 2003), and larger cerebellar volume (Hutchinson, Lee, Gaab, & Schlaug, 2003) compared to non-musicians. Differences in brain structure in the auditory-motor network between musicians and non-musicians have been also observed in numerous studies (for review see Jäncke, 2009; Wan & Schlaug, 2010). Furthermore, at least two research teams have shown that young adult musicians used the underlying network more efficiently by activating the same regions to a much lesser degree (Jäncke, Shah, & Peters, 2000) or by recruiting fewer brain regions for task performance (Chen, Penhune, & Zatorre, 2008) than non-musicians.

Relatively recently, researchers became interested in exploring whether musical activities, such as playing an instrument, listening to music, creating music, dancing, or singing stimulate multiple cognitive functions and lead to brain plasticity. This research is based on the idea that since musical training relies on a number of multisensory domains (e.g., motor, visual, and auditory functions), continuous stimulation of these functions could lead to transfer effects in different brain regions and cognitive domains (Schlaug et al., 2005). Indeed, in musicians, auditory regions were co-activated with premotor regions, suggesting functional interconnection between the two (Chen et al., 2008; Chen, Zatorre, & Penhune, 2006). This increased interconnection between brain areas in individuals with musical experience suggests that expertise may contribute to neuroplastic changes and brain reorganization (Munte, Altenmuller, & Jancke, 2002). Furthermore, it has been shown that in young musicians, musical training was associated with cortical reorganization such as enhanced sensorimotor functions (e.g., Koelsch, Fritz, Schulze, Alsop, & Schlaug, 2005; Peretz & Zatorre, 2005; Zatorre, Chen, & Penhune, 2007). Previous studies have shown that in finger tapping tasks, musicians demonstrated greater synchronization abilities than non-musicians (e.g., Baer, Thibodeau, Gralnick, Li, & Penhune, 2013; Repp, 1999; Chen et al., 2006; 2008).

Neuroimaging studies have shown that musicians have a more developed, specialized neural network that connects auditory and motor brain regions (Bangert & Altenmuller, 2003; Baumann, Koeneke, Meyer, Lutz, & Jäncke, 2005; Baumann, Koeneke, Schmidt, Meyer, Lutz, & Jancke, 2007; Bangert, Peschel, Schlaug, Rotte, Drescher, Hinrichs et al., 2006; Lahav, Saltzman, & Schlaug, 2007; Zatorre et al., 2007; Engel, Bangert, Horbank, Hijmans, Wilkens, Keller, et al., 2012; Engel, Hijmans, Cerliani, Bangert, Nanetti, Keller, et al., 2014). In a study conducted by Bangert and colleagues (2006) it was shown that when listening to a short piece of piano tones professional pianists demonstrated activity in the motor region. These results suggest that auditory information in musicians evoked not only activations in auditory areas but also in brain areas related to movements. The same group of researchers demonstrated that a neural linkage between the auditory and motor cortices could be developed after 20 minutes of piano practice (Bangert & Altenmuller, 2003).

Furthermore, researchers became interested in investigating whether musical experience may be associated with enhanced cognitive performance in nonmusical tasks (e.g., Moradzadeh, Blumenthal, & Wiseheart, 2014; Moreno, Bialystok, Barac, Schellenberg, Cepeda, & Chau, 2011). Most studies investigating this link have been conducted with children and young musicians and have revealed somewhat mixed results with respect to transfer effects from musical training to nonmusical cognitive functions. Ho, Cheung, and Chan (2003) observed enhanced verbal but not visual memory abilities in children with music training. Advantages in spatio-temporal reasoning were observed by a number of different research groups (e.g., Rauscher, Shaw, & Ky, 1995; Rideout & Taylor, 1997). Enhanced abilities were also observed in auditory learning (Fujioka, Ross, Kakigi, Pantev, & Trainor, 2006), visuo-spatial abilities (Brochard, Dufour, & Després, 2004; Rauscher & Zupan, 2000), and general intelligence (Schellenberg, 2004; 2006). Moradzadeh and colleagues (2014) found that musical experience was associated with enhanced executive functioning performance, namely task switching and dual-task performance, in young participants.

In contrast to studies of children and young adults, research on the effects of musical experience on cognitive (as well as other) processes in advanced age is relatively limited. One exception is a recent study in which older adults were classified into three groups: non-musicians - no musical training; low activity - less than 10 years of musical training; and high activity -

more than 10 years of musical experience (Hanna-Pladdy and MacKay, 2011). The results revealed an association between years of musical training and cognitive performance, such that participants from the high activity group demonstrated better performance than non-musicians on a number of cognitive measures (i.e., nonverbal memory, naming, executive processes – Trails A and Trails B) suggesting that musical training may have a general influence on cognition in older age. Interestingly, the findings also suggest that there may be a linear relationship between years of musical training and cognitive performance. Effects of musical experience were also observed in the auditory system of older adults. A number of studies revealed that musical experience might be associated with enhanced central auditory function in advanced age (e.g., Anderson, White-Schwoch, Parbery-Clark, & Kraus, 2013; Parbery-Clark, Anderson, Hittner, & Kraus, 2012; White-Schwoch, Carr, Anderson, Strait, & Kraus, 2013). For example, it was found that older musicians showed enhanced speech-in-noise perception and greater auditory working memory capacity (Parbery-Clark, Strait, Anderson, Hittner, & Kraus, 2011) as well as better detection of mistuned harmonics relative to non-musicians (Zendel & Alain, 2012). As for the cognitive benefits of musical experience, evidence supports the involvement of executive processes in musical performance (e.g., Degé, Kubicek, & Schwarzer, 2011; Pallesen, Brattico, Bailey, Korvenoja, Koivisto, Gjedde, et al., 2010). Moreno and colleagues (2011) observed that children showed improved performance on a go/no-go inhibition task following twenty days of a music-based computerized training program. Goolsby (1994a, 1994b) showed that while reading music, more skilled young sight reader musicians had better control over eye fixations, as compared to less skilled sight readers, presumably demonstrating better ability to monitor and shift attention. In another study, Hall and Blasko (2005) used an attentional interference task (i.e., monitoring, identifying and ignoring sounds) and found that the ability to respond to the incongruent trials (mismatch conditions when different instruments were heard) increased with the number of years of musical experience. Evidence linking musical experience with executive functioning was also observed in a study of young adults, where musicians outperformed non-musicians on several selective-attention tasks that required participants to ignore conflicting information, but showed no effects of musical experience on the baseline conditions (Bialystok & DePape, 2009). Similarly, Jentzsch and colleagues (2014) reported that young instrumental musicians were better able to detect errors than non-musicians in a simple conflict task. They also observed that high levels of musical experience were associated with more efficient responses when adjusting behaviours following conflicts. Zuk and colleagues (2014) observed that adult musicians demonstrated enhanced performance on measures of executive functioning such as cognitive flexibility, working memory, and verbal fluency compared to non-musicians. They also found that children with musical experience showed enhanced performance on measures of verbal fluency and processing speed compared to children without musical experience. Moreover, during task-switching performance children with musical experience demonstrated greater activation in the pre-supplementary area and the ventrolateral prefrontal cortex, which are associated with executive functioning performance, compared to non-musically trained children.

Although less is known about a link between musical experience and executive functioning in older adults, a few research groups have investigated this potential link (e.g., Amer, Kalender, Hasher, Trehub, & Wong, 2013; Hanna-Pladdy & Gajewski, 2012; Hanna-Pladdy & MacKay, 2011). It was found that older amateur musicians outperform non-musicians on tasks including speech perception in noise and auditory working memory (Parbery-Clark, Strait, Anderson, Hittner, & Kraus, 2011; Zendel & Alain, 2012). Similarly, in a six-month training study, Bugos and colleagues (2007) observed that older adults who underwent piano training showed significant improvements on tests of executive functioning such as the Trail Making Test and Digit Symbol test. Amer and colleagues (2013) compared older professional musicians and non-musicians on a near-transfer task, which assessed speed of auditory processing and auditory conflict resolution, and several far-transfer tasks, which included tasks assessing visuospatial memory span, conflict resolution and control over competing responses (Simon task), response inhibition (Go/No-Go), and control over distraction (reading with distraction). Interestingly, it was found that although musicians outperformed non-musicians on the near-transfer task, on the far-transfer tasks they outperformed non-musicians on most but not all of the far-transfer tasks (i.e., visuospatial span, conflict resolution, and control over distraction, but no reliable differences on the Go/No-Go task).

To summarize the extant work on aging, cognitive enrichment, and musical experience, there is general agreement that activities that enable older adults to repeatedly practice or exercise specific skills can serve to protect against or slow age-related cognitive decline. Generally, the scope of the observed benefits is constrained by the skill set associated with the activity (e.g., chess expertise strengthens visual-spatial memory but not verbal memory). The multi-faceted nature of musical engagement may be an exception to this pattern, given the requirements of divided attention, coordination, selective attention, and sensory-motor integration. The few studies of musical engagement and cognitive aging suggest potential for broader transfer of musical practice to higher order cognitive processes that are not specific to musical performance, such as executive functions. If so, musical experience may be a promising form of cognitive enrichment to examine in relation to fine motor response reprogramming.

1.9 Current studies

Taken together, limited studies on motor response reprogramming, as well as adaptation to conflicting stimuli, have revealed that older adults may experience more difficulties when reprogramming fine motor responses as compared to younger adults. However, previous studies have rarely considered the joint contribution of cognitive and motor aging to fine motor performance, despite evidence of increasing ability dedifferentiation and evidence of increasing involvement of compensatory executive control processes in old age. The current studies were designed to address this omission using methodology that enables the separate measurement of cognitive and motor efficiency within a response reprogramming task. In addition to examining how cognitive and/or motor declines might affect fine motor reprogramming, it is worth considering protective factors that might enhance, rather than disrupt, task performance. Musical experience appears to be a promising approach, given the noted advantages it confers to executive functions and neuroplastic changes associated with cognitive control networks. Therefore, a second aim was to examine the association of musical experience and the cognitive and motoric components of fine motor reprogramming performance.

To summarize, this dissertation includes three research studies that were designed to investigate the production of fine motor movements and reprogramming abilities of older adults, as well as the association of musical expertise and these processes. All studies used modified versions of the multi-finger sequencing task that were previously developed and used in our laboratory (Trewartha et al., 2009; 2011). In all three studies a 3D motion capture system was used to decompose finger movements into cognitive and motoric components (planning and motor execution times). The first study aimed to investigate the effect of attentional load on motor reprogramming in both young and older participants. The main underlying assumption of this study was that executive and motor control mechanisms become more interconnected in the process of reprogramming fine motor responses. To investigate this assumption, the basic motor task was paired with a serial subtraction task in a dual-task paradigm. It was expected that young adults would demonstrate compensatory hastening under single-task conditions when reprogramming motor responses, but dual-task conditions would compromise their ability to reprogram responses. It was further expected that older adults would not show evidence of compensatory hastening under either full attention or divided attention conditions. The second study used the same dual-task motor paradigm to investigate whether musical engagement interacts with cognitive and fine motor reprogramming abilities in later life. It was expected that older adults with musical experience would demonstrate better fine motor reprogramming abilities compared to older adults without musical training. The third study used a modified reprogramming task to further investigate the association of musical training and the ability to adapt to conflict over repeated exposures. It was expected that older adults with musical experience would derive greater benefit from repeated exposure to conflicts compared to older adults without musical training.

Chapter 2: Effects of age and cognitive load on response reprogramming

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2.1 Abstract

A dual-task paradigm was used to examine the effect of cognitive load on motor reprogramming. We propose that in the face of conflict, both executive control and motor control mechanisms become more interconnected in the process of reprogramming motor behaviors. If so, one would expect a concurrent cognitive load to compromise younger adults' (YAs) motor reprogramming ability, and further exacerbate the response reprogramming ability of older adults (OAs). 19 YAs and 14 OAs overlearned a sequence of key presses. Deviations of the practiced sequence were introduced to assess motor reprogramming ability. A Serial Sevens Test was used as the cognitive load. A 3-D motion capture system was used to parse finger movements into planning and motor execution times. Global response time analysis revealed that under single-task conditions, during pre-potent transitions OAs responded as quickly as YAs, but they were disproportionately worse than YAs during conflict transitions. Under dual-task conditions, YAs performance became more similar to that of OAs. Movement data were decomposed into planning and movement time, revealing that under single-task conditions, when responding to conflicting stimuli YAs reduced their movement time in order to compensate for delayed planning time; however, additional cognitive load prevented them from exhibiting this compensatory hastening on conflict transitions. We propose that age-related declines in response reprogramming may be linked to reduced cognitive capacity. Current findings suggest that

cognitive capacity, reduced in the case of OAs or YAs under divided attention conditions, influences the ability to flexibly adapt to conflicting conditions.

2.2 *Introduction*

Many everyday activities involve the ability to suppress responses that are inappropriate or no-longer required. For example, one must resist the tendency to walk a straight path if an obstacle appears ahead. Generally, response suppression is necessary to flexibly adapt our behaviours to changing environments (Verbruggen & Logan, 2009). Research in aging and response suppression indicates moderate to substantial declines across a variety of paradigms (McDowd & Shaw, 2000). A less frequently studied aspect of response suppression involves the revision of a prepared action, or response reprogramming. In general, older adults have shown more difficulty reprogramming well-learned responses compared to young adults. We have recently argued that age-related declines in reprogramming are attributable to aging of executive control mechanisms (Trewartha et al., 2009). However, because older adults may have less efficient cognitive control processes as well as diminished motor skills, the challenge remains to disentangle the concurrent contributions of cognitive and motor aging. In the current study, we used a dual-task paradigm to simulate the effects of reduced cognitive capacity in young participants and compared their performance with that of older adults. Based on the view that motor performance in old age is increasingly reliant on cognitive control processes, we expected that increased cognitive load would hinder young adults' ability to reprogram their well-learned motor responses and further exacerbate the response reprogramming ability of older adults.

2.2.1 Aging and response suppression

Response suppression has been included as a component of several major theories of inhibition (e.g., Hasher et al., 1999) and executive function (e.g., Miyake et al., 2000), and in general entails the avoidance of a familiar or pre-potent response. Among the tasks commonly used to investigate response suppression are the Stroop test (Stroop, 1935) and the Hayling test

(Burgess and Shallice 1996b). In the Stroop test, the interference condition requires participants to name the color of the printed words, which are incongruent color names (e.g., GREEN printed in red ink). In the Hayling test, participants complete sentences by saying the sentence-final word, but must not produce the expected completion. The evidence from a variety of response suppression paradigms indicates a decline in performance with aging (e.g., Andrés, Guerrini, Phillips, & Perfect, 2008; Bielak, Mansueti, Strauss, & Dixon, 2006; Earles, Connor, Frieske, Park, Smith, & Zwahr, 1997; Kramer, Humphrey, Larish, & Logan, 1994).

Response reprogramming is a related but less commonly studied aspect of response suppression. In this type of paradigm, participants are instructed to carry out a repeated motor response to predictable stimuli, but must occasionally revise their responses and reprogram new responses. Across a variety of reprogramming paradigms, older adults generally need more time to reprogram their motor movements compared to younger adults (e.g., Amrhein et al., 1991; Bellgrove et al., 1998). While at first glance, response inhibition studies appear to engage similar processes, it is possible that response reprogramming requires even more cognitive control than simple suppression paradigms due to the additional need to activate a new motor program.

2.2.2 Motor and cognitive interactions in old age

The involvement of cognitive control processes in motor performance has been an important theme in aging research. The shared variance between cognitive and sensory/ sensorimotor performances has been shown to increase with chronological age (e.g., Lindenberger & Baltes, 1997). Correlational studies demonstrate that gait characteristics (variability, speed) and falls frequency are significantly correlated with higher-level cognitive functions such as Stroop interference (e.g., Hausdorff, Yogev, Springer, Simon, & Giladi, 2005; Holtzer, Verghese, Xue, & Lipton, 2006). Similar conclusions are found in experimental studies of dual-task performance whereby participants perform the motor and cognitive tasks separately and concurrently, and dual-task costs are calculated by comparing single- and dual-task scores. If cognitive control processes play a greater role in motor performance with aging, one would predict that a concurrent cognitive load would exacerbate the age differences observed in motor task performance. Accordingly, it has been shown that older adults frequently show greater dual-task performance costs compared with younger adults in studies of dual-task gait or balance (Li et al., 2001; Lindenberger et al., 2000; Woollacott & Shumway-Cook, 2002; Yogev-Seligmann, Hausdorff, & Giladi, 2008). Investigations of dual-task fine motor performance reveal parallel findings. For instance, Fraser, Li, and Penhune (2010) compared healthy young and older adults on a visuo-motor finger tapping task paired with a concurrent subtract sevens task. Overall, older adults showed greater motor dual-task costs than younger adults.

2.2.3 Executive control and motor reprogramming in old age

We have investigated the role of executive control processes on response reprogramming using a cued finger-sequencing task (Trewartha et al., 2009; 2011; 2013). Healthy young and older adults are first trained on a specific pair of key-presses to create a pre-potent response. In the test phase, these pre-potent response sequences are occasionally violated with unexpected changes (conflict transitions) to assess the efficiency of response reprogramming as compared to pre-potent responses. To examine the joint contributions of cognitive control and motor processes we have used motion tracking to decompose task performance into broadly cognitive (planning) and movement (execution) components. Planning time is measured from stimulus onset to movement initiation. Execution time is measured from movement initiation to termination of the key press. Across several data sets, both older and younger adults showed longer planning times when responding to conflict transitions as compared to pre-potent transitions. Presumably this delay reflects the reprogramming requirements of the conflict transitions. Importantly, on conflict transitions, only young adults have shown faster execution times than on pre-potent transitions, suggesting a form of compensatory hastening to recover from the delayed planning time. Under the most simple version of this paradigm, Trewartha and colleagues (2009) reported that older adults showed no difference between executing movements of pre-potent and conflicting responses, suggesting that conflict processing declines with age. In a more complex version of the same paradigm with a variable number of transitions per trial, Trewartha and colleagues (2011) observed that older adults were differentially slowed during conflict transitions as compared to pre-potent conditions, whereas young adults continued to show the compensatory hastening effect.

We have interpreted our findings in the context of the age-related decline of cognitive control mechanisms such as working memory updating (e.g., Trewartha et al., 2013). However, it remains an open question as to whether age changes in basic motor processes also contributed to the older adults' inability to speed their movements when necessary. It has been well documented that advanced age is associated with general movement slowing in the context of reaching and grasping (Bennett & Castiello, 1994; Carnahan, Vandervoort, & Swanson, 1998) and continuous movements (Greene & Williams, 1996). Fast twitch muscles are significantly reduced with advanced age (Lexell, 1996), which affects voluntary strength and capability of full muscle activation in older adults (Yue, Ranganathan, Siemionow, Liu, & Sahgal, 1999), and muscle loss is one of multiple factors that contribute to motor decline in healthy aging (Ketcham & Stelmach, 2001).

Given that aging is associated with significant declines in motor functioning, it is difficult to dissociate the behavioral effects related to motor aging from those related to cognitive aging.

To avoid this issue, our approach in the present work was to simulate the effects of cognitive aging in healthy young participants, who are presumably at peak motor functioning. We paired our previously used motor reprogramming task with a concurrent cognitive task requiring working memory updating. A comparison sample of older adults underwent the same protocol. We reasoned that if, under dual-task conditions, young adults demonstrated reduced ability to flexibly adapt to conflicting conditions, this would support the interpretation that our previously observed age differences were due to reduced cognitive capacity more so than reduced motor abilities. We hypothesized that under full attention conditions, younger adults would demonstrate longer planning times when facing conflicting stimuli, but faster executions of finger movements to compensate for longer planning times, as compared to highly practiced motor responses. We also hypothesized that with the addition of a concurrent working memory load, younger adults' ability to compensate for longer planning times would decrease. Finally, we expected older adults to show no evidence of compensatory hastening in either their single-task or dual-task motor performance.

2.3 Methods

2.3.1 Participants

Nineteen young adults (19 - 29 years; female *n* = 17, male *n* = 2) and 14 older adults (63 - 74 years; female *n* = 8, male *n* = 6) were tested. To control for the effects of musical experience on task performance, all participants were selected to have less than three years of musical experience and no practice in the last 10 years. Participants were right-handed and were free from any medication, neurological disorder, or injury that could affect sensory, motor or cognitive functioning. Young participants were recruited from the Concordia University Participant Pool and received course credits. Older participants were recruited from a preexisting senior participant database at Concordia University and received a small honorarium. All participants provided written informed consent prior to the testing session, in compliance with the Concordia University Human Research Ethics Committee.

2.3.2 Materials and apparatus

2.3.2.1 Neuropsychological measures

To assess whether groups differed on basic cognitive abilities, a battery of neuropsychological tests was administered. The Digit Symbol Substitution subtest of Wechsler Adult Intelligence Scale IV (Wechsler, 2008) was used to measure processing speed, with the total number of correct items completed as the dependent measure. The Stroop test (adapted from Spreen & Strauss, 2001), forms C and CW, was administered to assess controlled attention. The difference between the seconds per item completed on the Congruent and Incongruent conditions was used as a dependent measure. To assess task switching, the Comprehensive Trail Making Test (Reynolds, 2002) was administered. The difference between the complex and simple task conditions was used as the dependent measure.

2.3.2.2 Cognitive task

For the concurrent cognitive task we used the Serial Sevens Test (SST), a measure of attentional control with a relatively high processing load (Lezak, Howieson, Loring, Hannay, & Fischer, 2004). Serial subtraction has been commonly used as attention demanding cognitive load in gait, balance and aging studies (e.g., van Iersel, Ribbers, Munneke, Borm, & Rikkert, 2007; Springer, Giladi, Peretz, Yogev, Simon, & Hausdorff, 2006; Yogev, Giladi, Peretz, Springer, Simon, & Hausdorff, 2005). The Serial Sevens Test (SST) was given to our participants to occupy working memory and mimic age-related reductions in the cognitive capacity available for motor performance. In the current experiment, the SST was performed without auditory or visual cues, thereby placing continuous demands on working memory and updating. Throughout the experiment, participants completed two blocks of single cognitive tasks and one block in which they performed the cognitive and motor tasks concurrently (dual-task condition). Each cognitive block consisted of six trials. At the start of each trial, participants were told a randomly generated number between 86 and 99, and instructed to subtract 7 from the given number, and continue subtracting 7 from successive answers until told to stop. The duration of each trial was 16 seconds, matching the duration of each motor sequence trial. Participants' responses were reported verbally and recorded by hand. Cognitive task performance was defined as the percentage of correctly subtracted responses per trial. The same cognitive task was performed under single- and dual-task conditions.

2.3.2.3 Motor sequence task

We used a very similar finger sequencing paradigm to the one described by Trewartha and colleagues (2009) for both single-and dual-task conditions. Participants were instructed to reproduce sequences of key presses that were cued by visual stimuli presented on a computer monitor using four fingers of their right hand (Figure 2.1).

A custom-built keyboard with four keys was used for this task. The keyboard was designed to mimic the physical characteristics (height, length, width, resistance, spacing) of a standard midi-keyboard (Yamaha PSR-290). Pieces of Velcro were attached to the keys as tactile cues for finger positioning. The visual stimuli consisted of four squares (3” x 3”) that were displayed horizontally on the computer monitor (17" flat screen). The squares mapped in a one-to-one manner onto each of four fingers (from left to right) and changed colour from grey to pink to cue the participant to respond with a particular finger. Each visual cue was shown for 800 ms and replaced by the next cue, so that each trial (20 stimuli) lasted for a total of 16000 ms. There was a pause between each trial of 3000 ms.

A 3-D motion capture system (VZ3000; Phoenix Technologies, Burnaby, British Columbia, Canada) was used to record the x, y, and z positions of each finger with an acquisition rate of 50 Hz and one light-emitting diode (LED) marker attached to each relevant finger nail. The stimulus presentation software (Inquisit 3.0.4.0 Millisecond Sofware LLC. Seatle, WA) was used to send the stimulus triggers, which were activated by each key press to a data acquisition (DAQ) card (NI USB-6221 BNC, National Instruments Inc.). A program written in C# on version 1.1 of the Microsoft.NET Framework was used to synchronize the motion capture data with the visual stimuli.

2.3.3 Motor task design and procedure

The motor sequence task consisted of a familiarization phase and an experimental phase. In the familiarization phase, the goal was to confirm that participants were comfortable with the apparatus and stimuli. In the experimental phase, the goal was to first build up the prepotent sequential response and then assess motor reprogramming when the sequences were perturbed. Accordingly, each motor performance block in the experimental phase was split into Learning and Test phases. To assess the effects of cognitive load, participants were presented with separate blocks of single- and dual-task trials.

2.3.4 Familiarization phase

The participants were first introduced to the motor apparatus by completing a simple 24-element fixed sequence (1, 2, 3, 4, 1, 2, 3 . . .). To practice responding to unpredictable sequences, they then completed 10 trials of 10 random elements each. In keeping with Trewartha et al’s. (2009) procedures, participants had to achieve 85% accuracy on the 10 random trials before advancing to the experimental phase. All participants met this criterion.

2.3.5 Experimental phase

Participants completed a block of single cognitive trials followed by a block of single motor trials, or vice versa. The order of the motor and cognitive single blocks was counterbalanced across participants. Following the single blocks, the dual-task condition was administered. Finally, another block each of single cognitive and single motor trials was administered to reduce the potentially confounding effects of practice and fatigue. The first trial of each block in the experimental phase was not scored to reduce the influence of transitioning from one task to another in the data.

Each motor block was sub-divided into six Learning and six Test trials. In each Learning trial, participants were visually cued to produce repeated pairs of the same key presses (e.g., 2, 1, 2, 1 . . .), totaling 20 stimuli per trial. Participants were assigned the same pre-potent pairs for the entire experiment, and this assignment was counterbalanced across participants in each age group. The Test trials contained a mixture of pre-potent and conflicting pairs. Conflicting response pairs started with the first key-press of the over-learned pair (e.g., “2”) followed by a conflicting cue (e.g., “3” instead of "1"). Within each conflict transition, the first stimulus was the same as in the pre-potent transition, but the second stimulus was unexpected, thus when responding to the unexpected stimuli participants had to suppress their overlearned behaviour. Each Test trial contained two pairs of pre-potent transitions (e.g., 2, 1 . . . 2, 1 . . .), two pairs of conflict transitions (e.g., 2, 3 . . . 2, 3 . . .), and 12 random filler stimuli (e.g., 4). The position of filler stimuli was counterbalanced across trials.

2.3.6 General procedure

Participants first completed a written consent form and the battery of neuropsychological tests. They then completed the Familiarization and Experimental phases of the motor sequence task. They were allowed short breaks in between each block. Finally, participants were debriefed and given course credit or an honorarium. Each session lasted approximately 90 minutes.

2.4 Data analyses

2.4.1 Motor task pre-processing

The second key press of each pair was used to calculate the measurements for pre-potent and conflict transitions. For each transition type, we calculated accuracy as the percentage of correct key presses out of the total number of key presses. If the key presses were made to the appropriate stimuli within the inter-stimulus intervals, then responses were considered correct. Global response times (RT) were defined as time from stimulus onset to the completion of the key press for correct responses. We further decomposed global RT into planning and execution times to better understand the relative contributions of cognitive (conflict detection, reprogramming) and motor (movement execution) processes.

The kinematic data were analyzed using a custom-written function in Matlab (2007a, The Mathworks Inc. Natick, Massachusetts). To extract planning (stimulus onset to movement onset) and execution time (movement onset to minimum key depression) parameters from the motion capture data, we identified the finger movement initiations and key-press terminations using a peak identification algorithm. To control for individual and age differences, each participant's own performance was used as a baseline in all algorithms. The identification algorithm was based on rate of change from the baseline in the vertical (z) dimension of the signal. To calculate the baseline, the data were centered around zero by means of low frequency removal and subtraction of a robust least squares fit of the data from the raw signal (see Trewartha et al., 2009).

For all cognitive and motor task variables, we used a 3 *SD* cutoff to define outliers within each age group. No such outliers were found. To analyze the cognitive accuracy data, we used a mixed factorial ANOVA with cognitive load (single-task vs. dual-task) and age group (young - YAs, older - OAs) as factors. To analyze motor task performance, four dependent variables (accuracy, global RT, planning time, and execution time) were subjected to a 2 x 2 x 2 Cognitive Load (single- vs. dual-task) x Transition Type (pre-potent vs. conflict transitions) x Age Group (YAs vs. OAs) mixed factorial ANOVA design. Bonferroni corrections were applied to all post hoc contrasts. As done previously (Trewartha et al., 2009; 2011), we compared pre-potent transitions during the learning phase with conflict transitions during the test phase, reasoning that the pre-potent transitions from the learning phase represent optimal performance that is free of interference from conflicts. Planning times and execution times were calculated for the correct key presses only.

2.5 Results

The main goal of this study was to explore the involvement of executive control mechanisms in adaptation or reprogramming of fine motor responses. As a preliminary check, we examined the neuropsychological data for outliers. Performance on all neuropsychological tests was within age-normative ranges (see Table 2.1).

2.5.1 Cognitive accuracy

Mean values and standard deviations for single- and dual-task performance on the SST are shown in Table 2.2. The mixed factorial ANOVA comparing age group (younger adults vs.

older adults) x attentional load (single-task vs. dual-task) revealed a significant main effect of attentional load, $F(1, 31) = 17.84$, $p < .001$, $\eta^2 = .365$ ($M_{YA} = 4.68$, $SEM = 3.78$; $M_{OA} = .37$, $SEM = .28$). There was a statistical trend toward a significant interaction between attentional load and age group, $F(1, 31) = 3.36$, $p = .077$, $\eta^2 = .098$. The age group effect was not statistically significant, $p = .374$. Current results suggest that participants did not reach a performance ceiling or floor with respect to the total number of correctly subtracted numbers, meaning that the task was relatively difficult for both age groups and created adequate loading on working memory (see Table 2.2). Similar to other studies (e.g., Fraser, Li, DeMont, & Penhune, 2007; Fraser et al., 2010), the dual-task effects were observed primarily in the motor task. This lack of an age group by attentional load interaction in the cognitive data allows for a clearer interpretation of any age effects in the movement data.

2.5.2 Key-press accuracy

We first confirmed that all participants were more than 85% accurate on the motor task by the end of the practice phase. Participants' motor accuracy during simple practice ranged from 90% to 98%, suggesting that all participants began the experimental phase at a relatively equal skill level. In the omnibus analysis of test phase accuracy scores (see Table 2.2), a significant main effect of cognitive load was observed, $F(1, 31) = 4.61$, $p = .04$, $\eta^2 = .13$, such that overall, participants were more accurate on the motor task under single-task conditions ($M = .858$, $SEM = .026$) than dual-task conditions ($M = .794$, $SEM = .027$). All other main effects and interactions were non-significant (ps $\geq .135$). The lack of significant age effects or interactions in the motor accuracy data reflects the very accurate performance on the motor task overall, replicating earlier work (Trewartha et al., 2009).

2.5.3 Global response time

We next examined global response times to assess whether young adults were more efficient than older adults at motor reprogramming overall. Mean values and standard deviations for single- and dual-task performance are shown in Table 2.2. We conducted an ANOVA using the mean reaction time (RT) in milliseconds. The Age Group x Attentional Load x Transition Type mixed factorial ANOVA revealed a significant main effect of attentional load, $F(1, 31) = 26.23$, $p < .001$, $\eta^2 = .458$, such that performance on the motor task was longer under dual-task conditions than under single-task conditions. A significant main effect of transition type was observed, $F(1, 31) = 106.13$, $p = < .001$, $\eta^2 = .774$, showing that reaction time for conflict transitions was longer than for pre-potent transitions. A trend towards statistical significance was observed in the interaction of attentional load and transition type, $F(1, 31) = 3.31$, $p = .078$, $\eta^2 = .097$. This two-way interaction was qualified by a significant interaction of attentional load, transition type, and age group, $F(1, 31) = 6.02$, $p = .020$, $\eta^2 = .163$. All other main effects and interactions were non-significant (ps $\geq .12$).

To explore the above three-way interaction, we conducted separate ANOVAs for the two attention conditions (single-, dual-task) with age group and transition type as factors. Under single-task conditions, a statistically significant main effect of age group was observed, $F(1, 31) = 6.59$, $p = .015$, $\eta^2 = .175$, showing larger response time for OAs (*M* = 460.02 ms, *SEM* = 16.21) than for YAs (*M* = 405.20 ms, *SEM* = 13.91). A significant main effect of transition type was observed, $F(1, 31) = 80.42$, $p = < .001$, $\eta^2 = .722$, showing that responses were slower for conflict (*M* = 510.07 ms, *SEM* = 8.20) than for pre-potent transitions (*M* = 355.15 ms, *SEM* = 15.61). Importantly, the interaction of age group and transition type was also statistically significant, $F(1, 31) = 8.46$, $p = .007$, $\eta^2 = .214$, such that OAs had longer response times than

YAs for the conflict transitions, *t*(31) = -6.41, $p = < .001$, whereas no age differences were found for the pre-potent transitions, *t*(31) = -.13, $p = .898$. This indicated that despite age-equivalent baseline performance on the pre-potent transitions, the presence of conflict was much more challenging for OAs than YAs.

Under dual-task conditions, we observed a statistically significant main effect of age group, *F*(1, 31) = 15.96, $p = < .001$, $\eta^2 = .34$, where OAs showed slower response times (*M* = 561.22 ms, *SEM* = 19.39) compared to YAs (*M* = 459.13 ms, *SEM* = 16.65). Similarly, the transition type main effect was also significant, *F*(1, 31) = 37.51, $p = < .001$, $\eta^2 = .547$, indicating that response time across pre-potent transitions was faster (*M* = 454.75 ms, *SEM* = 18.51) than across conflict transitions (*M* = 565.60 ms, *SEM* = 12.16). However, no significant interaction was observed, $p = .615$.

The above results suggest that under single-task conditions OAs were disproportionately worse than YAs when conflict transitions were presented despite responding as quickly as YAs during pre-potent transitions. The absence of a significant age group x transition type interaction under dual-task conditions suggests that YAs response reprogramming performance became more similar to that of OAs. To further investigate the efficacy of motor reprogramming processes as a function of aging, the key press data were decomposed into cognitive and motor components (planning and execution times) and examined separately.

2.5.4 Planning time

A similar ANOVA was conducted to evaluate the effects of age, cognitive load, and transition type on planning time (Figure 2.2a). We expected OAs to exhibit longer planning times than YAs, and to be disproportionally affected by the cognitive load manipulation. As predicted, we observed a significant main effect of cognitive load, *F*(1, 31) = 27.31, $p < .001$, η^2

= .468, such that overall planning time was longer under dual-task conditions (*M* = 273.90 ms, *SEM* = 9.62) than single-task conditions (*M* = 214.72 ms, *SEM* = 9.27). Further, a significant main effect of transition type was observed, $F(1, 31) = 98.51$, $p < .001$, $\eta^2 = .761$, such that planning times were longer for conflict transitions (*M* = 307.78 ms, *SEM* = 8.18) than pre-potent transitions (*M* = 180.83 ms, *SEM* = 11.37). Also as predicted, a significant interaction of cognitive load and age group was observed, $F(1, 31) = 7.24$, $p = .011$, $\eta^2 = .189$. Post-hoc contrasts indicated that YAs were unaffected by cognitive load, $F(1, 18) = 3.28$, $p = .087$, $\eta^2 = .154$, whereas OAs were substantially affected, $F(1, 13) = 34.65$, $p < .001$, $\eta^2 = .727$, such that planning times were longer under dual-task (*M* = 347.80 ms, *SEM* = 15.92) than single-task conditions (*M* = 258.13 ms, *SEM* = 6.38). All other main effects and interactions were non-significant (*p*s ≥ .181).

2.5.5 Execution time

A final ANOVA was carried out using the execution time data (Figure 2.2b). Based on the assumption that a concurrent cognitive load would mimic the effects of cognitive aging in the YAs, we predicted that under dual-task conditions, YAs would be less able to hasten their execution times during conflict transitions, relative to their single-task performance. The analysis revealed a marginally significant main effect of cognitive load, $F(1, 31) = 3.43$, $p = .074$, $\eta^2 = .099$, such that execution times were longer under dual-task (*M* = 236.27 ms, *SEM* = 10.94) than under single-task conditions (*M* = 217.89 ms, *SEM* = 5.77). We also found a significant interaction of transition type and age group, $F(1, 31) = 8.19$, $p = .007$, $\eta^2 = .209$, which, importantly, was qualified by a significant interaction of cognitive load, transition type, and age group, $F(1, 31) = 6.25$, $p = .018$, $\eta^2 = .168$. All other main effects and interactions were non-significant (*ps* ≥ .25). To examine the 3-way interaction, we conducted post-hoc contrasts between transition types for each age group. Under single-task conditions, YAs' execution time for conflict transitions was significantly shorter than for pre-potent transitions, $t(18) = 2.66$, $p = .016$, replicating previous work (Trewartha et al. 2009). Importantly, under dual-task conditions, YAs' execution times for conflict transitions and pre-potent transitions were not significantly different, $t(18) = 0.85$, $p = .404$, as we had predicted.

Unlike the YAs, the analysis of the OAs execution time data revealed an inability to speed up their movements during conflict transitions even under single-task conditions. Instead, OAs exhibited significantly slower execution times on conflict transitions than on pre-potent transitions, $t(13) = -3. 69$, $p = .003$. Furthermore, in the dual-task condition, similar to YAs, OAs showed comparable execution times in conflict and pre-potent transitions, $t(13) = -0.61$, $p = .553$.

2.6 Discussion

The primary purpose of this study was to investigate the role of executive control processes in response reprogramming using a dual-task paradigm. In our previous studies (Trewartha et al., 2009; 2011; 2013), we observed that young adults, but not older adults, sped up their movement times to compensate for longer planning times when unexpected stimuli were encountered. To disentangle the relative contributions of cognitive and motor aging we used a simulation approach to selectively limit the cognitive resources of young adults available during motor task performance, while leaving motor capacity intact. The principle finding of this study is that under full attention conditions, young adults reduced execution time of their finger movements for conflict compared to pre-potent transitions, but with the addition of a concurrent working memory load, this compensatory hastening effect was reduced. In contrast, older adults did not show any evidence of compensatory hastening. Together, our results suggest that age-related declines in response reprogramming are highly related to cognitive control resources, and independent of declines in motor functioning in aging.

The current behavioural findings fit into the general pattern of results observed in our recent work (Trewartha et al., 2011; 2013), which showed compensatory hastening (faster execution time in conflict transitions than in pre-potent transitions) for young adults, but slower execution in the older adults on conflict transitions than on pre-potent transitions. We note that our current findings differ slightly from those of Trewartha and colleagues (2009), where older adults spent the same amount of time executing movements for both pre-potent and conflicting responses under single-task conditions. To determine how representative this currently observed slowing pattern was, we visually inspected the individual condition means of the older participants. We found only three participants who showed numerically longer execution times in the conflict transitions relative to pre-potent transitions. The majority of our older participants seemed to follow the pattern observed in Trewartha and colleagues (2009). Moreover, there did not seem to be any systematic differences in those three participants in terms of their chronological age or neuropsychological profiles. Overall, these findings replicate well the older adult data from different versions of this paradigm in that in no cases did we observe systematic hastening in the same way as has been observed in multiple samples of young adults (Trewartha et al., 2009; 2011; 2013).

Our present results complement recent findings from our group in which we combined the same kinematic measurement of response reprogramming with event-related potential (ERP) recordings (Trewartha et al., 2013). There, young adults produced larger P3b amplitudes (central posterior P300 components) than older adults in response to the conflict transitions, and these amplitudes correlated with the magnitude of the hastening effect. In other literature, the P3b component has been associated with processes contributing to updating working memory (Polich, 2007). On a behavioral level, the anticipated (pre-potent) motor program must be rapidly revised, or updated, in order to correctly respond to conflict stimuli. Given that our concurrent cognitive task (SST) also requires memory updating (participants continually subtract 7 from the most recent product), the dual-task condition likely created competition for similar updating processes used during compensatory hastening in the motor task. To generalize these findings, future work may involve other concurrent updating tasks such as the n-back working memory task (Dobbs & Rule, 1989).

The current study extends what is known about aging and response inhibition in several important ways. Beyond replicating other work that shows age-related declines in response inhibition (Kramer et al., 1994; Williams, Ponesse, Schachar, Logan, & Tannock, 1999), ours is one of few studies employing motion tracking methods to isolate planning and motor execution times (Potter & Grealy, 2006). In Potter and Grealy's study, pre-potent grasping movements were occasionally interrupted by a requirement to revise the grasping trajectory. Those researchers reported disproportionately delayed planning time in older adults under conflicting conditions, however they did not report any evidence of compensatory hastening, perhaps because the movements in their task were more novel than in ours.

Our findings also extend current knowledge about the inter-dependence of sensorimotor and cognitive functions in old age by identifying a potential source of cognitive-motor interference at the process level (i.e., working memory updating). Observations of age-related increases in dual-task costs during sensory or motor performance suggest that advanced age is associated with an increase in shared resources (e.g., Li & Lindenberger, 2002; Schneider & Pichora-Fuller, 2000). When faced with increased task complexity, such as concurrent task performance, older adults may experience competition for scarce resources, hence greater dual-task costs. Our findings implicate working memory updating as a candidate “scarce resource” that is shared across tasks in the current study. These results fit broadly with functional neuroimaging studies of coordinated movements (Heuninckx et al., 2005) and response inhibition (Nielson et al., 2002) that show age-related increases in recruitment of frontal lobe regions associated with cognitive control processes (for a review: Seidler et al., 2010). At the same time, because cognitive control processes decline in healthy aging, the potential for compensatory cognitive recruitment during motor task performance is likely to be limited, as demonstrated behaviorally in the present study. Another possibility to consider in future work is that present results are due to the weakened connection or integration between cognitive and motor processing areas (Salek, Anderson, & Sergio, 2011), rather than the age-related decline of frontal lobe functions.

In summary, the current results extend our understanding of the motor-cognitive interaction associated with aging, and more specifically, the processes underlying age differences in response reprogramming. Specifically, our results suggest that working memory updating processes contribute to motor reprogramming and successful compensatory hastening of movement times, in line with recent electrophysiological evidence (Trewartha et al., 2013). Taken together, the findings generally suggest that in addition to diminished neuromuscular capacity, age-related declines in response reprogramming may be strongly linked to reduced cognitive capacity.

Table 2.1. Means and standard deviations for background variables

	Young Adults	Older Adults
Age (years)*	21.58 (2.32)	68.14 (3.96)
CTMT Simple vs. Complex (s)*	5.61 (5.91)	4.45 (3.57)
Stroop Interference (s/item)*	0.54 (0.22)	0.76 (0.18)
Digit Symbol*	92.63 (15.55)	68.50 (14.66)

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

* $p < .001$.

Table 2.2. Cognitive accuracy for the Serial 7s task, motor accuracy, and motor task global response time during testing blocks for single-task and dual-task conditions for younger and older adults.

Condition	Young Adults (*SD*)		Older Adults (*SD*)	
	Cognitive task accuracy (%)			
Single	79.39 (1.67)		76.55 (2.64)	
Dual	42.53 (1.33)		33.00 (1.86)	
	Prepotent	Conflict	Prepotent	Conflict
	Motor task accuracy (%)			
Single	83.90 (0.05)	93.60 (0.04)	82.10 (0.06)	83.40 (0.04)
Dual	82.50 (0.04)	87.00 (0.05)	76.80 (0.05)	71.20 (0.06)
	Motor task global RT (ms)			
Single	352.86 (22.94)	457.54 (10.68)	357.43 (26.72)	562.60 (12.45)
Dual	399.11 (24.12)	519.15 (15.84)	510.40 (28.09)	612.04 (18.45)

Note. Accuracy for the Serial 7s task and motor task = percentage of total correct responses. Motor task global response time in milliseconds. Standard deviations are shown in parentheses.

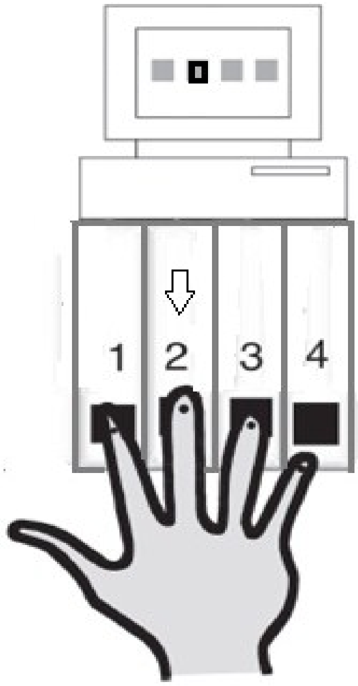


Figure 2.1. Illustration of the computer-keyboard setup used for the motor task. In order to record the movements of the fingers, six motion capture cameras were placed in front of the computer-keyboard apparatus. The arrow and the dark square on the illustration indicate the correspondence between the finger and the square. Numbers on the keys are used for illustration purposes only.

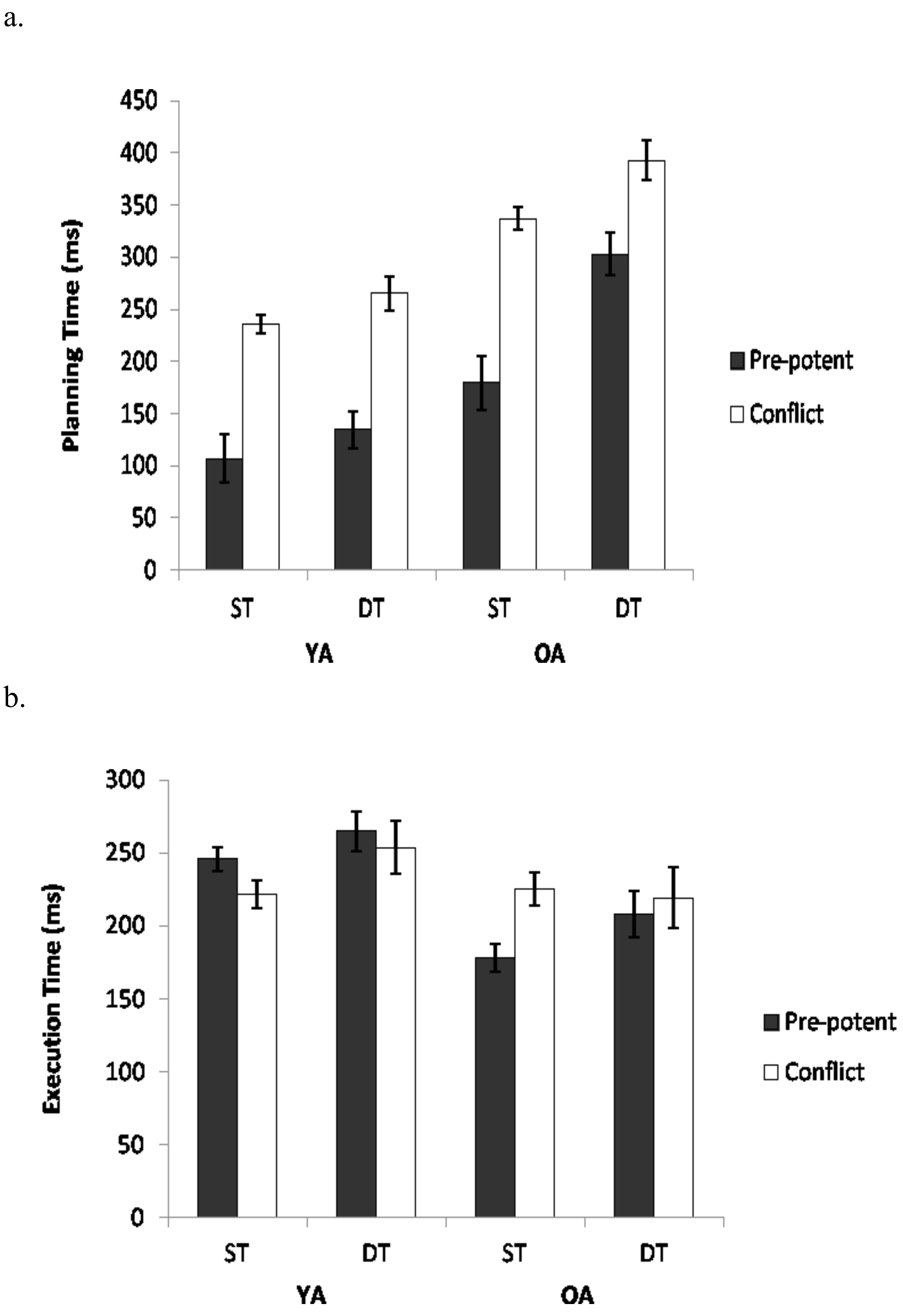


Figure 2.2. Mean planning time (a), and execution time (b) of key presses for pre-potent transitions during learning blocks and conflict transitions during test blocks for single-task and dual-task conditions per age group. Error bars represent ±1 standard error of the mean. ST = single-task; DT = dual-task; Acc = accuracy; PT = planning time; ET = execution time.

Chapter 3: Effects of musical experience on fine motor performance in old age

3.1 Abstract

It has been suggested that some types of cognitively stimulating activities are associated with slower cognitive decline in advanced age, but fewer studies have evaluated what specific skills influence cognitive processes in old age. The goal of the current studies was to explore whether musical experience was associated with enhanced cognitive and/or motor aspects of fine motor abilities. We expected that older musicians would show enhanced motor reprogramming abilities (Study 1) compared to older non-musicians in response to changes in the environment. We also hypothesized that musicians would demonstrate greater benefits from repeated exposure to conflicting stimuli or motor adaptation (Study 2) as compared to non-musicians. Finally, we predicted that better motor reprogramming and adaptation processes would be associated with enhanced executive functions. We tested 16 non-musicians (*M* age = 66) and 19 musicians (*M* age = 67) in Study 1 and 18 non-musicians (*M* age = 67) and 15 musicians (*M* age = 69) in Study 2. In both studies, participants overlearned a sequence of key presses. To assess motor reprogramming and adaptation, conflicting stimuli were introduced. In Study 1, a dual-task paradigm was used to investigate the effects of musical experience on motor reprogramming. A Serial Sevens Test was used as the cognitive load. In Study 2, frequency of conflicting stimuli was manipulated to investigate the contribution of musical experience to older adults' ability to adapt to conflicts. Motion capture was used to parse finger movements into broadly cognitive (planning time: PT) and movement (execution time: ET) components. In Study 1, compared to musicians, non-musicians slowed down their PTs for well-learned stimuli with increased attentional load, but the groups showed no differences in ETs. These results suggest that musical experience was more associated with enhanced cognitive processes than motor processes.

Moreover, older non-musicians failed to show motor adaptation effects with increasing conflict frequency, while older musicians benefited from previous exposure to conflict as expressed by PTs. Overall, the results suggest that musical experience might help older adults to preserve their executive functions, specifically, the inhibitory processes involved in motor reprogramming and conflict adaptation.

3.2 Introduction

Numerous studies have shown that advanced age is associated with changes in a range of cognitive control processes important for regulating behavior (e.g., Lindenberger & Baltes, 1994; Salthouse, 1991; Verhaeghen & Cerella, 2002; Verhaeghen & Salthouse, 1997). For several decades researchers have been trying to identify activities or experiences that may help to maintain these cognitive functions in old age. A large number of findings show that cognitively stimulating activities, for example, reading, attending classes, or solving puzzles are associated with slower cognitive decline in healthy older adults, and may delay or reduce cognitive deficits associated with pathological changes (e.g., Fratiglioni et al., 2004; Hertzog et al., 2008; Middleton et al., 2008; Scarmeas & Stern, 2003; Singh-Manoux et al., 2003). This led researchers to propose the concept of cognitive reserve where factors such as education and on-going engagement in stimulating activities can protect against cognitive decline (Stern, 2009). Although these studies have shown an association between cognitive stimulation and preserved cognitive abilities in old age, only a few studies have investigated whether expertise with specific skills can influence cognitive function (e.g., Charness, 1981; Lindenberger, Brehmer, Kliegl, & Baltes, 2008; Salthouse, 1984). For example, Munte and colleagues (2002) proposed that studying the influence of musical training on cognitive and brain processes may be important because making music is a highly complex activity that requires simultaneous integration of sensory and motor information, and monitoring of performance. Consequently, because musical training relies on a number of multisensory experiences, it may facilitate transfer effects in different brain regions and enhance cognitive stimulation. This multisensory experience makes musicians a good population in which to study whether specific skills can influence cognitive and motor processes in old age. Since music can be described as a chain of events or sequences that are organized in pitch and time, studying individuals with musical experience may provide insight into the nature of complex event sequences (Tillmann, 2012). It is also well known that cognitive and motor capacities seem to be connected to a greater degree with increasing age (e.g., Albinet et al., 2006; Li & Lindenberger, 2002; Li et al., 2001; Lindenberger et al., 2000), and that healthy aging is associated with declines in both cognitive and motor processes that are essential to the performance of complex tasks. Musical expertise, more specifically, instrumental training, involves intense practice in fine motor control, and at the same time places demands on high-level cognitive skills such as attention, planning and sequencing. However, it is still unknown whether musical experience may transfer to cognitive skills and if so, whether the transfer effect is due to the enhanced motoric skills or the more central cognitive benefits.

Whereas studies of general cognitive reserve in which educational attainment and lifetime intellectual experience may delay age-related cognitive decline or impairment, we examined the case of musical experience with a process-oriented approach, specifically, executive functioning (e.g., working memory, conflict monitoring, inhibition, and updating). That is, within measures of executive functioning, we aimed to distinguish between the potential motoric and cognitive benefits of musical experience. To do so, we used a visual-motor sequence paradigm (Trewartha et al., 2009), previously used to investigate the interaction between fine motor performance and cognitive inhibition in younger and older participants. Our previous experiments (Trewartha et al., 2009; 2011; 2013) revealed that when required to make un-predicted responses, younger adults sped up their motor movements to compensate for longer planning times, while older adults did not. The results of our recent study, where we used a dual-task paradigm suggested that declines in motor reprogramming of older adults were related to cognitive control resources, and most likely were independent of declines in motor functioning (Korotkevich, Trewartha, Penhune, & Li, 2015). In the current experiments, we tested older adults with and without music experience on the same visual-motor sequence task to assess whether musical experience would be associated with enhanced performance on the motor and/or cognitive aspects of task performance.

3.3 Expertise

The current examination of musical experience is embedded within the larger area of research on the protective benefits of expertise and specific experience on cognitive decline in old age (Hertzog et al., 2008). Numerous findings have shown that frequent engagement in cognitively stimulating activities later in life may slow rates of normal age-related brain changes, enhance levels of cognitive functioning, and delay cognitive deficits associated with pathological conditions such as mild cognitive impairment or dementia (e.g., Fratiglioni et al., 2004; Hertzog et al., 2008; Middleton et al., 2008). Cognitive reserve has been proposed to be the primary mechanism underlying the association between cognitively stimulating activities and slower cognitive decline in healthy older adults. Stern (2002; 2009) suggested that the individual differences in the brain's usage of preexisting cognitive resources and maintenance of its function may be explained by cognitive reserve, defined as a normal (non-pathological) process in healthy individuals that is activated to optimize performance when coping with demanding tasks and processing them in a more efficient manner through differential recruitment of brain networks. One of the processes that contributes to cognitive reserve is neural reserve, which implies that healthy older individuals may have preexisting inter-individual differences in their brain networks that developed as a function of innate capacity and/or personal experiences (Steffener & Stern, 2012).

Common global factors influencing cognitive reserve are related to general cognitive ability, such as education, career attainment and literacy. More specific factors include expertise or training e.g., music or bilingualism. Years of continuous training may lead to the establishment of memory representations and the development of complex skills that allow experts to perform tasks in a qualitatively different way compared to non-experts (Johansson, 2002). Explorations of the relationship between aging and expertise have revealed that a significant number of older adults continued to show advanced performance in their area of expertise while showing age-normative declines in other functions. In one early study, Charness (1981) observed that when selecting a move from an unfamiliar chess game, the quality of chess moves was unrelated to age but closely related to the players' skill level. In a more recent study, Lindenberger and colleagues showed that older graphic designers had higher scores on spatial tests than their peers (2008). Salthouse (1984) observed that older typists compensated for decreased perceptual-motor skills by developing larger eye-hand spans and showing greater anticipation of impending characters than did younger typists. In sum, these results suggest that older experts developed domain-specific mechanisms that helped them compensate for possible age related declines in general capacity (Krampe & Ericsson, 1996).

Occupational activities such as typing or graphic design usually begin in adulthood and end with retirement. As previously discussed, these activities confer specific advantages that are closely related to the area of expertise. In contrast to these activities, musical experience is an activity that may begin early in life and continue into old age, beyond one’s working years. Further, it encompasses a larger number of motor and cognitive skills. This suggests that musical experience may confer advantages in both specific and global processes. Results from studies in expertise and aging domains show the relative stability of performance amongst experts. Krampe and Ericsson (1996) observed that both older experts and older amateur pianists demonstrated expected age-related declines on a variety of measures that included general processing speed tasks. However, on the tasks that were specific to piano expertise older amateurs showed significant deterioration but older experts did not. Krampe and Ericsson suggested that continuous engagement in piano practice during later adulthood preserved older experts' piano-specific skills.

One approach to identify the effects of musical experience is to use functional and structural brain imaging techniques. It has been shown that music can modify both functional and structural levels of the brain that are involved in motor and auditory processing, including the planum temporale, the anterior corpus callosum, a motor network, and the cerebellum (Schlaug, Jäncke, Huang, Staiger, and Steinmetz, 1995; Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995; Krings, Topper, Foltys, Erberich, Sparing, Willmes, & Thron, 2000). It is also well-established that musicians are more efficient in integration of perception and action than non-musicians (Kraus, Schnitzler, & Pollok, 2010; Baer et al., 2013). This temporally precise integration of multimodal information is referred to as sensorimotor synchronization, and typically investigated by finger tapping tasks in which participants are instructed to tap in synchronization with the presented auditory or visual stimuli.

The other approach to identify the effects of music benefits is to investigate whether there is a link between musical experience and cognitive functions. The notion of a link between musical practice and enhanced cognitive processes is relatively new (Moreno, 2009), but it is a much discussed and highly controversial topic. Different musical activities such as playing an instrument alone or with others, creating or reading music, involve bimanual motor coordination, attention, concentration, precise timing, auditory stimulation, and feedback to varying degrees

(Johansson, 2002). Therefore, musical experience may lead to practice in a wider variety of non-musical skills. Along these lines, a large number of studies have related musical experience to better performance in various cognitive domains in children and young adults. For example, studies have shown that musical experience was associated with enhanced verbal abilities (Barwick, Valentine, West, & Wilding, 1989; Forgeard, Schlaug, Norton, Rosam, Lyengar, & Winner, 2008), verbal memory (Ho et al., 2003), symbolic and spatio-temporal reasoning (Rauscher et al., 1995; Rauscher, Shaw, Levine, Wright, Dennis, & Newcomb, 1997; Rideout & Taylor, 1997), visuo-spatial abilities (Brochard et al., 2004; Rauscher & Zupan, 2000), general intelligence (Schellenberg, 2004; 2006), and enhanced ability to understand speech in noise (e.g., Alain, Zendel, Hutka, & Bidelman, 2014; Strait & Kraus, 2014; White-Schwoch et al., 2013). These studies support the idea that musical experience may have a general positive transfer effect on cognition.

One of the main concerns of the present studies was to explore whether musical experience may confer benefits to non-musical skills. We propose that due to the complex nature of the training effects of musical expertise may be more generalizable to cognitive processes such as executive functioning. It has been shown that in older age, declines in executive functions were associated with declines in activities of daily living (ADL; e.g., Razani, Casas, Wong, Lu, Alessi, & Josephson, 2007). Cahn-Weiner and colleagues (2002) suggested that in normal aging, decline in executive functioning might have the strongest association with decline in ADLs compared to other cognitive processes. What is more central to the current research is the question whether musical expertise may provide protective benefits to executive functions. Empirical support has been reported in studies that investigate a link between music and executive functions in children and young adults (e.g., Ho et al., 2003; Moreno et al., 2011;

Bialystok & DePape, 2009). Musical training requires high levels of control that involves three commonly measured components of executive function: selective attention and inhibition, switching, and updating and monitoring (Miyake & Shah, 1999). Schellenberg (2003) proposed that musical training could have long-term cognitive benefits and enhanced executive control (Schellenberg & Peretz, 2008; Schellenberg, 2006). Bialystok and DePape (2009) found that musical experience in young adults was associated with enhanced executive control, even for tasks that were not directly related to music, such that musicians outperformed non-musicians on a number of tasks that involved executive functions components (i.e., auditory Stroop). Moradzadeh and colleagues (2014) observed that in young adults, long-term musical experience was associated with enhanced performance on such executive functioning tasks as task switching and dual-task performance. Overall, the extant findings on musical experience and its benefits in young adulthood suggest that there may be a transfer effect from musical experience to executive control involving both domain specific and domain general effects.

Very few studies have directly evaluated whether musical experience might influence cognitive aging. For example, enhanced auditory processing was observed in older adults with musical experience (e.g., Parbery-Clark et al., 2012; Parbery-Clark, Anderson, & Kraus, 2013; Parbery-Clark et al., 2011; Zendel & Alain, 2012). Similarly, benefits of musical experience were observed in studies that investigated speech-in-noise perception, such that older musicians showed enhanced speech-in-noise perception and greater auditory working memory capacity (Parbery-Clark et al., 2011) compared to non-musicians. In a recent study, Hanna-Pladdy and MacKay (2011) found that musicians with more than 10 years of experience outperformed non-musicians on a range of cognitive functions, including cognitive flexibility, as measured by the Trail-making test. Interestingly, across musician and non-musician groups they found a linear relationship between years of musical experience and performance on the task. In another study, Hanna-Pladdy and Gajewski (2012) controlled for general activity level in evaluating cognitive processes between older musicians and non-musicians, showing that although older musicians did not differ in general leisure activities, they showed better performance on a variety of skills (e.g., phonemic fluency, verbal working memory, and motor dexterity). Variability across verbal and visuospatial domains was predicted by recent and past musical activity and not general lifestyle activities. Furthermore, it was found that the effect of musical training might depend on age-of-start, as musicians who began training before the age of nine performed better on tests of verbal working memory. Similarly, it was found that musical experience was associated with enhanced central auditory function in advanced age (e.g., Anderson et al., 2013; Parbery-Clark et al., 2012; White-Schwoch et al., 2013).

In sum, previous studies converge to suggest that musical experience may confer specific benefits for motor performance and cognitive processes such as working memory, attentional control, and inhibition. However, even where cognitive benefits have been shown, many measures in previous studies required some sort of manual response or visual-manual coordination. Because many instrumentalists engage in intense training and practice of fine motor control and synchronization, it is important to know whether musical experience transfers to cognitive skills because of the motor benefit or a more central cognitive benefit. There are no studies to our knowledge that separately quantify the cognitive and motor benefits of musical experience within the same task. Another understudied question is whether older musicians show enhanced performance on executive function tasks, and whether this advantage might transfer to non-musical tasks. While making music, self-monitoring is required to detect errors and correct mistakes, but there are relatively few studies evaluating the connection of musical experience to changes in more basic error-detection and response reprogramming functions. Thus, in the current experiments we used motion capture methods to decompose a visual-manual task into cognitive and motor components to better understand whether the benefits are more motoric or cognitive.

The novel contribution of our work is in addressing the above questions by exploring the separate contributions of cognitive and motor benefits of musical experience in older age. In the first study, we used visual-motor tasks that were previously developed and used in our laboratory to investigated response reprogramming/inhibition processes. Additionally, we manipulated working memory load in our participants by using a dual-task paradigm to explore the possible benefits of musical experience on divided attention. Furthermore, previous research has shown an age-related decline in conflict adaptation, demonstrating that young adults benefited from repeated exposure to conflicting trials whereas older adults did not show such a learning effect (Trewartha et al., 2011). Therefore, in our second experiment we sought to explore whether musical experience might help attenuate this age-related decline in motor adaptation by facilitating learning/adaptation to repeated conflicts.

3.3.1 Experiment 1

Our main goal in this experiment was to examine the effect of musical experience on the cognitive and motor components of our previously used motor reprogramming task (Trewartha et al., 2009; Korotkevich et al., 2015). In addition to the manipulation of stimulus expectation (prepotent vs. conflict trials), we manipulated cognitive load, given that dividing attention is another aspect of executive functioning that might benefit from musical experience. We hypothesized that older adults with musical experience would show enhanced fine motor reprogramming abilities compared to older adults without musical experience.

3.3.1.1 Method

3.3.1.1.1 Participants

Participants were healthy older adults with no history of significant head injury, vision or hearing impairments, or neurological disease, and who were not taking any medication that could affect cognitive or fine motor performance. To screen for Mild Cognitive Impairment, all participants received a score of at least 26 on the Montreal Cognitive Assessment (MoCA; Nasreddine, Phillips, Bedirian, Charbonneau, Whitehead, Collin et al., 2005). Participants were selected to fall into two groups: Non-musicians (*N* = 16; *M* = 65.68; *SD* = 4.88; age range: 63.33 – 68.03) who had little musical experience and were not currently practicing (participants had less than 5 years of musical experience; they stopped playing at least 10 years ago); and Musicians (*N* =19; *M* = 67.31; *SD* = 4.41; age range: 64 – 70) who had greater than three years of experience and who were currently playing (*M* = 47 years of experience; participants were practicing for the last 10 years). Experience was assessed using the Musical Experience Questionnaire (MEQ: Bailey & Penhune, 2010) that was administered to participants over the phone. The most common instruments played were piano, guitar, and clarinet. The participants were recruited through a preexisting senior participant database at Concordia University Psychology and through a newspaper advertisement placed in a local newspaper for older adults. All participants received a small honorarium. In compliance with the Concordia University Human Research Ethics Committee, participants provided written informed consent before beginning the testing session. All testing procedures were approved by the Concordia University Human Research Ethics Committee.

3.3.1.1.2 Neuropsychological measures

A neuropsychological battery including the Digit Symbol Substitution, Vocabulary, Matrix Reasoning, and Digit Span subtests of the Wechsler Adult Intelligence Scale IV (WAIS-IV; Wechsler, 2008) was administered to measure processing speed, verbal IQ, perceptual organization, and working memory respectively. For the Digit Symbol Substitution subtest, the total number of correct items completed served as the dependent measure. For the Vocabulary and Matrix Reasoning subtests, the score was obtained by summing all the points for the correct responses. The obtained score served as the dependent variable. In the Digit Span subtest, participants were instructed to repeat a series of digits that were presented to them verbally by the examiner, in the same order (forward) or in reverse order (backwards). We recorded the maximum numbers of digits for both conditions that participants could repeat without two mistakes. These values were summed and used as the dependent variable of this subtest.

In addition to the WAIS subtests, we used the Stroop test (adapted from Spreen and Strauss, 2001), forms C (congruent condition) and CW (incongruent condition), to assess controlled attention. To control for individual differences in motor speed and perceptual efficiency, we calculated the difference between the seconds per item completed on the congruent and incongruent conditions and used it as the dependent variable. Lastly, task switching capacity was assessed with the Comprehensive Trail Making Test (Reynolds, 2002). Times needed for completing the complex and simple task conditions were recorded. To control for individual differences in motor speed and visuo-motor coordination, the difference between conditions was compared and used as the dependent variable.

3.3.1.2 Dual-task paradigm

3.3.1.2.1 Cognitive task

The cognitive task used was the modified Serial Seven Test (SST; described by Korotkevich et al., 2015). The SST is a verbal working memory task requiring updating and mental arithmetic (Kazui, Kitagaki, & Mori, 2000), in which participants are given a 2-digit number (between 86 and 96, not including numbers ending with 0 or 7), and are instructed to subtract 7 from the starting number and continue subtracting 7 from successive answers until they are told to stop after 16 seconds. This time interval was chosen to match the duration of each motor sequence trial. Participants reported their answers verbally and responses were recorded by the examiner. We scored the percentage of correct responses per trial.

We used the SST separately and concurrently with the motor sequencing task. The SST served as the concurrent cognitive load, to occupy working memory and cognitive capacity while concurrently performing the motor task. It has commonly been used as a cognitive load measure in dual-task gait, balance, and aging studies (Kang & Lipsitz, 2010; Karzmark, 2000; Van Iersel, Kessels, Bloem, Verbeek, & Rikkert, 2008).

3.3.1.2.2 Motor task

The finger sequencing paradigm used in the current experiment is described in detail elsewhere (Trewartha et al., 2009). Participants sat down in front of a computer monitor (17" flat screen) and were instructed to press the keys on a custom-built keyboard while following the stimuli presented on a monitor. To reproduce sequences of key presses, participants were instructed to use the four fingers of their right hand (index finger to small finger). Four gray squares (3” x 3”) were presented horizontally on the screen and represented each of four fingers in a left-to-right manner. Participants were instructed to press the corresponding keys with the corresponding fingers once the stimulus was presented on the computer screen and changed colour from grey to pink. Each stimulus was presented on the screen for 800 ms. Each experimental trial consisted of 20 stimuli and lasted for a total of 16000 ms. The pause between each trial lasted 3000 ms.

We evaluated finger sequencing task performance in counterbalanced blocks of single- and dual-task trials. To explore the difference between overlearned motor responses and violations of well-learned responses, we further sub-divided each motor block into Learning and Test phases. The Learning phase consisted of a repeated pair of keys that prompted participants to over-learn a pair of responses (e.g., 2, 3, 2, 3, 2, 3 ...). To create a response prepotency, each participant was assigned the same pre-potent pair for the entire experiment. Pre-potent pairs were counterbalanced across participants in each group. The Test phase that comprised of a mixture of pre-potent and conflicting pairs and random filler stimuli followed the Learning phase. Each pair of key presses in conflicting responses started with the first key press of the well-learned response (e.g., “2”). Next, participants were prompted to press a different, unexpected key (e.g., unexpected “1” instead of expected "3"), which made them violate their over-learned response and suppress their over-learned behaviour. We included two pairs of pre-potent transitions (e.g., 2, 3 . . . 2, 3 . . .), two pairs of conflict transitions (e.g., 2, 1 . . . 2, 1 . . .), and 12 random counterbalanced filler stimuli (e.g., 4) in every trial of the Test phase. We provide an example of a Test block sequence in Figure 3.1.

A 3-D motion capture system (VZ3000; Phoenix Technologies, Burnaby, British Columbia, Canada) was used to record the kinematics of finger movements during the task. Four light-emitting diode (LED) markers were attached to the participants’ relevant fingernails using adhesive Velcro. The finger movements were recorded on the x, y, and z axes of the spatial field by the motion capture system. The stimulus triggers were sent using the stimulus presentation software (Inquisit 3.0.4.0 Millisecond Sofware LLC. Seatle, WA). Stimulus triggers were activated by each key press to a data acquisition (DAQ) card (NI USB-6221 BNC, National Instruments Inc.). To synchronize the motion capture data with the stimuli presented on the computer monitor, a custom program written in C# on version 1.1 of the Microsoft.NET Framework was used.

3.3.1.2.3 Experimental procedure

This investigation required participants to attend a single individual testing session that lasted for approximately 2 h. At first, participants completed the battery of neuropsychological tests. Next, participants were familiarized with the motor apparatus. To this end, they were given one simple repeating sequence (1, 2, 3, 4, 1, 2, 3...) and 10 sequences of 10 random elements before the beginning of experimental phases. Each block of trials began with one warm-up trial of the relevant task condition that was not scored. After the familiarization phase, the participants were instructed to perform a block of five single cognitive trials followed by a block of five single motor trials, or vice versa. The order of the motor and cognitive single task blocks was counterbalanced across participants. Five trials of the dual-task condition followed the single task blocks. Under dual-task conditions, both motor and cognitive task were initiated simultaneously, and participants were instructed to perform both tasks to the best of their ability. To reduce the potentially confounding effects of practice and fatigue, another block each of single cognitive and single motor tasks was administered. At the end of the experiment, participants were debriefed and given a small honorarium.

3.3.1.3 Data analyses

3.3.1.3.1 Motor task preprocessing

We used a custom-written function in Matlab (2007a, The Mathworks Inc. Natick, Massachusetts) to analyze the kinematic data. We first calculated the response times (RT) which was defined as time from stimulus onset to the completion of the key press for correct responses only. Responses were coded as correct if the key presses were made to the appropriate stimuli within the inter-stimulus intervals. As we sought to investigate the relative contributions of cognitive (conflict detection) and motor (movement execution) processes, we further decomposed RT into planning and execution times. For each individual, a peak identification algorithm was used to extract planning and execution time parameters from the motion capture data and establish baseline rates. The data were centered around zero and subtraction of a robust least squares fit of the data from the raw signal was used to calculate the baseline (see Trewartha et al., 2009). Each participant's own performance was used as a baseline to control for individual differences. When calculating the measurements for pre-potent and conflict transitions, we used the second key press of each pair. The purpose of the first key press in each pair was to prime participants for the pre-potent response; thus, the dependent variables were calculated for the second key presses only. Similar to our previous work (Korotkevich et al., 2015; Trewartha et al., 2009; 2011), we compared pre-potent transitions during the Learning phase with conflict transitions during the Test phase. We used pre-potent transitions from the Learning phase rather than from the Test phase to assess optimal performance prior to the introduction of interference from conflict trials.

To analyze cognitive and motor task variables, we used a 3 *SD* cutoff to identify potential outliers. We investigated outliers for each condition within individuals and within groups. Exploratory data analysis showed that no data points exceeded this cutoff. Therefore, all further analyses were conducted on the full data set. The cognitive accuracy data were analyzed using a cognitive load (single-task vs. dual-task) by group (musicians - MU, vs. non-musicians - NM) mixed factorial analysis of variance (ANOVA). Motor task performance was analyzed using a 2 X 2 X 2 Attentional Load (single- vs. dual-task) X Transition Type (pre-potent vs. conflict transitions) x Group (MU vs. NM) mixed factorial ANOVA design for each of the following dependent variables: accuracy, planning time, and execution time. A significance level of 0.05 was set for the primary analyses and Bonferroni corrections were made for post-hoc analyses. The relationships among musical and background demographics, neuropsychological measures, and motor task performance were examined using Pearson correlation analyses. Raw scores on the neuropsychological measures were used to examine the cognitive abilities of the participants.

3.3.1.4 Results and discussion

In the current study we sought to explore the contribution of musical experience to the adaptation or reprogramming of fine motor responses in older adults. Performance on all neuropsychological tests was examined for outliers and was found to be within age normative ranges. Descriptive statistics for each group are presented in Table 3.1.The groups were comparable on all background measures (e.g., age, MoCA scores). The only group difference that was observed was on the Vocabulary subtest of the WAIS favouring the musicians.

3.3.1.4.1 Cognitive accuracy

The mixed factorial ANOVA comparing musical experience (MU vs. NM) x attentional load (single-task vs. dual-task) revealed a significant main effect of attentional load, $F(1, 33) = 49.59$, $p < .001$, $\eta^2 = .600$. The effect of musical experience, $p = .874$, and the interaction of attentional load and musical experience, $p = .965$, were not statistically significant. Mean values and standard deviations for single- and dual-task performance on the SST are shown in Table 3.2. Current results suggest that participants in both groups almost reached a performance ceiling with respect to the total number of correctly subtracted numbers, under single-task conditions, but they did not reach a performance ceiling under dual-task conditions. These results suggest that the cognitive task was relatively easy when performed on its own, but it became relatively difficult for both groups when combined with the motor task, which confirmed that we created an adequate cognitive load in the dual-task condition (see Table 3.2). Similar to other studies (e.g., Fraser et al., 2007, 2010; Korotkevich et al., 2015), the dual-task effects were observed primarily in the motor task.

3.3.1.4.2 Key press accuracy

The omnibus analysis of motor accuracy scores revealed a significant main effect of attentional load, $F(1, 33) = 20.56, p < .001, \eta^2 = .38$ (see Table 3.2). As expected, participants in both groups demonstrated more accurate performance on the motor task under single-task conditions ($M = .857$, SEM = .037) than dual-task conditions ($M = .741$, SEM = .03). All other main effects and interactions were nonsignificant ($p\text{s} \geq .215$). The lack of significant group interactions in the motor accuracy data was previously observed in our studies (Korotkevich et al., 2015; Trewartha et al., 2009) and reflects a high level of performance accuracy on the motor task (Fig. 3.2a).

Next, we decomposed the key press data into cognitive and motor components (planning and execution times) and analyzed them separately.

3.3.1.4.3 Planning time

We conducted mixed-factorial ANOVAs to evaluate the effects of musical experience (MU, NM), attentional load, and transition type on planning time (Fig. 3.2b). We expected musicians to exhibit shorter planning times on conflict transitions than non-musicians. Planning time analysis revealed a significant main effect of attentional load, $F(1, 33) = 50.96, p < .001, \eta^2 = .607$, such that overall planning time was longer under dual-task conditions ($M = 317.56$ ms, SEM = 13.21) than single-task conditions ($M = 225.78$ ms, SEM = 8.11). We also observed a significant main effect of transition type, $F(1, 33) = 106.73, p < .001, \eta^2 = .764$. As predicted, planning times for conflict transitions were longer ($M = 341.00$ ms, SEM = 8.60) than pre-potent transitions ($M = 202.34$ ms, SEM = 13.18). We also observed a significant interaction of attentional load and transition type, $F(1, 33) = 15.14, p < .001, \eta^2 = .314$. Lastly, a marginally significant interaction between attentional load, transition type, and musical experience was observed, $F(1, 33) = 3.88, p = .057, \eta^2 = .105$.

Post hoc analyses indicated that musicians were affected by attentional load, $F(1, 18) = 29.18, p < .001, \eta^2 = .619$, such that planning times were shorter under single-task ($M = 224.90$ ms, SEM = 13.20) than under dual-task conditions ($M = 312.23$ ms, SEM = 18.79), and transition type, $F(1, 18) = 44.05, p < .001, \eta^2 = .710$, such that pre-potent transitions were shorter ($M = 197.87$ ms, SEM = 20.92) than conflict transitions ($M = 339.26$ ms, SEM = 13.65). However, the interaction of attentional load and transition type was not significant in the musician group, suggesting that even with a cognitive load musicians were able to respond differentially to pre-potent and conflict trials.

In non-musicians, post-hoc analyses indicated that they were affected by attentional load, $F(1, 15) = 22.19, p < .001, \eta^2 = .597$, such that planning times were shorter under single-task (M

= 226.66 ms, SEM = 8.13) than under dual-task conditions (*M* = 322.89 ms, SEM = 18.18). There was a significant effect of transition type, $F(1, 15) = 86.39$, $p < .001$, $\eta^2 = .852$, revealing shorter planning time for pre-potent transitions (*M* = 206.81 ms, SEM = 14.38) than conflict transitions (*M* = 342.75 ms, SEM = 9.39). Furthermore, in contrast to the musician group, there was a significant interaction between attentional load and transition type, $F(1, 15) = 15.43$, $p = .001$, $\eta^2 = .507$. In order to explore this interaction, pair-wise comparisons were conducted using a Bonferroni correction. Under single-task conditions, non-musicians spent less time planning for the pre-potent transitions (*M* = 120.19 ms, SEM = 10.12) than for the conflict transitions (*M* = 333.14 ms, SEM = 14.70), $t(15) = -11.04$, $p < .001$, but under dual-task conditions, the trial type effect was only marginally significant, $t(15) = -2.05$, $p = .058$ (pre-potent: *M* = 293.43 ms, SEM = 26.53; conflict *M* = 352.35 ms, SEM = 19.23). Furthermore, non-musicians' performance on pre-potent transitions under single-task conditions was shorter than under dual-task conditions, $t(15) = -6.19$, $p < .001$. No difference was observed for conflict transitions, $p = .512$. Together, the pattern of planning time data suggests that whereas musicians were able to respond differentially to pre-potent and conflict trials even with a cognitive load, non-musicians were significantly slowed down in the pre-potent trials with the addition of the cognitive task. This pattern of results indicates that despite the fact that both groups were affected by the divided attention manipulation, non-musicians were less able to handle the increased attentional load.

3.3.1.4.4 Execution time

Turning to the motoric component of the sequencing task, we assessed whether musicians would show faster motor reprogramming responses than non-musicians by conducting a mixed-factorial ANOVA using the execution time data (Fig. 3.2c). We predicted that under both attentional load conditions musicians would outperform non-musicians by showing faster response reprogramming. The analysis revealed a significant main effect of attentional load, *F*(1, 33) = 4.25, $p = .047$, $\eta^2 = .114$, such that execution times were shorter under single-task (M = 187.17 ms, SEM = 8.03) than under dual-task conditions (M = 202.48 ms, SEM = 8.57). All other main effects and interactions were nonsignificant ($p \geq .17$). Contrary to expectation, the analysis of the execution time data did not reveal an advantageous effect of musical experience on the motoric component of our sequencing task. Instead, the groups exhibited relatively similar execution times under both single- and dual-task conditions.

3.3.1.4.5 Individual differences analysis

We conducted a series of correlational analyses to examine in more detail the potential benefits of specific facets of musical experience to fine motor and cognitive performance. Criterion measures included: age of start, total number of years played, number of instruments played, and all the neuropsychological tests that were administered (see Table 3.3 for correlations). We derived cost measures for the PT and ET data, thus any significant relationships observed reflect a relation between the efficiency of conflict processing and reprogramming, and not baseline speed of responding. It was found that the number of instruments played was related to faster movements during conflict compared to pre-potent trials under single-task conditions (ET for pre-potent minus conflict, $r = .342$, $p = 0.044$), suggesting that, not surprisingly, individuals with extensive experience manipulating instruments showed an ability to shorten their movement times in an adaptive way in the face of conflicting stimuli. This is similar to the pattern found in young adults in our previous work (Trewartha et al., 2009; 2011). Independent of musical experience, we also found that larger Stroop interference scores were positively related to longer ETs during conflict compared to pre-potent trials under single-task conditions (see Table 3.3). This suggests that individuals who were more susceptible to

Stroop interference (i.e., had poor response inhibition) also showed a greater motoric cost in the face of conflict in the sequencing task.

In summary, the main question posed in this experiment was whether musical experience confers benefits to cognitive and/or motor aspects of task performance. Our motion capture analyses revealed that musicians and non-musicians exhibited different kinematic signatures (planning and execution times) when preparing their motor movements, such that with increased attentional load non-musicians slowed down their planning times for pre-potent transitions. Interestingly, the two groups showed no differences in execution time. These results suggest that musical experience may confer more benefits to cognitive (PT) than motor processes (ET). In addition, we observed that the more instruments participants played, the more efficiently they were able to handle conflicts. Lastly, our data suggest that musical experience may be also beneficial to certain aspects of executive functions, suggesting that musicians may have better developed inhibitory processes. The second experiment was conducted with the aim of replicating and extending the findings from Experiment 1, and to further investigate the contribution of musical experience to another aspect of fine motor performance: the ability to adapt to conflict over time.

3.3.2 Experiment 2

To explore whether musical experience might help attenuate age-related decline in motor adaptation, conflicting responses were embedded within strings of repeated pairs of key presses. This allowed us to manipulate the frequency with which conflicts were presented to explore whether there were any group differences in movement adaptation. We included one-, two-, or three-conflicting key presses within each 10-key press conflict trial. Consistent with a conflict adaptation effect and results of our previous study (Trewartha et al., 2011), it was hypothesized that older musicians should show greater benefit from repeated exposure to conflicting key presses as compared to older non-musicians.

3.3.2.1 Method

3.3.2.1.1 *Participants*

New samples of older adults were recruited for Experiment 2. The non-musician group consisted of eighteen older people (*M* = 67.22, *SD* = 3.80; age range: 65– 69) who had little experience in music and were not currently playing (participants had less than 5 years of musical experience; they stopped playing at least 10 years ago). The musician group included fifteen older people (*M* = 68.93, *SD* = 6.08; age range: 65– 72) who had three or more years of musical experience and were currently practicing (*M* = 49 years of experience; participants were practicing for the last 10 years).The same inclusion criteria as in Experiment 1 were used. Similar to the first study, a Musical Experience Questionnaire (MEQ; Bailey & Penhune, 2010) was used to determine the musical experience of each participant. The most common instruments played were piano and guitar. The participants were recruited through a preexisting senior participant database at Concordia University Psychology or through a newspaper advertisement placed in a local newspaper. All participants received a small honorarium for their participation. Written informed consent was obtained from all participants, and all procedures were approved by the Concordia University Human Research Ethics Committee.

3.3.2.1.2 Neuropsychological measures

Each participant completed the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2010), which was used as a gross measure of cognitive function to screen for possible mild cognitive impairment. The same battery of neuropsychological tests was used as in Experiment 1 to assess whether groups differed on specific cognitive functions and whether musical experience was associated with better performance on these measures. Performance scores on the MoCA and neuropsychological tests are reported in Table 3.1. The only group difference that was observed was on the Digit Span subtest of the WAIS favouring the musicians.

3.3.2.1.3 Apparatus, task, and procedures

We used the same apparatus for the motor sequencing task as in Experiment 1, with similar verbatim instructions and stimulus parameters: participants were instructed to press the corresponding keys with the corresponding finger as quickly and accurately as possible following visual stimuli presented on a computer screen. Throughout the sequencing task, stimulus duration was 400 ms, and the interstimulus interval (ISI) was 400 ms, with a 3,000 ms pause between each trial.

The trial arrangement was modified from that used in Experiment 1 to allow for the manipulation of conflict trial frequency. Similar to Experiment 1, in the first orientation sequence, participants performed a simple 24-element fixed sequence (1, 2, 3, 4, 1, 2, 3…). Next, participants performed one block of 30 sequences each consisting of 10 random key presses. This block was designed to act as a baseline to assess participants' ability to react to the visual stimuli. Following the random condition, participants were presented with a homogeneous "pre-potent only" condition. In this condition, 20 trials were presented, which involved the repetition of the same pair of key presses five times in every trial (e.g., 3, 4, 3, 4, 3, 4, 3, 4, 3, 4). Four different pre-potent pair combinations were counterbalanced across participants. The purpose of this condition was to create the prepotency effect. In the final condition, participants were presented with nine heterogeneous blocks of 20 trials each. Each sequence in this condition consisted of both pre-potent only and conflict trials (see Figure 3.1). Pre-potent only trials were identical to those in homogeneous conditions. Conflict trials started with the first key press of the pre-potent pair and were followed by a new, unexpected second key press (e.g., pre-potent: 3, 4; conflict: 3, 1 or 3, 2). This final condition consisted of 120 pre-potent only trials and 60 conflict trials that were embedded within trials of pre-potent pairs. To manipulate conflict frequency, we included one, two, or three conflicts in each trial. Twenty trials of each conflict frequency were randomly inserted in the heterogeneous blocks. Each conflict trial was separated by one, two, or three pre-potent only trials. To ensure that participants would not predict the locations of conflicting responses, the serial position of the conflicts within each trial was randomized. All conditions in the current experiment were conducted without performance feedback.

3.3.2.2 Data analyses

3.3.2.2.1 Motor task preprocessing

We analyzed the kinematic data using the same custom software as described in Experiment 1. Likewise, we followed the same technique when parsing finger movements into kinematic components identifying the planning time as the amount of time from stimulus presentation to movement initiation and execution time as the time from movement initiation to the completion of finger movement. All the dependent variables were calculated for the second key press only. For the random sequences, all accurate key presses were included. To analyze motor task variables, we used a 3 *SD* cutoff to identify potential outliers. We investigated outliers for each condition within individuals and within groups. Exploratory data analysis showed that no data points exceeded this cutoff. As done previously (Trewartha et al., 2011), in the current experiment, we separated the data into five different conditions: (a) random; (b) pre-potent key presses in the homogeneous block; (c) pre-potent key presses in the heterogeneous block; (d) pre-potent key presses within conflict trials; and (e) conflicting key presses, separated into one, two, or three conflicts. Homogeneous blocks consisted of pre-potent key presses, while heterogeneous blocks consisted of a combination of pre-potent and conflict key presses. Condition (c) refers to a full trial of pre-potent pairs, while condition (d) refers to the pre-potent key presses that were embedded within conflict trials. Similar to Experiment 1, four dependent variables (accuracy, RT, PT, ET) were subjected to a 2 (Musical Experience) × 7 (Transition Type) analysis of variance (ANOVA). In addition to this analysis where all conflict trials were pooled, we also separated the conflict trials in terms of their serial position within a trial, to explore the effects of musical experience on the ability to learn or adapt to repeated conflicts. A significance level of 0.05 was set for the primary analyses and Bonferroni corrections were made for post-hoc analyses. The relationships among musical and background demographics, neuropsychological measures, and motor task performance were examined using Pearson correlation analyses. Raw scores on the neuropsychological measures were used to examine the cognitive abilities of the participants.

3.3.2.3 Results and discussion

In the current study we sought to further investigate the association of musical experience with older adults' ability to adapt to conflict over time. We predicted that older adults with musical experience would benefit from repeated exposure to conflicting key presses compared to non-musicians. Performance on all neuropsychological tests was examined for outliers and was found to be within age normative ranges (see Table 3.1). Similar to Experiment 1, the groups were comparable on all background measures (e.g., age, education, MoCA scores). Similar to Trewartha and colleagues (2011), we explored participants' performance on seven different transition types: random, pre-potent only-homogeneous, pre-potent only-heterogeneous, pre-potent with conflict, and conflicting responses in one-, two-, and three-conflict trials.

We first explored the overall effect of exposure to conflict including all seven levels of transition type in keeping with the strategy of analyses used by Trewartha and colleagues (2011). For keyboard and motion capture data see Figure 3.3. Analysis of the motor accuracy data revealed a significant main effect of transition type, $F(1, 31) = 2.61$, $p = .041$, $\eta^2 = .376$, but no significant effect of musical experience, $p = .280$ or interaction of musical experience and transition type, $p = .882$. Likewise, planning time analysis revealed a significant main effect of transition type, $F(1, 31) = 24.12$, $p < .001$, $\eta^2 = .848$, but no significant effect of musical experience, $p = .369$ or interaction between musical experience and transition type, $p = .134$. Execution time analysis revealed a significant main effect of transition type, $F(1, 31) = 19.77$, $p < .001$, $\eta^2 = .820$, significant effect of musical experience, $F(1, 31) = 4.57$, $p = .040$, $\eta^2 = .129$ (MU: $M = 148.20$ ms, $SEM = 10.00$; NM: $M = 177.16$ ms, $SEM = 9.13$), but no significant interaction between musical experience and transition type, $p = .839$. Although the interaction between Musical Experience x Transition Type was not significant we examined the two groups separately to explore whether there were any subtle effects masked by variability in the larger ANOVA, consistent with the strategy of analyses used by Trewartha and colleagues (2011). In order to explore group differences, pair-wise comparisons were conducted using a Bonferroni correction for each dependent variable.

The main goal of this experiment was to explore whether musicians and non-musicians differed on their response adaptation abilities. To this end, we investigated participants' performance on conflicting responses across different conflict levels, we conducted within-group analysis comparing pre-potent only responses in the heterogeneous conditions with conflicting responses across different levels of conflict. We found that musicians were equally accurate for conflicting and pre-potent only responses, $t(14) = 0.49$, $p = 0.634$, $t(14) = 0.56$, $p = 0.582$, and

$t(14) = 1.11, p = 0.287$ (averaged within one-, two-, and three-conflict trials respectively). There was also no difference in PT for pre-potent and conflicting responses, $t(14) = -0.32, p = 0.756$, $t(14) = 0.11, p = 0.912$, and $t(14) = 1.78, p = 0.097$. However, they showed significant differences in execution time, $t(14) = 2.69, p = 0.017$, $t(14) = 3.29, p = 0.005$, and $t(14) = 5.27, p < 0.001$, respectively, such that musicians were faster for all levels of conflict relative to their pre-potent only responses.

In contrast, non-musicians were less accurate when two-conflict trials $t(17) = 2.34, p = 0.032$ and three-conflict trials $t(17) = 2.62, p = 0.018$ were presented compared to their performance on the pre-potent only responses, but there was no difference between one conflict trial and pre-potent only responses $t(17) = 1.48, p = 0.156$. These results indicate that although musicians' accuracy performance was not affected by conflict trials, non-musicians performed less accurately when more violations were introduced. Planning time analysis revealed that non-musicians spent more time planning the conflicting responses when one- and two-conflict trials were introduced, $t(17) = -2.36, p = 0.031$, $t(17) = -2.10, p = 0.051$, respectively, but their planning time decreased when three-conflict trials were presented, $t(17) = -0.62, p = 0.54$ and was not statistically different compared with their pre-potent only responses. These results may suggest that while musicians' planning time was not affected by the conflict trials, non-musicians took longer to prepare their responses when one or two conflicts were introduced. Additionally, the non-musicians demonstrated shorter execution time in two trial types (i.e., two- and three-conflict trials) compared with their pre-potent only responses, $t(17) = 2.11, p = 0.05$, $t(17) = 3.54, p = 0.003$, respectively. These results suggest that the execution time pattern was somewhat different between the musicians and non-musicians. While musicians took less time to execute conflicting responses at all three frequency levels compared to pre-potent only responses, non-musicians required more repetitions compared to musicians before they shortened their execution times.

In sum, the above results indicate that although musicians' accuracy performance was not affected by conflict trials, for non-musicians, conflicts interfered with their performance. We also observed that musicians' planning time was not affected by the conflict trials, while non-musicians took longer to prepare their responses when one or two conflicts were introduced. Moreover, non-musicians required more repetitions compared to musicians before they shortened their execution times when conflicting trials were introduced.

3.3.2.3.1 Adaptation to conflicts

We further compared the conflicting responses based on their position within each type of conflict trial. While in our previous analyses, we averaged across conflicts in each trial, in the current analysis we separated conflicts into six different transition types: one-conflict only; first and second conflict in a two-conflict trial; and first, second, and third conflict in a three-conflict trial. To conduct this analysis, we compared each dependent variable using a 2 (Musical Experience) x 6 (Conflict Position) ANOVA. For accuracy, there was a significant interaction between musical experience and transition type, $F(5, 27) = 1.12$, $p = 0.005$, $\eta^2 = .445$, but no main effect of transition type, $p = 0.374$, nor musical experience ($p = 0.935$). For planning time, there was a significant main effect of transition type, $F(5, 27) = 6.52$, $p < 0.001$, $\eta^2 = 0.55$, a marginally significant interaction between musical experience and transition type, $F(5, 27) = 2.43$, $p = 0.060$, $\eta^2 = 0.31$, but no main effect of musical experience, $p = 0.517$. Execution time analysis revealed that there was a significant main effect of transition type, $F(5, 27) = 3.15$, $p = 0.023$, $\eta^2 = 0.37$, a significant interaction between musical experience and transition type, $F(5, 27) = 2.58$, $p = 0.050$, $\eta^2 = 0.32$, but no main effect of musical experience, $p = 0.259$.

To further understand the significant musical experience x transition type interactions, we conducted within-group comparisons on the dependent variables for each level of repetition within those trials containing three conflicts. Pair-wise comparisons revealed that musicians became significantly less accurate on the third conflicting response compared with the first, $t(14) = 2.32$, $p = .036$, but there was no significant difference between the first and second, $p = .200$, and second and third, $p = .982$ conflicting responses. Older non-musicians improved in accuracy on the third conflict in a three-conflict trial compared with the second, $t(17) = -3.09$, $p = .007$ (no other comparisons reached significance, $p \geq .09$). As for planning time, pair-wise comparisons revealed a conflict adaptation effect in the three-conflict trials for musicians as their planning time was marginally shorter on the second and significantly shorter on the third conflicting responses compared with the first, $t(14) = 2.06$, $p = .058$ and $t(14) = 2.32$, $p = .036$, respectively. Older non-musicians demonstrated significantly shorter planning times on the second conflicting response compared with the first, $t(17) = 2.59$, $p = .019$, and second conflicting response compared with the third, $t(17) = -2.48$, $p = .024$, but they did not shorten their planning time on the third conflict in a three-conflict trial compared with the first. Planning time results suggest that musical experience was beneficial when preparing for conflicts. For execution time, no comparisons were significant in the three-conflict trials, $p \geq .09$. These results suggest that despite the fact that musicians benefited from previous exposure to conflict when adapting their planning times, they were not able to exhibit faster responses.

3.3.2.3.2 Individual differences analyses

As in Experiment 1, we examined whether different facets of musical experience were associated with motor performance and the neuropsychological tests. Correlations among variables appear in Table 3.4. Criterion measures for this experiment included: age of start, total number of years played, number of instruments played, and all the neuropsychological tests that were administered. It was found that earlier age of start was related to faster planning time during conflict trials ($r = -.35$, $p = 0.048$). Additionally, faster execution time during pre-potent trials under heterogeneous conditions was associated with earlier age of start ($r = -.42$, $p = 0.015$), higher number of years played ($r = -.58$, $p < 0.001$), and larger number of instruments played ($r = -.46$, $p = 0.007$). Furthermore, better performance on the Stroop task, as reflected by Stroop interference score, was associated with faster execution time during pre-potent trials under homogeneous conditions ($r = -.38$, $p = 0.027$), which suggests that participants with better developed inhibitory processes were able to exhibit faster responses.

In summary, we observed that musicians learned faster to plan their motor responses when conflicts occurred as opposed to non-musicians. Additionally, when conflicts occurred musicians needed fewer repetitions compared to non-musicians before they learned to shorten their execution times. Our conflict adaptation analyses suggested that musicians benefited from previous exposure to conflict when adapting their planning times, but they were not able to exhibit responses faster. When examining what facets of musical experience were associated with motor performance and the neuropsychological tests, similar to our findings in Experiment 1, we observed that different types of musical experience could affect different aspects of task performance. Specifically, we found that earlier age of musical experience was beneficial for older adults' ability to plan when reprogramming their motor responses. Participants who started playing early, played for longer, played more musical instruments, and had better inhibitory processes, as shown by their Stroop interference scores, showed faster response production. Overall, our results indicate a selective benefit of musical experience that extends to more effective adaptation to repeated conflict.

3.4 General discussion

The main purpose of these studies was to explore whether musical experience provides older adults an advantage in motor and/or cognitive aspects of performance on a motor sequence task. We also sought to identify whether any specific aspects of musical experience would be associated with enhanced performance on the cognitive tasks. We anticipated that due to musicians' frequent opportunities to practice cognitive (e.g., performance monitoring, shifting and coordination between tasks, suppression of undesired responses) and motor (e.g., pressing keys when playing instruments) skills, they might outperform their age-matched peers who had little musical experience on the cognitive aspects of the motor sequence task (i.e., dual-tasking, conflict resolution, adaptation). Overall, we found differences between musicians and non-musicians in their ability to plan movements, which we attribute to cognitive processes (Trewartha et al., 2009, 2011; Korotkevich et al., 2015). More specifically, we observed that musicians required less time to plan their movements when conflicts occurred, which we attributed to enhanced aspects of executive functioning namely, reprogramming/inhibition and divided attention skills. Furthermore, musicians needed fewer conflict repetitions when learning to modify their motor responses, which we attributed to another aspect of executive functioning, namely, adaptation. These differences in cognitive processes underlying planning time are consistent with previous findings suggesting that musical experience might provide protective benefits in old age by contributing to enhanced executive functioning skills. Finally, our correlational analyses suggest that different types of musical experience could affect different underlying aspects of motor performance. More specifically, we observed that instrumental practice might have a specific effect on motor performance.

The main goal of the first experiment was to use a dual-task paradigm to examine the potential association of musical experience with response reprogramming in advanced age. To investigate this, we used a similar dual-task approach that was used in a recent study (Korotkevich et al., 2015). Experiment 1 revealed that the benefits of musical experience were specific to performance on the sensorimotor task, rather than to concurrent task performance in general. We observed that older adults with musical experience had faster planning times in single-task conditions when encountering conflicts. Furthermore, the execution time analyses revealed that manipulation of attentional load differentially affected musicians and non-musicians, such that non-musicians were negatively affected by the increased load in pre-potent responses.

Additionally, our correlational results suggest that different types of musical experience appear to affect different aspects of task performance. Specifically, when controlling for baseline motor speed, the more instruments the person played, the more efficiently they were able to handle conflicts by adjusting execution time. One explanation for the observation that intense instrumental experience benefits execution time (motor component) could be that intense training leads to enhanced manual dexterity. Support for this idea comes from an observation that different groups of musicians may show training-related effects specific to their unique experience. For example, Kraus and colleagues (2010) observed that on an auditory synchronization task drummers demonstrated less variability compared to pianists and singers. Likewise, drummers demonstrated better discrimination abilities compared to pianists and singers on a cross-modal discrimination task. During musical practice, drummers are specifically trained on time discrimination while pianists are trained on sequencing finger movements.

In our second experiment, conflicting key presses were embedded in a series of repeated pairs with different numbers of conflicts within each series. Similar to Trewartha and colleagues (2011), one of the main goals of this experiment was to isolate the executive functioning skill of adapting to repeated conflicts. The hypothesis that musicians would be superior to non-musicians at adaptation to conflict was supported across a variety of measures. We observed that while conflicts interfered with non-musicians' motor accuracy, musicians' accuracy was not affected by conflict trials. Furthermore, musicians' planning time was less affected by the introduction of the conflict trials, while non-musicians took longer to prepare their responses when one or two conflicts were introduced. Moreover, when conflicting trials were introduced, non-musicians needed more repetitions compared to musicians before they learned to shorten their execution times. These findings are consistent with the conflict-monitoring hypothesis (Botvinick, Braver, Barch, Carter, & Cohen, 2001) according to which increased exposure to conflicts should lead to adjustments in cognitive control processes, which in turn should reduce the effect of future conflicts. They are also in line with studies in which behavioral improvements were observed with increased frequency of conflicts (e.g., Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002). The current data suggest that musical experience might help to preserve these specific executive processes because musical practice requires continuous use of cognitive control processes.

We further explored conflict adaptation effects by comparing participants' responses to conflicting stimuli based on their serial position within each conflict trial. In our previous study, it was observed that increased conflict frequency was associated with improved motor performance in younger compared to older adults (Trewartha et al., 2011). Consistent with these findings, in the present study older non-musicians failed to show motor adaptation effects with increasing conflict frequency. In contrast, similar to younger adults, older musicians benefited from previous exposure to conflict when adapting their planning times; however, this benefit came at a cost to their accuracy on trials with more conflicts.

While a number of studies have yielded evidence for the generalizability or far transfer effect of musical expertise to broader cognitive abilities (e.g., Bialystok & DePape, 2009; Hanna-Pladdy & Gaiewski, 2012), our results provide only limited support for this. This lack of supporting evidence in our studies from the traditionally used tests is important in and of itself. We observed that in the first experiment, musicians outperformed non-musicians on Vocabulary, and in the second experiment, they performed better on short-term memory, as measured with the Digit span of the WAIS-IV scale (see Table 3.1). It should be pointed out that, similar to other studies (e.g., Moreno et al., 2011), raw scores were used for these analyses rather than scaled scores in order to preserve any identified group differences. Despite the fact that we did not observe any large group differences on their neuropsychological task performance, the kinematic analyses revealed important information regarding the contribution of cognitive processes to fine motor performance. As previously described, we observed that musicians demonstrated faster planning times on a number of various conditions compared to non-musicians. When breaking down fine motor movements into separate components, we regard planning time as an observable phenomenon that underlies motor performance and involves suppression of the pre-potent response and preparation of the appropriate response. These results suggest that although we did not observe far transfer effects from musical expertise to global cognitive functions, which were assessed by the WAIS-IV subtests, we observed some near transfer to the skills that were more directly related to musical experience, more specifically instrumental training, such as movement planning time and response inhibition and reprogramming.

A number of factors might contribute to musicians' faster planning times. As described in the above sections, a number of studies on musical expertise have shown that musicians demonstrated better performance on various cognitive tasks compared to individuals without musical experience. This enhanced performance on the cognitive tasks was explained by the complex demands associated with musical experience that involves frequent and intense training, and integration of complex processes that generalized from musical experience to broader cognitive processes (e.g., Carey, Rosen, Krishnan, Pearce, Shepherd, Aydelott, & Dick, 2015; Moreno & Bidelman, 2014; Zatorre & McGill, 2005). Musical performance also involves selective attention, planning, monitoring, shifting, and adaptation processes, which are different aspects of executive functioning. These processes may underlie the effects observed in our studies. Although very limited, there is some evidence to suggest that musical experience may be associated with enhanced general executive functioning (e.g., Bialystok & DePape, 2009; Hanna-Pladdy & MacKay, 2011; Moradzadeh et al., 2014; Moreno et al., 2011). For example, in a study conducted by Bugos and colleagues (2007), older adults' performance on a test measuring executive functioning significantly improved following a short Individualized Piano Instruction program, suggesting that there was a transfer effect from domain-specific, sensorimotor training to executive functioning. Our results are in line with these earlier findings, suggesting that older adults with musical experience had better ability to reprogram and adapt motor responses (as measured with planning time) compared to adults with no musical experience. These results imply that musical experience may transfer to and have an impact on cognitive processes that underlie motor reprogramming and adaptation processes.

Another factor that may contribute to musicians' better planning time might be enhancements in structure, function, and/or connectivity of brain regions. Previous findings from imaging studies have shown that musicians had larger corpus callosum (Schlaug, 2001) compared to non-musicians. A larger corpus callosum can contribute to faster inter-hemispheric communication between bilateral auditory and motor areas, which become activated when participants engage in fine motor tasks, consequently leading to enhanced performance and better results observed in musicians (Müller, Schmitz, Schnitzler, Freund, Aschersleben, & Prinz, 2000; Pollok, Gross, & Schnitzler, 2006).

A secondary goal of the current studies was to investigate what specific aspects of musical experience might be associated with improved motor and cognitive performance. We observed that those who played a larger number of different instruments had better movement adaptation times. Faster execution time during pre-potent trials was associated with earlier age of start, more years of experience, and larger number of instruments played. Our results are in line with the previous findings that suggest that various aspects of musical experience may have differential effects on cognitive processes. For example, Ragert and colleagues observed that intensity of musical practice, and not total years of musical training, was associated with better ability to improve tactile discrimination in the index fingers of pianists (2004). The type of musical instrument was found to affect timing variability when comparing percussionists, pianists, singers, and non-musicians, with drummers being the least variable (Kraus et al., 2010).

3.5 Limitations and future directions

Whereas our group analyses suggest that the difference between musicians and non-musicians lies in the cognitive aspects of task performance, the correlational results show a more nuanced picture with respect to specific musical experience as well as cognitive processes that may underlie these group differences. However, one potential limitation of this study is the correlational nature of our group designs, which suggests caution in interpreting our results. Although our results revealed that musical experience might be beneficial to different aspects of motor and cognitive processes, we cannot conclude that musical experience causally led to enhanced cognitive or motor processes in older individuals. We also cannot exclude the possibility that certain factors that we did not investigate determined who became involved in musical training. For instance, it is possible that individuals with better executive functions were more likely to initiate and sustain musical training than individuals with lower executive functions abilities.

3.6 Conclusions

To summarize, the question of benefits of musical experience and expertise has intrigued researchers for several decades. Numerous studies have revealed that musical experience could be associated with beneficial effects that might generalize to different cognitive, sensory, and motor domains (for review, see Moreno & Bidelman, 2014; Kraus et al., 2010). The results of the current studies suggest that musical experience may be associated with a mild overall enhancement on visual-motor task performance, with a more pronounced effect on the underlying cognitive processes (as expressed by planning time) but not simple motoric component (as expressed by execution time) of baseline responding. Additionally, we observed that musical experience was associated with better cognitive processes underlying motor performance such as executive functioning, specifically, reprogramming, divided attention, and adaptation. Despite the small group differences, the closer examination of facets of musical experience and potential performance benefits revealed more selective advantages depending on the type of musical experience (e.g., larger number of different instruments played). Future work is necessary to systematically explore the contribution of specific aspects of musical experience (e.g., drummers vs. pianists; instrumentals vs. dancers) and their potential benefits to motor reprogramming and adaptation skills.

Table 3.1. Mean and standard deviations for background variables

	Experiment 1		Experiment 2	
	Musicians	Non-musicians	Musicians	Non-musicians
Age (years)	65.68 (4.88)	67.31 (4.41)	68.93 (6.08)	67.22 (3.78)
MoCA	28.05 (1.35)	28.25 (1.44)	26.22 (3.46)	27.60 (1.59)
CTMT simple versus complex (s)	5.39 (4.55)	6.67 (7.16)	4.18 (4.58)	4.95 (3.44)
Stroop interference (s/item)	0.56 (0.25)	0.64 (0.16)	0.38 (0.26)	0.38 (0.22)
Digit symbol	73.68 (13.06)	74.31 (15.13)	69.80 (11.80)	65.39 (15.70)
Vocabulary	50.84 (5.75)*	44.06 (10.43)*	46.67 (7.54)	45.33 (9.04)
Digit span	28.47 (5.53)	26.50 (4.63)	32.20 (3.26)*	27.00 (6.84)*
Matrix reasoning	20.05 (3.34)	17.75 (4.97)	17.87 (4.31)	16.50 (5.06)

Note. Values reflect mean scores per group with standard deviations shown in parentheses. Comprehensive Trail Making Test (CTMT) score is based on the difference between completion times (s) in the complex and simple task conditions; the color Stroop test score is based on the difference between the seconds per item completed on the Congruent and Incongruent conditions; Vocabulary, Matrix reasoning, Digit span, and Digit symbol values of the Wechsler Adult Intelligence Scale (WAIS-IV) are based on the total number of correct responses; MoCA scores are based on the total number of correct responses.

*$p < .05$.

Table 3.*2*. Experiment 1. Cognitive accuracy for the Serial 7s task and motor accuracy during testing blocks for single-task and dual-task conditions for older adults musicians and older adults non-musicians.

Condition	Musicians (*SD*)		Non-musicians (*SD*)	
	Cognitive task accuracy (%)			
Single	98.77 (2.85)		96.67 (3.14)	
Dual	65.43 (2.03)		62.92 (2.73)	
	Pre-potent	Conflict	Pre-potent	Conflict
	Motor task accuracy (%)			
Single	79.70 (0.07)	86.70 (0.05)	83.70 (0.07)	92.70 (0.05)
Dual	72.30 (0.07)	74.80 (0.05)	72.00 (0.07)	77.40 (0.05)

Note. Accuracy for the Serial 7s task and motor task = percentage of total correct responses. Standard deviations are shown in parentheses.

Table 3.3. Correlations among variables including musicians and non-musicians - Experiment 1

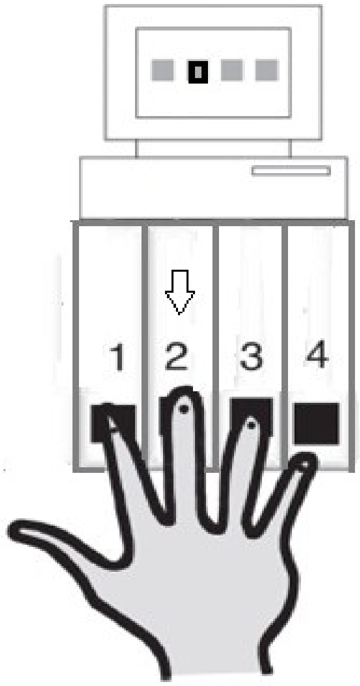
Variables	*1*	*2*	*3*	*4*	*5*	*6*
1. Conflict cost PT (DT)	-					
2. Conflict cost ET (ST)	-.10	-				
3. Age of start	.18	-.24	-			
4. Total number of years played	-.10	.41	-.55*	-		
5. Number of instruments played	-.30	.34*	-.65**	.61**	-	
6. Stroop interference	.27	-.37*	-.13	-.06	-.16	-

$*p < .05$. $** p < .01$.

Table 3.4. Correlations among variables including musicians and non-musicians - Experiment 2

Variables	*1*	*2*	*3*	*4*	*5*	*6*	
1. PT Heterog. conflicts	-						
2. ET Heterog. pre-potent (with 3 conflicts)	.09	-					
3. ET Homog. pre-potent	-.07	.10	-				
4. Age of start	-.35*	-.42*	-.03	-			
5. Total number of years played	-.13	-.58**	-.23	.22	-		
6. Number of instruments played	-.25	-.46**	-.27	.29	.84**	-	
7. Stroop interference	.01	.04	-.38*	-.03	.01	.06	-

Note. Heterog. = heterogeneous condition; Homog. = homogeneous condition.
**p* < .05. ** *p* <.01.



	Homogeneous	
Random	30 trials	42 13 21 41 23
Pre-potent only	20 trials	34 34 34 34 34
	Heterogeneous	
Pre-potent only	120 trials	34 34 34 34 34
1-Conflict	20 trials	34 34 **31** 34 34
2-Conflicts	20 trials	34 34 **31** 34 **32**
3-Conflicts	20 trials	**32** 34 **32** 34 **31**

Note. Pre-potent pairs are underlined and conflicts are in bold.

Figure 3.1. Illustration of the computer-keyboard setup used for the fine motor task. In order to record the movements of the fingers, six motion capture cameras were placed in front of the computer-keyboard apparatus. The arrow and the dark square on the illustration indicate the correspondence between the finger and the square. Numbers on the keys are used for illustration purposes only. Illustration of examples of the sequences used in experimental conditions. Adapted from Trewartha et al., 2011.

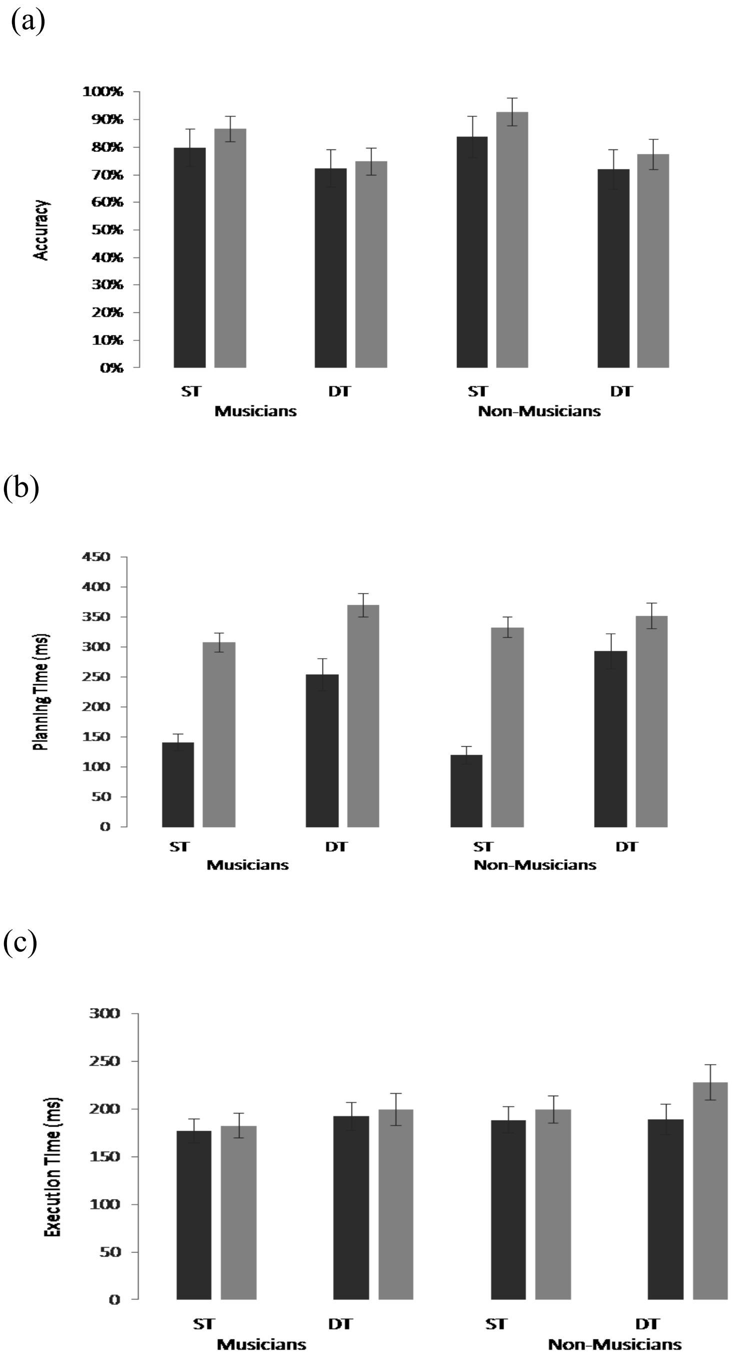


Figure 3.2. Experiment 1 Mean accuracy (a), planning time (b), and execution time (c) of key presses for pre-potent transitions during learning blocks and conflict transitions during test blocks for single-task and dual-task conditions per age group. Dark bars represent pre-potent transitions, light bars represent conflict transitions. ST = single-task; DT = dual-task. Error bars represent ±1 standard error of the mean.

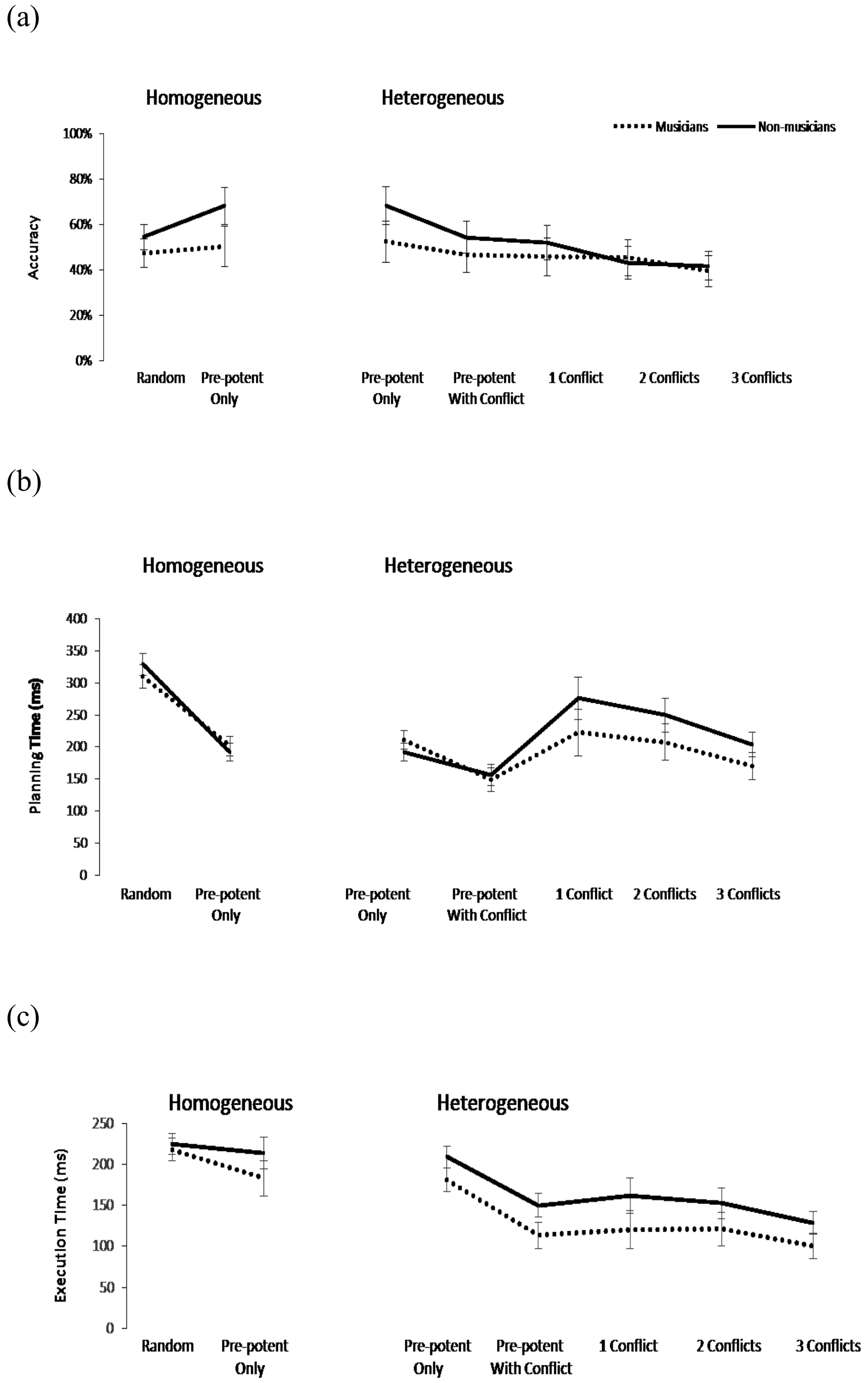


Figure 3.3. Experiment 2 Musicians and Non-musicians keyboard and motion capture data in the homogeneous and heterogeneous conditions. Averages are depicted for seven conditions. Panel (a) averaged accuracy, (b) averaged planning time, and (c) execution time. Error bars represent ±1 standard error of the mean.

Chapter 4: General Discussion

One of the primary goals of the current thesis was to investigate age-related changes in movement reprogramming and adaptation of fine motor responses. In the first study in this dissertation, we proposed that both executive and motor control mechanisms become connected to a greater degree while reprogramming motor behaviors. However, previous studies on aging and motor behaviours did not disentangle the concurrent contributions of cognitive and motor processes to motor reprogramming behaviours. To address this challenge, the first study was designed to explore the independent contribution of motor and cognitive processes in younger and older adults to reprogramming of fine motor movements using a dual-task paradigm. The work presented here also aimed to investigate evidence for a possible contribution of specific skill, namely, musical experience to the cognitive and motor processes in older adults. To address this question, the second study used the same dual-task paradigm that was used in the first experiment to investigate whether musical experience was associated with better performance on motor reprogramming task and if so, whether better performance on the task was due to the enhanced motoric skills or the more central cognitive benefits. The third study aimed to provide further insight into the association between musical experience and motor reprogramming processes. To this end, a different approach was taken to examine the potential link between musical experience in older age and response reprogramming by investigating cognitive control and movement adaptation processes. Another novel contribution of this dissertation included investigation of whether musical experience might provide benefits to specific aspects of executive functions, namely, working memory/divided attention, inhibition, and adaptation.

4.1 Review of main findings

The first study of this dissertation examined the effect of cognitive load on motor reprogramming. In this study a dual-task paradigm was used to investigate whether executive control and motor control processes become more interconnected in the process of fine motor reprogramming in advanced age. In a previous study conducted in our laboratory (Trewartha et al., 2009) we used motion tracking to decompose fine motor task performance into cognitive and motor components. Using this method, our previous results revealed that when responding to conflict transitions under the simplest conditions (single-task), both younger and older adults had longer planning times compared to pre-potent transitions; however, only younger adults were able to hasten their execution times. We interpreted these results as an evidence for a compensatory hastening that helped younger adults to recover from the delayed planning time. An open question remained as to whether age changes in basic motor processes were associated with the observed group differences that revealed that older adults were not able to speed their movements. To address this question, in Study 1, we paired a motor reprogramming task from our previous study with a concurrent cognitive task reasoning that with increased attentional load younger adults would experience reduced ability to flexibly adapt to conflicting conditions, which would support the idea that in addition to reduced motor abilities in older age, our previously observed age differences were also linked to reduced cognitive capacity. In line with our prediction, with increased attentional load (under dual-task conditions) younger adults' motor performance became more similar to that of older adults. Specifically, the movement pattern revealed that under full-attention conditions, when responding to conflicting stimuli younger adults reduced their movement time as if compensating for delayed planning time. In contrast to full-attention conditions, increased attentional load hindered younger adults' ability to exhibit this compensatory hastening. This observed pattern supports the idea that age-related declines in fine motor reprogramming abilities may be associated with reduced cognitive abilities in aging.

Given the finding that cognitive processes play an important role in fine motor reprogramming processes, the first aim of Study 2 was to investigate whether older adults with specific skills that involve frequent motor-cognitive training, specifically musical experience, would be better able to reprogram their fine motor movements compared to older participants with no musical experience. To this end, we applied the same dual-task paradigm that was used in Study 1 to compare musicians' and non-musicians' performance on motor and cognitive tasks. Consistent with our prediction, musicians and non-musicians exhibited different kinematic signatures (planning and execution times) when preparing their motor movements, such that older adults with musical experience showed better fine motor reprogramming abilities compared to older adults without musical experience. This was evidenced by observing a musician advantage in shortening planning times when conflicts occurred. However, we also observed that benefits of musical experience were specific to performance on the sensorimotor task, and not to concurrent task performance in general. A secondary goal of this experiment was to explore whether specific aspects of musical experience would be associated with better performance on motor and cognitive tasks. The more instruments participants played, the more efficiently they were able to handle conflicts. However, participants who did not play any musical instruments, but rather participated in singing or dancing, took longer to plan their movements during conflicts. This finding suggests that instrumental activity may be more beneficial for cognitive processes, such as reprogramming and inhibition, than musical activities that do not involve instrumental training. One possible explanation for this observed difference could be that instrumental practice requires more intense training and activation of executive function processes, specifically, inhibition, conflict monitoring, and reprogramming, needed for successful performance. To our knowledge this is the first study that has investigated the effects of different types of musical experience on cognitive processes involved in fine motor reprogramming. Further work will be necessary to investigate what specific aspects of instrumental training (e.g., different types of instruments, different types of instruction) are associated with enhanced motor reprogramming processes.

In one of the previous studies conducted in our laboratory, we observed that in addition to motor reprogramming difficulties, older adults exhibited an age-related decline in conflict adaptation (Trewartha et al., 2011). Thus, the main rationale for Study 3 was to examine another aspect of executive functioning, namely, adaptation to repeated conflict, and how musical expertise might benefit the cognitive and motor components of that behaviour in older age. To investigate this question, a motor adaptation paradigm that was used by Trewartha and colleagues was used to investigate whether musical experience would help older participants to exhibit greater benefits from repeated exposure to conflicts compared to participants with no musical experience. An important key finding of this study was that while musicians' planning time was not affected by the conflicts, non-musicians took longer to prepare their motor responses. In addition, when conflicts occurred, non-musicians required more repetitions compared to musicians before they shortened their motor movements. We also examined whether motor performance would be associated with different measures on the musical questionnaire and neuropsychological tests. Our results are consistent with the results of Study 2, suggesting that different types of musical experience influence different aspects of task performance. As well, musical experience does not appear to have a global effect on every aspect of fine motor and cognitive performance, but rather its effect is relatively selective.

4.2 Integration of findings across studies

Several pieces of evidence from the studies described in this thesis suggest that cognitive processes become increasingly important in fine motor reprogramming and adaptation processes in older age, and that musical experience may attenuate age-related declines in these processes. Results of our studies are consistent with previous research showing that, in general, older age is associated with declines in response inhibition. Evidence supporting this view comes from numerous studies in which older adults demonstrate greater difficulties with pre-potent response suppression compared to younger adults (e.g., Trewartha et al., 2009, 2011, 2013; Korotkevich et al., 2015; Potter & Grealy, 2008). As reviewed in the Introduction, in our previous studies we used a 3D motion capture system to decompose fine motor movements into planning (cognitive process) and execution (motoric process) times to investigate pre-potent response suppression processes in older age. In our previous studies, we observed that when encountering conflicts younger adults were able to quickly reprogram their movement responses in order to compensate for longer planning times, while older adults were slower to modify their movements (Trewartha et al., 2009, 2011, 2013). One important question that remained to be answered was whether older adults could not quickly reprogram their movements due to declining cognitive or motor processes, or both. To answer this question, in our first experiment we applied a dual-task approach to limit the attentional resources of younger participants. We observed that under dual-task conditions young adults performed more like older adults. We interpreted this finding as support for the idea that the observed age difference in pre-potent response suppression in our previous studies resulted from the fact that cognitive processes play an important role in motor reprogramming processes. These findings are in line with other evidence which suggests that motor and cognitive processes become more intertwined in advanced age (Anstey et al., 2003;

Baltes & Lindenberger, 1997). We proposed that the greater inter-dependence between motor and cognitive processes in elderly adults might negatively affect their ability to efficiently reprogram their fine motor responses in the face of conflicts.

Studies on expertise and cognitive aging revealed that certain highly trained abilities or skills are preserved in older age despite age-related declines in other areas (e.g., Charness, 1981; Krampe & Ericsson, 1996; Salthouse, 1984). Thus, in our second experiment we sought to explore whether musical experience, given its intense training of multiple sensory and motor domains, would help older adults to better preserve cognitive and fine motor skills important for movement planning and adaptation. Contrary to the more intuitive expectation that musicians would show greater benefits to motor speed due to their experience of key pressing and playing instruments, our results revealed the opposite: musical experience did not affect the simple motoric component (ET) of baseline responding. Instead, the musicians demonstrated superior performance when recovering from unexpected conflict stimuli, suggesting a more cognitive benefit. This could be because musical training involves continuous engagement of a number of cognitive processes such as increased attention, working memory, conflict identification, and inhibition of unwanted responses.

In Study 3, we sought to further investigate whether musical experience would be beneficial for conflict adaptation processes in older age. Our results are in line with the conflict monitoring theory (e.g., Botvinick et al., 2001), which suggests that conflict monitoring process become activated in response to stimulus/response conflict identification. Conflict identification and control activation are necessary for future response improvements in the face of later conflicts. A number of studies using sequential trial analyses with pre-potent responses revealed that while encountering conflicts on initial trials, participants learned to improve their performance when conflicts were introduced on the following trials (e.g., Gratton, Coles, & Donchin, 1992; Kerns, Cohen, MacDonald, Cho, Stenger, & Carter, 2004; Stürmer et al., 2002). Similarly, within-trial adjustments or adaptations were observed when encountering conflicts (e.g., Scherbaum, Fischer, Dshemuchadse, & Goschke, 2011). This effect is known as conflict adaptation effect. While our findings are consistent with the theory, we offer the novel method of parsing the response time into execution time and planning time. Data from our previous studies revealed that conflict monitoring processes and response inhibition declined with increased age (Korotkevich et al., 2015; Trewartha et al., 2009; 2011). We also observed that repeated exposure to conflicts helped younger adults but not older adults to improve their motor performance (Trewartha et al., 2011). In Study 3, we were interested in investigating whether musical experience would be associated with enhanced conflict monitoring and motor adaptation skills in older participants. We observed that, similar to our previous findings, non-musicians did not benefit from repeated exposure to conflicts (Trewartha et al., 2011). In contrast to musicians, non-musicians took longer to prepare their motor responses, and they required more repetitions before they shortened their motor movements. Thus, these data provide support for the association between musical experience and better conflict detection and motor adaptation in older age. Our observation that older musicians were better able to plan for conflicts, which reflects enhanced executive functions, compared to older non-musicians, is in line with the findings that reported that older participants with musical experience showed enhanced executive functioning abilities (e.g., Hanna-Pladdy & Gajewski, 2012; Hanna-Pladdy & MacKay, 2011). It is worth mentioning that although numerous studies investigated the effects of musical experience on child and young adults cognitive functioning, this research is relatively limited in cognitive aging domain.

Another key finding of our studies conducted with musicians was that specific aspects of musical experience were associated with specific advantages on motor task performance and neuropsychological tests. This finding may suggest that musical experience may have near-transfer to non-musical skills, however, these effects are relatively limited rather than general, and they do not support far-transfer concept. The term near-transfer effect usually refers to transfer of skills between similar domains, while the term far-transfer effect refers to transfer of skills between less similar domains. Recently, transfer of skills has become a prominent question in many training and rehabilitation studies (e.g., Moreno, Marques, Santos, Santos, Castro, & Besson, 2009; Moreno et al., 2011). Mixed results have been reported from these studies, which show either improved performance on untrained tasks (e.g., Lovett & Anderson, 1994) or no transfer effects to untrained tasks (Olesen, Westerberg, & Klingberg, 2004). For example, Moreno and colleagues found that after a short music-training program, children demonstrated enhanced performance on measures of verbal performance and executive functions, as well as changes in brain-activation patterns as expressed by larger peak amplitudes in a P2 component (2011). The researchers proposed that a shared-resource interpretation that is based on a parieto-frontal integration theory (P-FIT; Jung & Haier, 2007) could account for this association due to its emphasis of structural links common to music and language. To our knowledge no training studies were done with older musicians using the dual-tasking or motor adaptation paradigms to investigate whether musical training benefits could transfer to cognitive and motor domains. As previously described, in our current studies we found some support for the benefits of musical experience to cognitive processes, which was observed in shorter planning times in the older musician group, but these findings are only partially in line with studies on musical training that suggest that benefits from specialized musical experience may transfer to broader cognitive abilities or other non-musically related domains (e.g., Bialystok & DePape, 2009; Hanna-Pladdy & Gajewski, 2012).

As previously noted, several pieces of evidence from the studies described in this thesis suggest that cognitive processes become increasingly important in fine motor reprogramming and adaptation processes in older age, and that musical experience may attenuate age-related declines in these processes. One of the novel contributions of this thesis was the application of kinematic analyses to investigate the contribution of executive functions to fine motor reprogramming and adaptation processes. Importantly, findings revealed that musical experience enhanced older adults' executive functions rather than simply their visuo-motor movement speed. Despite the fact that our findings provide only limited evidence to support this generalized transfer effect, the lack of supporting evidence for this generalizability is important in and of itself. While no significant group differences were observed on the neuropsychological tasks, kinematic analyses revealed that musical experience was beneficial for faster planning time, which we view as an observable phenomenon that underlies motor inhibition, reprogramming, and adaptation processes.

Intact working memory, inhibitory and adaptation processes play an essential role in our daily functioning. Older adults' ability to function independently relies heavily on these aspects of executive functions. Decline in these functions negatively influences older adults' activities of daily living (ADLs; Gaugler, Duval, Anderson, & Kane, 2007; Luppa, Luck, Weyerer, König, Brähler, & Riedel-Heller, 2010). Difficulty performing activities of ADLs is not only limited to individuals with pathological age-related changes such as dementia. As previously stated, these functions decline with increased age even in healthy individuals. Findings of this thesis suggest that musical experience may attenuate these age-related declines in executive functions or protect certain aspects of cognitive processes from an earlier decline. Thus, preserved executive functions in older age may have an overall positive effect on older adults' ADLs.

4.3 Limitations and future directions

One criticism of our studies could be that our findings do not demonstrate a causal relationship between musical experience and transfer effects to improved fine motor skills. The correlational nature of our design does not warrant claims of a causal link between musical experience and better cognitive abilities in older age. It may be argued that people with innate predispositions, for example, better executive functions, would find musical training more pleasurable compared to individuals with weaker executive functions and would be more motivated to continue practicing. Although it is true that we are only able to make limited conclusions about the association between executive functioning and musical experience, as we are only able to do so when comparing younger and older adults in Study 1. However, the experimental manipulation of attentional load, and of conflict frequency, helped us to rule out general confounds and isolate specific functions. Despite the aforementioned shortcoming, studies on brain plasticity suggest that differences in brain structure observed between musicians and non-musicians could be a result of musical training. Musical training effects on brain plasticity have been reported in studies with young children. For example, Hyde and colleagues (2009) observed that there were brain differences in auditory and motor areas between children who received 15 months of musical training and a control group. Moreover, observed brain changes correlated with better performance in melody, rhythm discrimination, and fine motor tests in the musicians group. In other studies researchers observed that the brain structure differences between musicians and non-musicians were associated with the amount of musical experience, which supports the idea that these differences could be, at least partly, attributable to experience-dependent plasticity (Foster & Zatorre, 2010; Gaser & Schlaug, 2003). To address this and to assess for transfer effects, it could be beneficial to conduct short- or long-term training studies with older adults who have no musical training to further explore these transfer effects.

Another important area that is under-investigated in the cognitive aging literature is the effect of training paradigms on cognitive functions. The main goal of these paradigms is to design training studies to explore how particular training, for example musical lessons, could contribute to enhanced cognitive functions. Moreno and colleagues (2011) observed that following a brief training children from the music group showed improved performance on a measure of verbal intelligence compared to children from the visual art group. Moreover, there was a positive correlation between the enhanced performance in verbal intelligence with changes in functional brain plasticity during a task involving executive functions.

One of the advantages of training studies is that they are designed to develop techniques and methods to help improve functioning in various cognitive and sensorimotor domains of individuals. However, to my knowledge, no single training study has examined the effects of musical lessons on the combined cognitive and motor functioning of older participants. Considering transfer of skills may be important when developing rehabilitation programs for older adults. Consequently, additional work is also needed for better understanding whether music lessons could help older adults to develop better motor adaptation skills similar to those observed in older musicians.

Another area that should be further investigated relates to other experiences that could potentially contribute to enhanced cognitive processes associated with better motor adaptation in older age. It has been shown that such experiences as physical activity (e.g., Albert, Jones, Savage, Berkman, Seeman, Blazer et al., 1995; Kramer & Ericson, 2007; Larson, 2006; Rovio, Kareholt, Helkala, Viitanen, Winblad, Tuomilehto et al., 2005) and social engagement (e.g., Barnes, Mendes de Leon, Wilson, Bienias, & Evans, 2004; Lovden, Ghisletta, & Lindenberger, 2005; Zunzunegui, Alvarado, Del Ser, & Otoro, 2003) could maintain or enhance cognitive functioning in old age. In our studies we did not control for these experiences; however, they could mediate the relationship between musical experience and cognitive and motor advantages observed in our studies. Since various studies have shown that these activities could be associated with enhanced cognitive performance in elderly adults, further research could investigate the possibility of mediation. It is also important to acknowledge that despite the fact that it is important to investigate whether these other experiences would contribute to cognitive stimulation, it is difficult to account for all the other potential experiences or activities that participants could be engaged throughout their life.

In practice, while conducting studies with participants who have musical experience, various methodological issues regarding the participant inclusion criteria should be considered. For example, it may be difficult to distinguish between expert and amateur musicians. It may also be challenging distinguishing between very high quality performance and casual amateur levels. Although we might not consider singing in an amateur choir led by a conductor as formal instruction, there is still some guidance and feedback involved in working with a conductor. The discrepant findings reported in the literature may be due to the variety of inclusion criteria used (e.g., intensity and variability of musical training). These are aspects that should be distinguished more carefully in future studies and taken into consideration when interpreting mixed findings obtained from the broad categories such as engaging in musical activity or not.

4.4 Conclusion

The current dissertation explored changes in movement reprogramming and adaptation of fine motor responses in older age. The data from the first experiment extended the cognitive aging literature by providing support for the hypothesis that reduced cognitive capacity might influence the ability to flexibly reprogram motor responses in the face of conflict. These data also support the view that both executive processes (i.e., working memory/divided attention, inhibition, adaptation) and motor control mechanisms play an important role in fine motor reprogramming processes. Furthermore, the data presented in the first study suggests that due to the reduced cognitive capacity older adults' ability to reprogram motor responses could become disproportionally worse as opposed to younger adults' motor reprogramming abilities. Moreover, the observations from the second and third experiments are consistent with the literature on the involvement of musical experience in executive control processes. The results also extend these existing findings by providing support for the idea that musical experience contributes to enhanced cognitive functions that play a significant role in fine motor reprogramming and adaptation processes in older age. Lastly, the findings suggest that musical experience may be more beneficial to the cognitive processes (PT), such as inhibition and adaptation, than the pure motor component (ET) involved in motor response reprogramming processes.

Taken together, this work highlights the important role of executive functioning in fine motor reprogramming and adaptation processes as well as contribution of musical experience to these processes in older age. The results outlined in the present manuscript are in line with enrichment and aging research that investigates contribution of various cognitively and socially stimulating activities to maintenance and/or enhancement of cognitive processes (e.g., Hertzog et al., 2008). It appears that musical experience fits well into the large area of leisure or cognitively stimulating activities, and it may be another type of stimulating activity that may protect from or slow cognitive and motor declines associated with advanced age by contributing to cognitive reserve.

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